SBI3U-C

Lesson 18

Bacteria and Viruses

Introduction

Bacteria and viruses are the smallest forms of life on the planet. You can't see them, but they affect you every day in both good and bad ways. Bacteria are used to make a lot of the food products we eat such as yogurt and cheese. Bacteria living in your gut allow you to digest foods you could not on your own. But bacteria and viruses can also cause deadly disease. Acquired immune deficiency syndrome (AIDS) is a disease caused by the human immunodeficiency virus (HIV).

In this lesson, you will learn about the biology of bacteria and viruses. You will learn about the viral disease AIDS as well as common bacterial diseases.

Planning Your Study

You may find this time grid helpful in planning when and how you will work through this lesson.

Suggested Timing for This Lesson (hours)	
Bacteria and Archaea	½
Bacteria	1
Bacteria and Humans	½
Viruses	1
Viruses and Human Health	½
Key Questions	1

What You Will Learn

After completing this lesson, you will be able to

- demonstrate an understanding of the diversity of living organisms in terms of the principles of taxonomy and phylogeny
- use appropriate terminology related to biodiversity, including genetic diversity, species diversity, structural diversity, protists, bacteria, fungi, binomial nomenclature, and morphology
- compare the structure and function of different types of prokaryotes, eukaryotes, and viruses (including such elements as genetic material, metabolism, organelles, and other cell parts)

Bacteria and Archaea

As you learned in the previous lesson, scientists have divided organisms into six kingdoms. The kingdoms Bacteria and Archaea are probably the least known, mostly because they are microscopic in size. Bacteria and Archaea are two very different kinds of organisms, each with their own identities and use in our daily lives.

Archaea are the oldest of organisms found on earth. They are prokaryotic and unicellular. Today, members of the kingdom Archaea are usually found in areas with extreme conditions. This is probably because they appeared on earth at a time when it was full of poisonous gases and unbearable heat. Archaea could survive in those extreme conditions, and are found in similar harsh conditions today.

Bacteria are more widespread. They are more complex in structure, and can live in all but the most extreme conditions. You can find bacteria everywhere, including in food and on your body.

Types of Archaea

Archaea are usually categorized into three phyla:

- methanogens, which harvest energy by changing hydrogen gas (H_2) and carbon dioxide gas (CO_2) into methane (CH_4);
- halophiles, which thrive in very salty conditions where most bacteria would die;
- thermoacidophiles, which thrive under acidic conditions and high temperatures—they can happily survive in areas with low pH and temperatures up to 110 degrees Celsius. They can be found in hot springs, and even in whirlpool baths at a public pool!

Types of Bacteria

Bacteria are hard to classify, because many species can exchange genes with one another. Using genetic analysis, bacteria have been grouped into at least 15 phyla. However, biologists often organize bacteria into groups based on their attributes that are important to us. For example, in medicine, bacteria are often categorized into two groups: gram-positive and gram-negative, where "gram" refers to a method of staining. Gram-negative bacteria tend to be the ones that cause disease in humans, while gram-positive ones don't generally cause disease, and include the good bacteria that we use to produce foods like yogurt.

Another way to classify bacteria is based on whether they can make their own food (autotrophs) or not (heterotrophs). For example, cyanobacteria use photosynthesis to make food from the sun's energy. Most bacteria can't do this, so they need to get their food some other way.

Differences between Archaea and Bacteria

Both archaea and bacteria are single-celled organisms, but bacteria are more complex. Bacteria live in normal environments, while archaea live under extreme conditions. Bacteria have been studied more extensively than archaea for several reasons. Archaea usually live in the most hostile of environments, such as undersea volcanic vents, which makes them difficult to study. Bacteria have also been more important to humans. Bacteria cause many serious human diseases such as food poisoning, pneumonia, and cholera. Some bacteria also have economic importance. For example, lactobacillus is a type of bacteria used to produce many food products such as yogurt, cheese, sauerkraut, pickles, beer, wine, cider, kimchi, and chocolate.

