

CHAPTER 6

Structure, Growth, Physiology, and Genetics of Prokaryotes and Viruses

**Read This Chapter to Learn About**

- Cell Theory
- The Three Domains
- Viruses
- Subviral Particles

CELL THEORY

Eukaryotic cells were considered in Chapter 5 and prokaryotic cells will be discussed in this chapter. One foundational concept relating to cells is that of the **cell theory**. The cell theory proposed in the 1800s explains the relationship between cells and organisms. The primary tenets of the original cell theory proposed by Theodor Schwann and Matthias Schleiden include:

- All organisms are composed of one or more cells.
- The cell is the basic unit of structure, function, and organization in all organisms. Rudolf Virchow elaborated on the cell theory, adding the third tenet:
- All cells arise from preexisting cells.

Since the time the original cell theory was proposed, the original tenets have been elaborated on. Modern interpretations of the cell theory include the following additions to the original version:

- The cell contains hereditary information (DNA) that is passed on from cell to cell during cell division.
- All cells are basically the same in chemical composition and metabolic activities.
- All basic chemical and physiological functions are carried out inside the cells.

THE THREE DOMAINS

There are three domains to which living organisms can be classified: Eukarya, Bacteria, and Archaea. All eukaryotic organisms classify in the domain **Eukarya**, leaving all prokaryotic cells to be classified as either **bacteria** or **archaea**. Although both of these domains share the characteristics of being single-celled, absorbing their nutrients, having a single loop of DNA, and lacking organelles, there are some differences between the two groups. Archaea used to be mistakenly classified as bacteria, but their molecular and cellular structures were found to be quite different. They have a unique cell wall, ribosomes, and membrane lipids. Archaea live in very diverse environments, and some species are termed **extremophiles** due to their extreme habitats such as polar ice caps, thermal vents, jet fuel, and others. Most Archaea species are anaerobes, and none are known to be pathogens.

Because of their medical and environmental significance, the focus of this chapter will be on bacteria.

Bacteria

Bacteria are extremely diverse. They may be classified according to the way they obtain nutrients from the environment or by their oxygen requirements. The following are the basic bacterial classifications:

- **Photoautotrophs.** These organisms produce their own nutrients through the process of photosynthesis, using carbon dioxide from the environment.
- **Photoheterotrophs.** These organisms perform photosynthesis but cannot use carbon dioxide from the environment. They extract carbon from a variety of other sources.
- **Chemoautotrophs.** These organisms get their energy from inorganic compounds, and their carbon needs are obtained from carbon dioxide.
- **Chemoheterotrophs.** These organisms obtain energy from inorganic substances, and their carbon is obtained from a variety of sources, excluding carbon dioxide. These organisms are further subdivided based on the source of carbon they use. Some species can extract carbon through parasitic or symbiotic interactions with a host or through the decomposition of other organisms.

Bacteria can also be classified based on their oxygen requirements, or lack thereof, for cellular respiration.

- **Obligate aerobes** always require oxygen for aerobic cellular respiration.
- **Obligate anaerobes** never need oxygen, generally do not divide, and in some cases, are killed by exposure to oxygen.
- **Facultative anaerobes** sometimes use oxygen and sometimes do not require oxygen for cellular respiration.

BACTERIAL STRUCTURE

As compared to eukaryotic cells, the structure of bacteria is less complex due to a lack of membrane-bound organelles. Figure 6-1 diagrams basic bacterial structure. Some structures such as the cytoplasm and ribosomes are common between eukaryotic and prokaryotic cells. However, many bacterial structures are unique as compared to eukaryotic structures. The table that follows shows the major structures present in bacterial cells as well as their functions.