Because bacteria are much more common, widespread, and important to us, the rest of this lesson will focus on the characteristics of bacteria and how they affect our lives.

Support Questions

Be sure to try the Support Questions on your own before looking at the suggested answers provided.

9. Describe two features that distinguish archaea from bacteria. Suggested answer

Bacteria

Bacteria are extremely small; they range in size from 0.2–10 μm (microns). A typical eukaryotic cell is about 10 times larger.

As a group bacteria are very diverse, but they share certain characteristics:

- All bacteria are single-celled.
- All bacteria are prokaryotes. Their DNA is not surrounded by a membrane.
- Cell organelles in bacteria are not surrounded by membranes.
- The DNA of bacteria is made of a single chromosome.
- All bacteria reproduce asexually by binary fission.

Bacteria are classified by shape, as shown in Figure 18.1.

Bacilli (singular: bacillus) are rod-shaped.

Cocci (singular: coccus) are spherical.

Spirilli (singular: spirillus) are spiral-shaped.

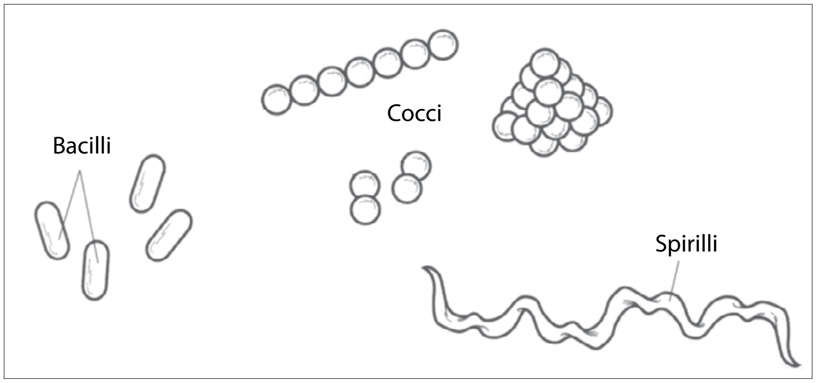

Figure 18.1: Drawing of the three shapes of bacteria: bacilli, cocci, and spirilli

Bacteria can live with or without oxygen. Aerobic bacteria are those that can or must live in the presence of oxygen. The bacteria on your skin are of this type. Anaerobic bacteria are those that can or must live in the absence of oxygen. The bacteria living in your intestines are of this type. We have found the anaerobic types to be especially useful to us in making foods. Although some species of bacteria can be both aerobic and anaerobic, most bacteria are either one or the other.

Structure of Bacteria

The structure of bacteria is quite simple. The structure of a bacillus bacterium is shown in Figure 18.2 below.

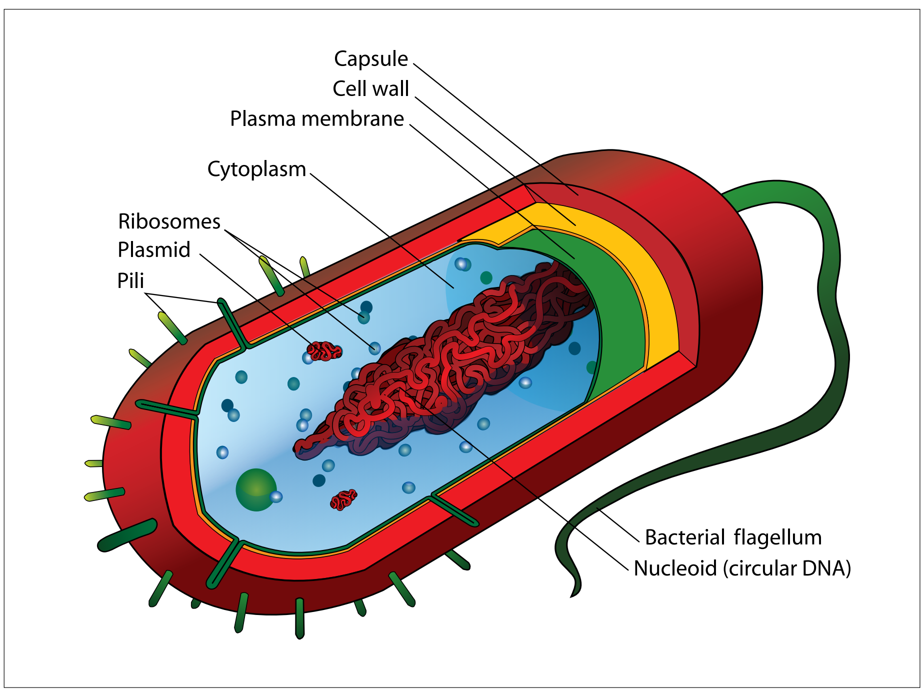

Figure 18.2: Diagram showing the structure of a typical bacterium

Source: Wikipedia

Structures Common to All Bacteria

The following structures can be found in all bacteria:

- the cell wall, which provides support and protection for the contents of the cell;
- the capsule, which is a layer of sticky material outside the cell wall that allows the cell to cling to surfaces;
- the cytoplasm, a liquid that contains ribosomes, responsible for the formation of proteins and DNA; and
- plasmids, which are small rings of DNA outside of the chromosomes. Plasmids contain far fewer genes than the bacterial chromosomes, but they code for enzymes to break down antibiotics.

Extra Structures Found in Some Bacteria

In addition to the structures described in the previous section, the following structures can also be found in some bacteria:

- flagella, which are rotating tails that allow some bacteria to move around;
- pili, which are short hair-like strands of protein that enable bacteria to stick to a surface or obtain food; and
- colonies—some bacteria stick together in small groups called colonies.

Bacterial Reproduction

Bacteria can reproduce both asexually and sexually.

Asexual Reproduction

Bacteria reproduce asexually by binary fission. This process is similar to mitosis, but is much simpler (Figure 18.3). In the first step, the single strand of DNA replicates, resulting in two identical copies of the chromosome. The next step is segregation, in which the duplicated chromosome splits apart and each half moves to opposite ends of the cell. The third step is cytokinesis, in which the bacterium produces a wall to divide the cell into two identical bacteria. These can remain attached or may separate.

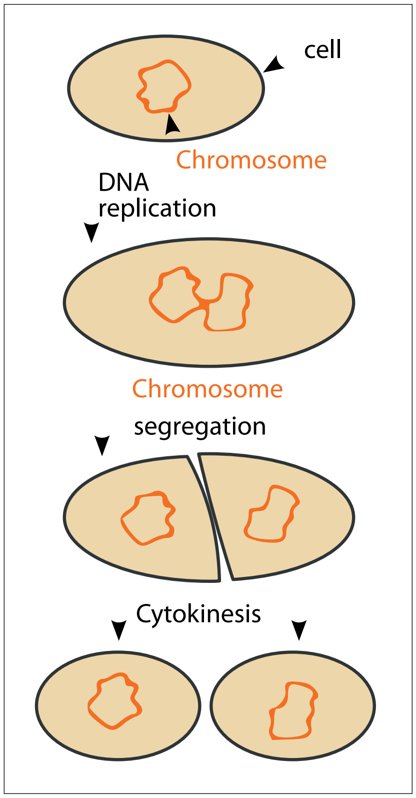

Figure 18.3: Binary fission is a form of asexual reproduction in bacteria.

Source: Wikipedia

Sexual Reproduction

As long as the conditions for survival are ideal, most bacteria reproduce through binary fission because it is simpler and faster. In less favourable conditions, some bacteria are able to reproduce sexually. This produces cells with new genetic combinations (new genotypes), and thereby offers a chance that some may be better adapted to the changing conditions.

Changes in the genotype may allow the bacteria

- to survive in a more hostile environment;
- to obtain nutrition from sources that were previously inaccessible;
- to avoid the action of destructive chemicals (such as antibiotics); and
- to produce chemicals that protect them from organisms capable of destroying them.