TABLE 6-1 Major Bacterial Structures

| Structure | Function |
|--------------------------|---|
| Plasma membrane | Outer boundary of the cell that displays selective permeability |
| Cytoplasm | Liquid portion of the cell where chemical reactions occur |
| Ribosomes | Site of protein synthesis |
| Chromosome | Contains the genes needed to provide instructions for protein synthesis in the cell. The bacterial chromosome consists of a single loop of DNA located in the nucleoid region of the cell. |
| Plasmids | Small, extra-chromosomal loops of DNA. Plasmids often contain genes to code for resistance to antibiotics. |
| Cell wall | Most bacteria have a cell wall that contains peptidoglycan. The cell wall is found on the outer surface of the cell membrane and typically occurs in one of two conformations that can be determined using the Gram-staining method. Gram-positive bacteria have a cell wall consisting of a single layer of peptidoglycan while Gram-negative bacteria have two layers: one layer of peptidoglycan and another layer of lipids in their cell wall. |
| Capsule and slime layers | A layer of sugars and proteins on the outer surface of some bacterial cells. It forms a sticky layer that can help the cell attach to surfaces. |
| Flagella | Bacteria may have a single flagellum, multiple flagella, or no flagella. Those with one or more flagella are motile as the flagella rotate to propel the cell. The bacterial flagella are different from eukaryotic flagella in structure. Bacteria flagella consist of the protein flagellin in a hollow, helical conformation that anchors into the cell membrane. A proton pump in the membrane provides power to rotate each flagellum. |
| Pili | Tiny proteins that cover the surface of some types of bacterial cells. They assist the cell in attaching to surfaces. |
| Spores | A few species of bacteria are capable of creating spores when environmental conditions are not favorable. When bacteria exist in spore form, they are capable of surviving adverse conditions for many years. When conditions become favorable, the spores germinate into the vegetative cell form. |

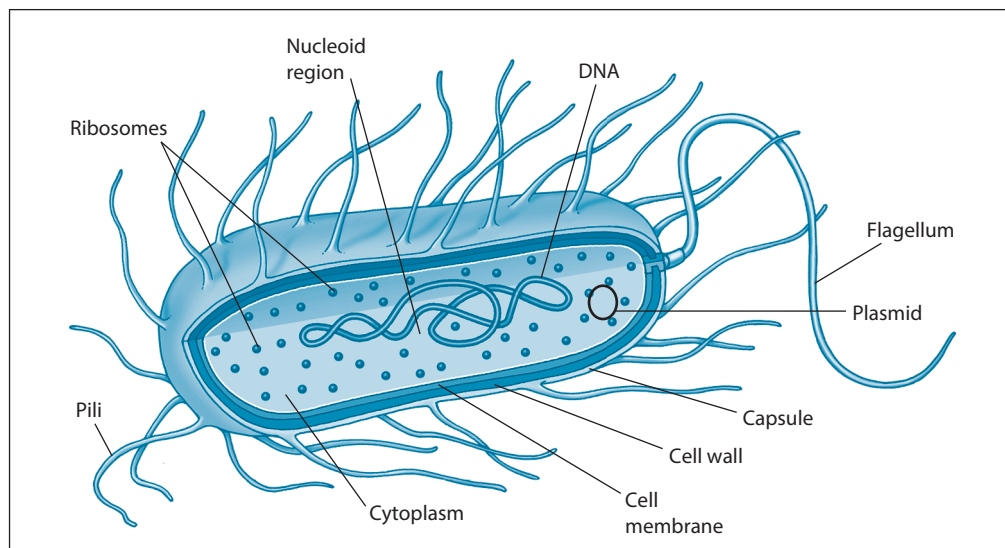


FIGURE 6-1 Bacterial structure. Bacterial cells lack membrane-bound organelles but have a variety of cell structures. *Source:* From George B. Johnson, *The Living World*, 3rd ed., McGraw-Hill, 2003; reproduced with permission of The McGraw-Hill Companies.

BACTERIAL MORPHOLOGY

Most bacteria have shapes that correspond to one of three typical conformations. These shapes and organization amongst cells can be used as diagnostic features. The shapes exhibited by most bacteria are as follows and can also be seen in Figure 6-2:

- **Cocci** are circular in shape. They may exist singly, in pairs (diplococci), in clusters (staphylococci), or in chains (streptococci).
- **Bacilli** are rod or oblong shaped. They may occur in chains.
- **Spirilli** have a spiral shape.

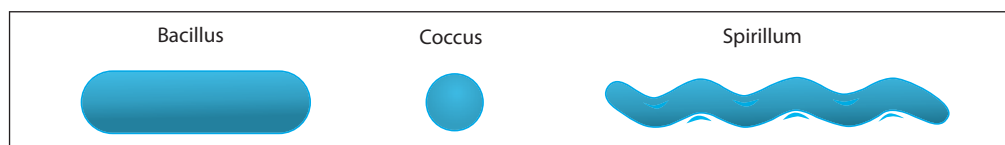


FIGURE 6-2 Bacteria come in a variety of shapes.