There are three ways bacteria can exchange genetic information in sexual reproduction:

- conjugation;
- transduction; or
- transformation.

Conjugation

During conjugation, bacterial cells become linked to one another through a bridge called a pilius (plural "pili") (Figure 18.4). One bacterium transfers all or part of its chromosome to the other across the pilius. In this example, one bacterium is donating a copy of a plasmid to the other. The receiving cell now has a new set of genetic information. It then undergoes binary fission to produce daughter cells with the same genetic make-up.

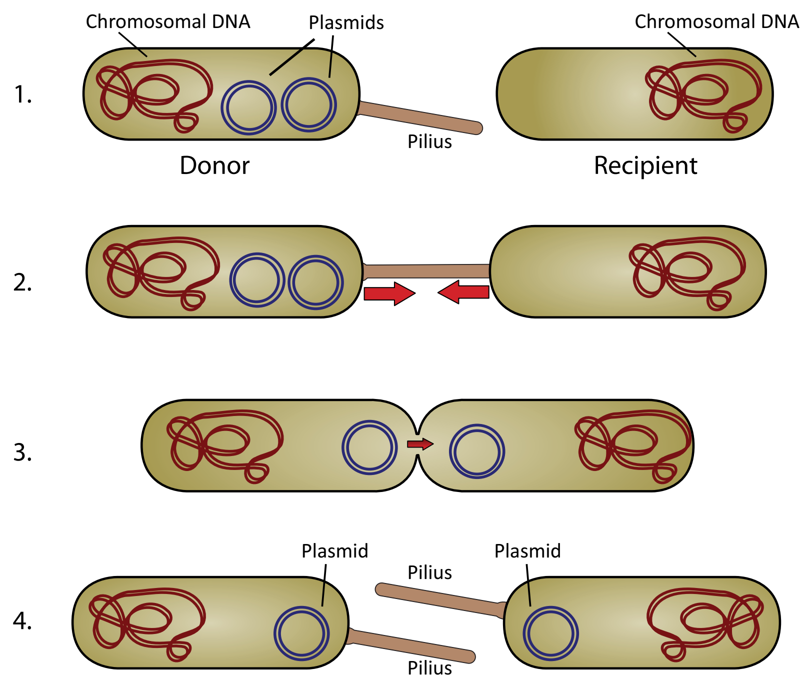

Figure 18.4: Diagram showing conjugation between two bacterial cells. Genetic material is exchanged across the pilius.

Source: Wikipedia

Transduction

Bacteria, like humans, can be attacked by viruses. These bacteria-attacking viruses are known as bacteriophages. They can change the DNA of bacteria by inserting some of their own DNA into the bacterial genome. Bacteriophages may also carry DNA from one bacterium to another. These actions alter the genotype of the bacterium in a process known as transduction.

Transformation

In the process called transformation, free pieces of DNA move from a donor cell to a recipient cell. Bacteria can "take up" this DNA (even from another species of bacteria) and incorporate it into their genomes. This changes their DNA, and allows them to express a new genetic trait.

Support Questions

Be sure to try the Support Questions on your own before looking at the suggested answers provided.

10. Name the three types of bacteria based on shape. Draw a sketch of each type.

Suggested answer

11. Describe two ways that new genetic material can be incorporated into the genome of a bacterium.

Suggested answer

Bacteria and Humans

People tend to fear bacteria. If you were told that there were bacteria on your shirt, you might not want to wear it. But bacteria are everywhere and, most of the time, they do not bother us. Our bodies are used to defending themselves against them. Only some bacteria cause disease, and some are very beneficial to us, especially the bacteria that live in our digestive system and help digest food. Bacteria are so important that chances are you couldn't survive very long without them.

Harmful Bacteria

It is a well-known fact that bacteria can cause serious diseases. Some of the harmful diseases caused by bacteria are summarized in Table 18.1, below.