BACTERIAL REPRODUCTION

Bacteria lack the mitotic apparatus needed to perform mitosis, and because they only have a single chromosome, they really do not have a need for cell division as complex as mitosis. Bacteria do, however, have several ways of passing genetic material to other bacteria.

Binary Fission. Bacteria divide by the process of **binary fission**. It involves the replication of the single chromosome of DNA and the passing of a copy of the DNA to each of two daughter cells. This process can occur fairly quickly, in some cases as often as once every 20 minutes. Because bacteria are unicellular, creating a new cell means creating a new organism. This process is a type of asexual reproduction as each division produces genetically identical offspring. The only way to introduce variation into the population is by mutation, conjugation, or transformation.

In addition to their single chromosome, some bacteria may contain extra-chromosomal plasmids. It is possible for genetic information to be moved from plasmids to the chromosome and from the chromosome to plasmids. Transposons found in bacteria allow this sort of transfer. In addition to carrying genes for the transfer, transposons often carry genes for antibiotic resistance.

Conjugation. Some bacteria have another means of passing genetic material to other bacteria. During the process of **conjugation**, illustrated in Figure 6-3, a single bacterial cell may copy its plasmid and pass it to another cell. The most commonly studied type of plasmid to be passed is called the **F plasmid** or F factor (the *F* standing for *fertility*). In order to pass the plasmid to another cell, a physical connection must be established. This connection is referred to as the **sex pilus**, and it is made by the cell that contains the plasmid (the male, or F^+). The sex pilus connects to a cell lacking the plasmid (the female, or F^-) and serves as a bridge to pass a copy of the plasmid to the female. Once complete, both cells are male and contain the plasmid.

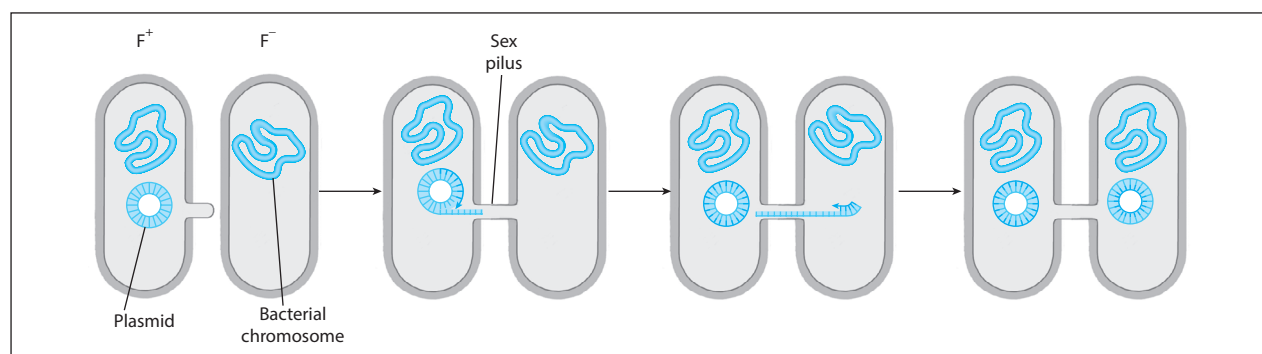


FIGURE 6-3 During conjugation, a bacterial cell containing a plasmid forms a sex pilus, which allows for the transfer of a copy of the plasmid to another bacterial cell that is lacking the plasmid. *Source:* From George B. Johnson, *The Living World*, 3rd ed., McGraw-Hill, 2003; reproduced with permission of The McGraw-Hill Companies.

Conjugation provides a rapid mechanism to pass plasmids within a population. Occasionally, plasmids become integrated into the chromosome, and when the plasmid is transferred via conjugation, some of the bacterial chromosome may be transferred as well.

Because many plasmids encode for resistance to antibiotics, rapid conjugation can quickly render an entire bacterial population resistant to a particular antibiotic under

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the right selective pressures. This has important medical significance in that an antibiotic is used to kill bacteria causing infections, and if the bacteria are resistant to that antibiotic, it is useless in stopping the infection. Some bacteria are resistant to multiple antibiotics as a result of having picked up several plasmids via conjugation.