Type of bacteria	Diseases
Clostridia	Botulism, tetanus, and gangrene
Streptococci	Strep throat, scarlet fever, and pneumonia
Staphylococci	Boils, food poisoning, and skin infection

Table 18.1: Harmful diseases caused by bacteria

Bacterial disease can be spread from one individual to another by direct contact, as well as dust and moisture droplets in the air, fecal contamination, animal bites, and wounds. You can protect yourself from bacterial disease by not letting your hands come in contact with your mouth, by strengthening your body's own natural defences, and by taking antibiotics when necessary.

Antibiotic Resistance

When antibiotics were discovered, they were called “magic bullets” and “wonder drugs” because they were so effective at killing bacteria. People believed they were a miracle cure for any illness they might have. Soon, these powerful medicines were being overused, either to treat conditions for which other options are available, or prescribed incorrectly for illness not caused by bacteria. In addition, unused antibiotics are often disposed of improperly, ending up in water systems or soil.

The problem with the widespread use of antibiotics is that it has allowed the fittest (strongest) bacteria to survive and multiply in this new environment. This has left scientists racing to create new antibiotics to keep ahead of the evolving bacteria. But progress has been slow, and now some antibiotic-resistant bacteria are themselves becoming widespread. These bacteria are very hard to treat, so that even minor infections can lead to death.

It is important to avoid overusing antibiotics, and for patients to take their entire prescription of antibiotics when it is warranted. Any unused medication should be taken to the pharmacy for proper disposal, not flushed down the toilet where it could contaminate the environment.

Beneficial Bacteria

Even though we generally think of bacteria as being harmful, they provide many benefits to us and the earth. In fact, most bacteria are non-pathogenic, meaning that they do not cause disease. These beneficial bacteria help us in many ways.

Soil Bacteria

All plants require nitrogen to make proteins. Most plants cannot absorb pure nitrogen, but they can absorb nitrogen in the form of nitrates (NO_3). Nitrates are readily absorbed by the root systems of plants. Soil bacteria, in eating dead organic matter, put pure nitrogen back into the soil, while other species of bacteria change this pure nitrogen into nitrates. In addition, other types of bacteria, called nitrogen-fixing bacteria (cyanobacteria), are able to take nitrogen directly from the air (air is 80% nitrogen) and change it into nitrates so that plants can use it. This process is essential to the cycling of matter and the functioning of ecosystems. It couldn’t be accomplished without the help of bacteria.

Decay Bacteria

Decay bacteria help break down the biological wastes inside septic tanks and sewage disposal systems. Almost all sewage treatment uses decay bacteria at some point in the process.

Manufacturing of Food Products

Bacteria are useful for the production of many food products. For example:

- Bacteria are used in the production of many dairy products such as cheeses, butter, buttermilk, and yogurt.
- Anaerobic bacteria (bacteria that do not require oxygen) decompose the sugars present in cabbage leaves stored in an air-tight container into lactic acid and ethyl alcohol, giving pickled foods such as sauerkraut and kimchi their distinctive flavours.
- Bacteria found in the air can change the ethyl alcohol produced by yeast into vinegar (acetic acid) by using the alcohol as food for metabolism.

Manufacturing of Drugs and Industrial Products

Bacteria are used to make drugs such as insulin as well as industrial products. Bacteria can be used as tiny factories to produce specific proteins; to accomplish this, large containers of specially-chosen bacteria are provided with nutrients and ideal growing conditions, and the products are then collected. Bacteria are also used to prepare animal skins for making leather goods, and genetically-engineered bacteria are used to break down oil spills.

Support Questions

12. Humans have various bacteria that are normally present in their mouth. Some of these bacteria are essential for maintaining health. Based on this, do you think that antibacterial mouthwashes are a good thing? Explain. Suggested answer

Viruses

In the mid-1800s, Louis Pasteur demonstrated that many diseases of plants and animals were caused by bacteria. The bacteria could be observed clearly under the light microscope. But not all diseases could be traced to bacteria. For example, biologists could find no evidence of bacteria in tobacco plants with tobacco mosaic disease. This disease causes the leaves to wrinkle and become mottled. Clearly, there was another disease-causing agent.