Transformation. Another way that bacteria can pick up genetic variations is through **transformation**. Some bacteria are able to pick up DNA from their environment and incorporate it into their own chromosomal DNA. Bacteria that are able to pick up foreign DNA are termed *competent*. Although some bacteria are naturally competent, others can be coerced to develop competence by artificial means within the lab.

THE BACTERIAL GROWTH CYCLE

Bacteria follow a typical growth cycle, shown in Figure 6-4, which is limited by environmental factors as well as the amount of nutrients available. The following are the stages of the growth cycle:

- **Lag.** There is an initial lag in growth that occurs when a new population of bacteria begins to reproduce. This lag time is normally brief.
- **Logarithmic growth.** As bacteria begin to perform binary fission at a very rapid rate, logarithmic growth occurs. This can last for only a limited amount of time.
- **Stationary.** As the number of bacteria increase, resources decrease, and while some bacteria are still dividing, some are dying. This evens out the population count.
- **Decline (death).** As the population hits its maximum, the lack of nutrients along with a variety of wastes means that the population will begin to decline and more cells die than are being replaced by cell division. For the few species of bacteria that are capable of making spores, they would do so at this point in the growth cycle.

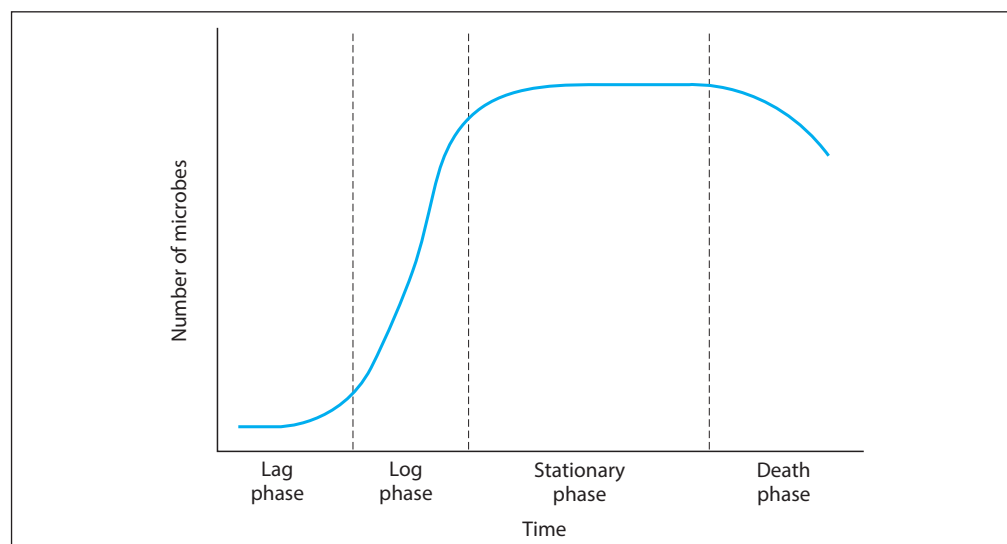


FIGURE 6-4 A growth curve of bacteria. Bacteria exhibit logarithmic growth until conditions are no longer ideal. At this point, a stationary phase occurs followed by a decline phase in which bacterial numbers decrease.

VIRUSES

Viruses are a unique biological entity in that they do not resemble typical cells. There is debate over whether viruses are living organisms at all because they are unable to reproduce without a host cell nor can they perform many of the duties associated with living organisms without the help of a host. Because viruses lack typical cell structures such as organelles, they are much smaller than any form of prokaryotic or eukaryotic cells.

Although some viruses contain more sophisticated structures, the only items required for a virus are a piece of genetic material, either DNA or RNA, and a protective protein coating for the genetic material. The viral genome can consist of only a few genes upward to a few hundred genes.

The Life Cycle of a Virus

Viruses are specific to the type of host cell that they infect. In order for a cell to be infected, it must have a receptor for the virus. If the receptor is absent, the cell cannot be infected by the virus. Although it seems odd that cells would evolve receptors for viruses, it is usually a case of mistaken identity. The viruses actually mimic another substance for which the cell has a legitimate need and thus has a receptor present. The process of viral infection is seen in Figure 6-5.