In 1898, a Dutch biologist named Beijerinck was researching the cause of tobacco mosaic disease. He hypothesized that if diseased tobacco plants were ground up to produce a juice and if the juice were rubbed onto a healthy plant, this would cause the healthy plant to get the disease. Beijerinck extracted the juice from an infected tobacco plant and strained the juice through a very fine filter made of porcelain. The idea was to remove all the bacteria from the juice, leaving a bacteria-free filtrate. Next, he rubbed the filtrate on the leaves of a healthy tobacco plant. The healthy plant soon showed signs of the disease. He concluded that there must be something smaller than bacteria in the filtrate that was causing the disease. He called this new pathogen a “virus.”

What is a Virus?

A virus is a tiny organism made of nucleic acid and protein. Viruses are so simple that they lack most components of a cell, and therefore can’t survive on their own more than a few hours. Some biologists don’t even consider them to be living organisms, just mobile genes that live off cells. Viruses fall somewhere between living and non-living things. Here are some features of viruses that show why they are so hard to define.

Living

- Viruses possess genetic material that is capable of mutation or genetic recombination.
- Viruses can adapt to changing environments through replication and mutation within their host cells.

Non-living

- Viruses have no cell organelles, and are unable to produce their own cellular energy or proteins; they must rely on their host for all cellular functions.
- Viruses can only replicate within living cells.
- Viruses do not grow.
- Viruses can be crystallized, which is common for non-living things.

Structure of Viruses

Viruses are very tiny, and can only be seen directly with the aid of the electron microscope. A large virus has about one-tenth the volume of a small bacterium. Viruses have nucleic acid that may consist of a single or double strand of DNA or RNA. The amount of genetic information in any virus is small. Most viruses have fewer than 10 genes, while a few large viruses may contain 100 genes—far fewer than bacteria, since even the very simple bacterium *E. coli* has 200 genes.

Viral nucleic acid is surrounded by a protein coat called the capsid. A capsid is made up of several hundred protein molecules packed together in a geometric pattern. Some larger viruses such as the human rotavirus (Figure 18.5) have a complex envelope surrounding the capsid. This helps the virus recognize and attach to a host cell.

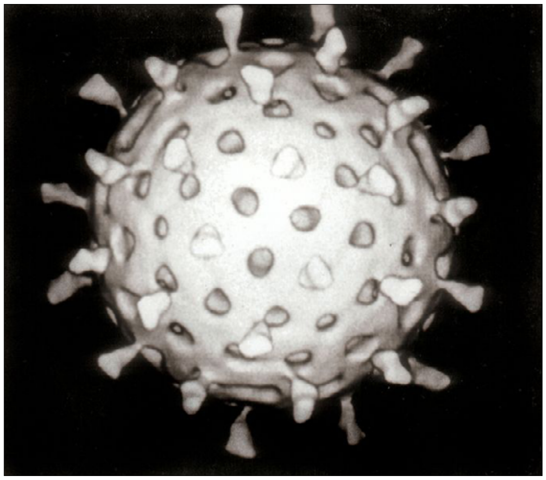

Figure 18.5: Computer-aided reconstruction of a human rotavirus based on several electron micrographs. This rotavirus causes diarrhea.

Source: Wikipedia

Bacteriophage

A bacteriophage (Figure 18.6) is a virus that attacks bacteria. They are often called phages for short.