Once a virus binds to a receptor on the membrane of the host cell, the viral genetic material enters the host cell either by injecting itself across the cell membrane or by being taken in via endocytosis. At some point, the viral genes are transcribed and translated by the host cell. The nucleic acid of the virus is also replicated. Eventually new viruses are produced and released from the host cell. Because each virus contains a copy of the original genetic material, they should all be genetically identical. Mutations are the primary way to induce variation into the viral population.

TYPES OF VIRUSES

Viruses are categorized as animal viruses, plant viruses, or bacteriophages. They can be further categorized according to the type of nucleic acid they contain.

Animal Viruses. As the name implies, **animal viruses** are designed to infect the cells of various animals. Their genetic material may be DNA or RNA, depending on the virus. Animal viruses are usually categorized according to the type of DNA they possess, and whether the nucleic acid is single stranded or double stranded. Once the host cell takes in the DNA or RNA of the virus, the virus may immediately become active using the host cell machinery to transcribe and translate the viral genes. New viruses are assembled and released from the host cell by one of two methods: **lysis** of the host's cell membrane, which immediately kills the host cell, or by **budding**, where the new viruses are shipped out of the host cell via exocytosis. Budding does not immediately kill the host

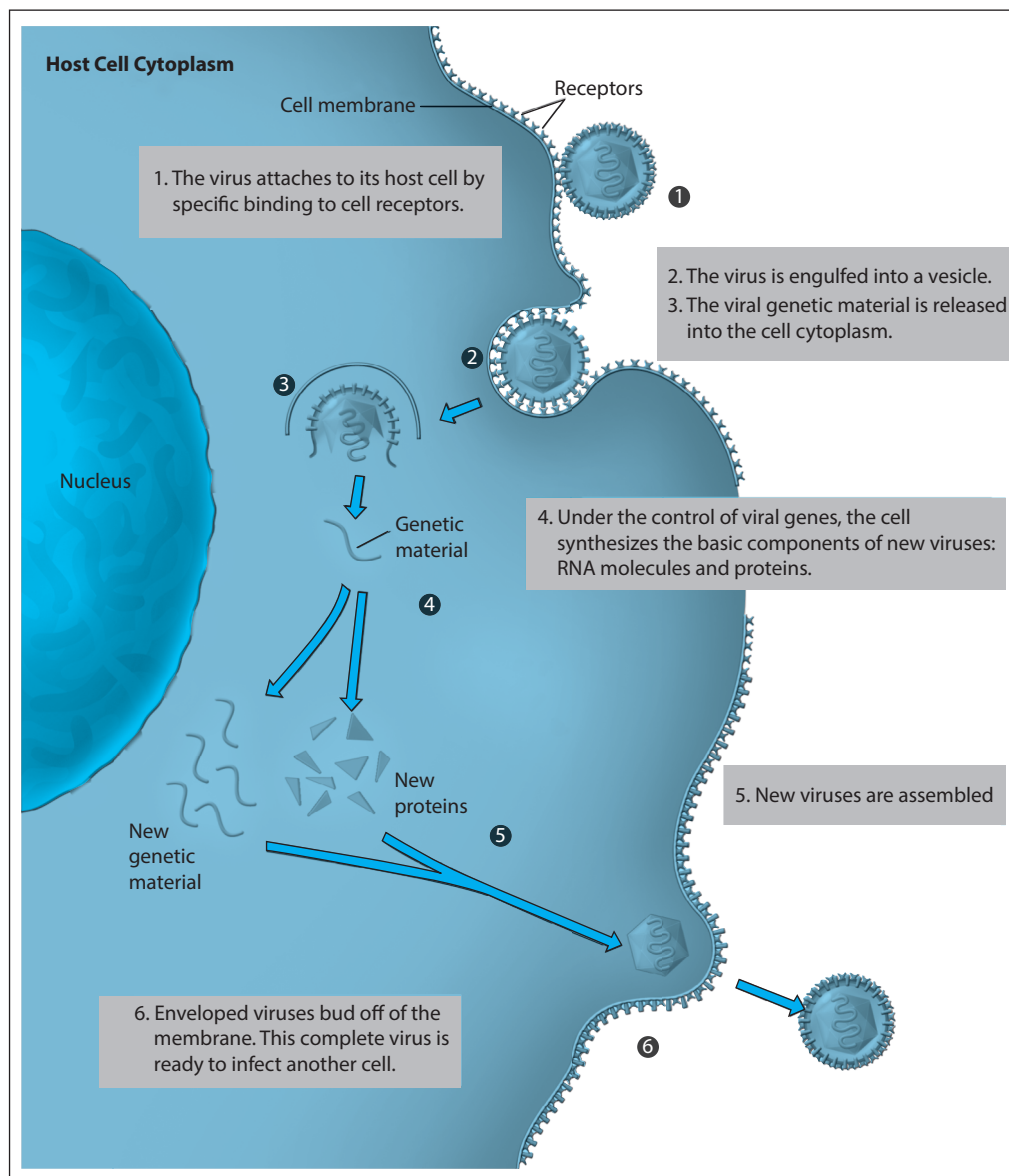


FIGURE 6-5 Viral infection. *Source:* From Marjorie Kelly Cowan and Kathleen Park Talaro, *Microbiology: A Systems Approach*, McGraw-Hill, 2004; reproduced with permission of The McGraw-Hill Companies.

cell, but it may eventually prove fatal to the host. Once the new viruses are released from the original host cell, they seek out new host cells to infect.

Alternatively, the virus may become latent, integrating itself into the chromosomes of the host cell, where it may stay for variable amounts of time. Eventually, the latent virus excises from the host chromosome and becomes active to produce and release new viruses. Some viruses are capable of alternating between active and latent forms multiple times. Infections caused by members of the herpes viruses family, such as cold sores and genital herpes, are notorious for alternating between active and latent forms.

Retroviruses. Retroviruses are a unique category of RNA viruses. The **human immunodeficiency virus** (HIV) was the first retrovirus to be discovered. The key