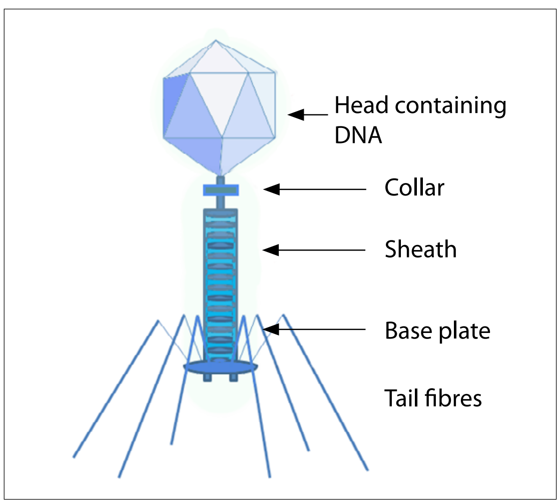

Figure 18.6: Diagram of a bacteriophage

Source: Wikimedia Commons

A bacteriophage has three main parts: head, sheath, and tail. The head contains the DNA. The sheath is the body of the virus, which contains the mechanism to insert the viral DNA into the bacterium once the phage has attached. The tail is where the phage attaches to the cell wall of the bacteria. It can be specially designed to attach to specific types of bacteria.

Replication of Viruses

The term replication is used instead of reproduction to describe the creation of new viruses because viruses are not true cells. Viruses can replicate themselves in host cells two ways: the lytic cycle and the lysogenic cycle.

Lytic Cycle

Most viruses replicate using the lytic cycle, which has five phases (Figure 18.7).

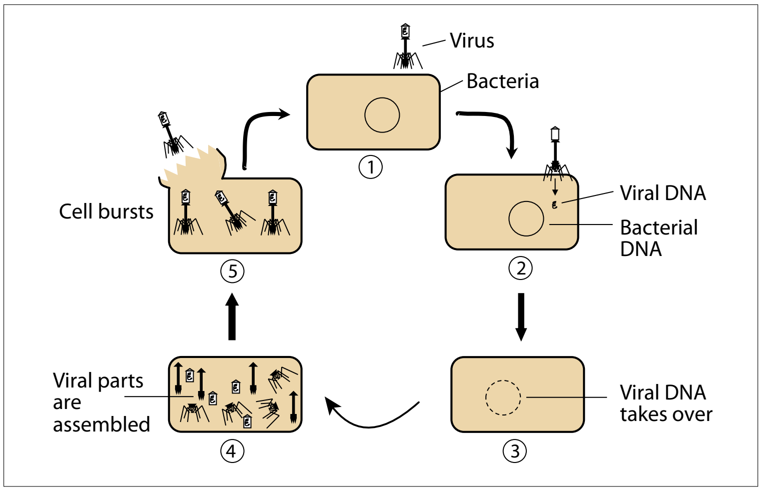

Figure 18.7: Diagram showing viral replication in the lytic cycle

Steps

1. Attachment

The phage attaches itself to the cell by its tail. The protein on the tail fibres have a shape that fits with the molecules on the outer surface of the host cell's membrane.

2. Injection

The phage releases an enzyme that breaks down the cell membrane. The viral nucleic acid is then injected into the cell.

3. Synthesis

The viral nucleic acid takes over, rendering the host cell's DNA inactive. Normal cellular metabolism stops. The host cell is directed to make copies of the viral nucleic acid and proteins.

4. Assembly

The viral protein and nucleic acid are assembled into new viruses.

5. Cytolysis

The host cell then makes an enzyme that digests the cell membrane from the inside. This causes the cell to burst open, releasing hundreds of new viruses.

Lysogenic Cycle

Not all viruses cause rapid destruction of the host cell. Some viruses enter a host cell, but do not take over by destroying the host's DNA as in the lytic cycle. Instead, the viral DNA combines with the host DNA in a way that does not interfere with the host cell activity. When the host cell copies its own DNA, the viral DNA is also copied. The viral DNA can be copied in this manner through several generations of host cell reproduction. During this period of normal replication, the virus appears to be in a dormant state, called latency. This is how the AIDS virus invades human white blood cells and can stay dormant for many years.

External stimuli (such as a change in temperature, stress, or another infection) can cause the viral DNA to become active. The host cell is then directed by the viral DNA to manufacture new viruses using the lytic cycle.

Support Questions

13. Why are viruses, although considered to be non-living, frequently referred to as parasites?

Suggested answer

14. Explain the differences between the lytic and lysogenic cycles of viral replication.

Suggested answer

Viruses and Human Health

Many diseases are caused by viruses. Viral diseases cannot be treated with antibiotics as bacterial infections can, because viruses are too simple to be killed by the antibiotic agent.

We can protect ourselves against some viruses using vaccines. Vaccines are made of weakened forms of the virus that can be given to build up immunity in the body. When people are vaccinated against viral diseases such as polio or smallpox, their body reacts to the vaccine as if it were a real virus, producing antibodies. The antibodies provide immunity to the disease or reduce the effects of the disease. Some of the harmful diseases caused by viruses are summarized in Table 18.2, below.

Disease	Transmission method
Smallpox	Direct contact, air-transmitted droplets
Chicken pox	Direct contact, air-transmitted droplets
Polio	Direct contact, fecal contamination
Common cold	Direct contact, air-transmitted droplets
Measles, mumps	Direct contact
Rabies	Bite from infected animal
AIDS	Direct contact, sharing infected needles

Table 18.2: Harmful diseases caused by viruses

Safe Handling of Dangerous Biological Materials

Every person who works with biological samples in a laboratory, health facility, or industry needs to be aware of the potential hazards from some biological material. For example, exposure to some viruses or bacteria can kill you very quickly. Others can make you sick or pose special risks to developing babies. Special precautions should always be observed when working with bacteria and viruses. At the very least, protective clothing, gloves, glasses, and sometimes a face mask are required. With especially dangerous bacteria like anthrax, or viruses like ebola, the level of protection is extreme. In these cases, workers wear body suits and helmets with their own air supply, and work in specially sealed rooms.

Besides pathogens, other material commonly found in biology laboratories can be hazardous. Chemicals, radio isotopes, UV lights, lasers, and sharp objects can all cause injury or death. It is important that biologists learn how to work with these hazardous materials. Canada has set up a system to educate workers about the hazards of the materials, biological and otherwise, they may be working with. This system is called the Workplace Hazardous Materials Information System, or WHMIS, and training in this system is required for many careers.

Now follow this link to the activity called Understanding WHMIS. This system of labelling and describing hazardous materials is designed to protect anyone working with or storing potentially hazardous materials, including biological samples. You will gain practice learning and recognizing the hazard symbols and the uses of personal protection equipment.

Viral Vectors and Gene Therapy

Although viruses can be deadly when they infect a host cell, scientists have also been able to use some viruses in gene therapy to help treat human disease. Using a viral vector means inserting a desired gene into a host cell using a virus, to alter a person's genetic code in order to help them prevent or treat disease.

Here are the stages of a typical viral vector treatment:

1. The virus's own (viral) gene is removed from the virus that will act as the vector
2. The desired normal gene is inserted into the virus
3. The modified virus enters the affected cell, depositing the desired normal gene there
4. The desired normal gene integrates into the affected cell's DNA, repairing it
5. The affected cell replicates with the repaired DNA

Support Questions

15. If you have a cold, does taking an antibiotic help? Explain. Suggested answer

Key Questions

Now work on your Key Questions in the online submission tool. You may continue to work at this task over several sessions, but be sure to save your work each time. When you have answered all the unit's Key Questions, submit your work to the ILC.

(15 marks)

56. In many viral diseases (such as smallpox, mumps, or influenza), illness occurs shortly after exposure to the virus. In others (such as AIDS), the victim may not show symptoms for many years following the initial exposure. How would you explain the difference between these two situations? **(6 marks)**

57. **a)** Why are bacteria considered living organisms, while viruses are usually considered non-living? **(2 marks)**

b) Describe three characteristics that define bacteria. **(3 marks)**

58. Various bacteria are normally present in most of our body systems. These "good" bacteria are essential for maintaining health. Describe two risks and two benefits of using antibacterial creams to cure vaginal infections. **(4 marks)**

Now go on to Lesson 19. Send your answers to the Key Questions to the ILC when you have completed Unit 5 (Lessons 17 to 20).