characteristic of retroviruses is that they enter the cell in RNA form that must be converted to DNA form. This is the opposite of the normal flow of information in the cell, which dictates that DNA produces RNA during transcription. The process of converting viral RNA backward into DNA is called **reverse transcription** and is achieved by an enzyme called **reverse transcriptase**.

This viral genome codes for reverse transcriptase. When the retrovirus enters the host cell, its RNA is immediately transcribed, and one result of this is the production of reverse transcriptase. The reverse transcriptase then produces a DNA copy of the viral genome. In the case of HIV, the DNA then integrates into the host cell's chromosomes (the host cell is CD4⁺ T cells) and enters a latent phase that may last more than 10 years. When the viral DNA excises from the host chromosome, it becomes active and begins producing new viruses. When this happens on a mass scale, the death of host cells will signal the beginning of deterioration in the immune system that causes **acquired immunodeficiency syndrome (AIDS)**.

BACTERIOPHAGES

Bacteriophages are DNA viruses that infect bacteria exclusively. They always inject their DNA into the host bacterial cell and then enter either a lytic cycle or a lysogenic cycle as seen in Figure 6-6. Bacteriophages can also transport parts of the bacterial genome to other cells.

The Lytic Cycle. In the **lytic cycle**, a bacteriophage immediately activates once in its host cell. New viruses are synthesized and leave the host cell via lysis, always killing their bacterial host. The new viruses then go out and infect new host cells.

The Lysogenic Cycle. The **lysogenic cycle** is a variation that some viruses use. After injecting DNA into their host cell, the viral DNA integrates into the bacterial chromosome. The viral DNA may stay integrated for variable lengths of time. Each time the bacterial cell divides by binary fission, the progeny receive a copy of the viral genome. Eventually, the viral DNA that has integrated into the chromosome excises and enters the lytic cycle, releasing new viruses and killing their host.

TRANSDUCTION

When new viruses are being packaged in a bacterial host, sometimes portions of the bacterial chromosome get packaged with the new viruses. When these viruses infect new bacterial hosts, not only do they deliver the viral genome but also some bacterial genes that can recombine with the new host's chromosome. This is the process of **transduction**.

SUBVIRAL PARTICLES

Prions are infectious agents that are composed solely of protein and contain no nucleic acid. The prions are products of a human gene that produces a misfolded prion protein

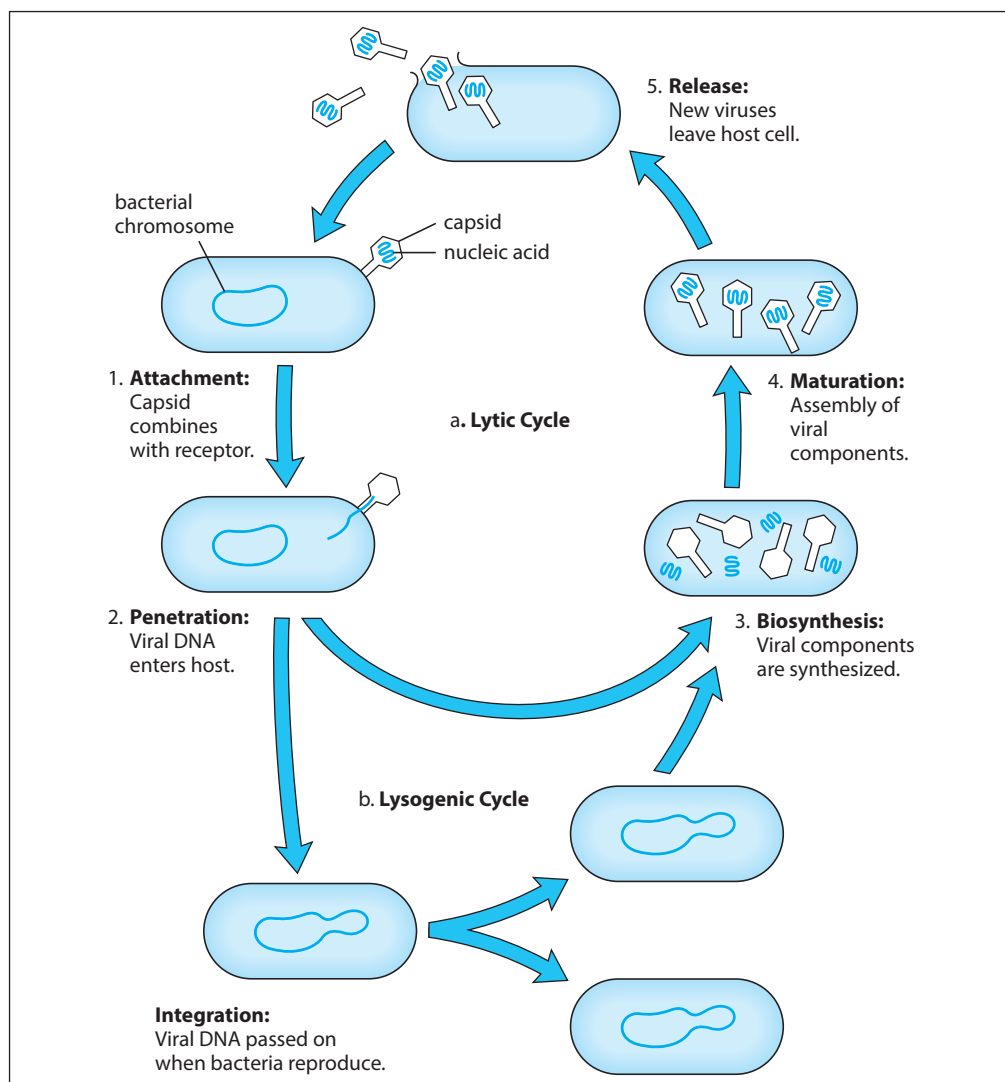


FIGURE 6-6 Bacteriophage life cycles. (a) In the lytic cycle, viral particles are released when the cell is lysed. (b) In the lysogenic cycle, viral DNA integrates into the host cell chromosome. The lysogenic cycle can be followed by the lytic cycle. *Source:* From Sylvia S. Mader, *Biology*, 8th ed., McGraw-Hill, 2004; reproduced with permission of The McGraw-Hill Companies.

called PrP. These prions act by inducing other normal proteins to convert to misfolded forms, which then convert additional proteins to prion form in a chain reaction. Prions can arise spontaneously or they can be acquired from the environment. They are best known for their association with **Creutzfeldt–Jakob disease** in humans, which causes a degenerative and fatal form of neurological encephalopathy.

Viroids are infectious agents that have similar structure to a virus but are smaller. They consist solely of a strand of RNA and lack a capsid or other proteins typically associated with viruses. Once a viroid is inside a host cell, the host cell's RNA polymerase replicates the viroid. The viroids appear to cause disease by altering gene regulation in the host cell. To date, viroids have been associated only with disease in plants.