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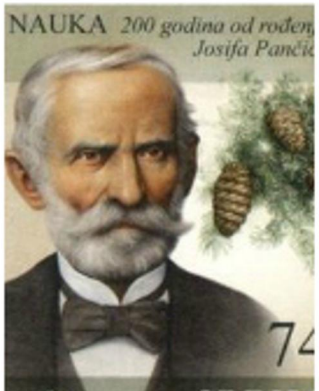

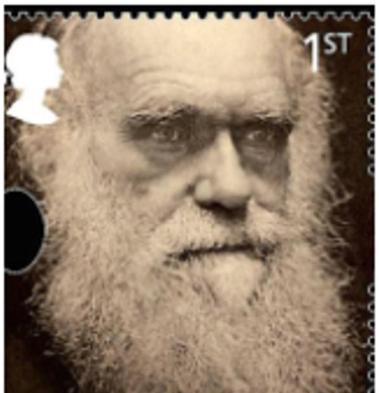

Biology for Online Learning

Dana Desonie, Ph.D.
Douglas Wilkin, Ph.D.
Niamh Gray-Wilson
Jessica Harwood
Barbara Akre
Ck12 Science
Jean Brainard, Ph.D.
Milton Huling, Ph.D.

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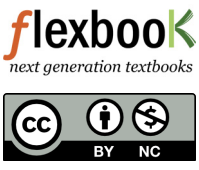

AUTHORS
Dana Desonie, Ph.D.
Douglas Wilkin, Ph.D.
Niamh Gray-Wilson
Jessica Harwood
Barbara Akre
Ck12 Science
Jean Brainard, Ph.D.
Milton Huling, Ph.D.

EDITORS
Aleks Stosich
Douglas Wilkin, Ph.D.

CONTRIBUTORS
Doris Kraus, Ph.D.
Niamh Gray-Wilson
Jean Brainard, Ph.D.
Sarah Johnson
Jane Willan
Corliss Karasov

Contents

CONCEPT 1 Characteristics and Origins of Life

Learning Objectives

- Describe the origins of life on Earth.
- Explain how scientists study early life.

What is ?

How can you tell a blob of organic material from a living creature? What characteristics does something need to be considered alive? Does this photo resemble early Earth? Erupting geysers? Mats of bacteria? Maybe so! Of course, you have to ignore the trees in the distance.

The Origin Of Life

No one knows how or when life first began on the turbulent early Earth. There is little hard evidence from so long ago. Scientists think that it is extremely likely that life began and was wiped out. Possibly even more than once! If there was life, it would have been wiped out by the impact that created the moon.

This issue of what's living and what's not is important. It helps us to think about the origin of life. When does a blob of organic material become life? As you can see, we need to have a definition of life.

Characteristics of Life

To be considered alive, a molecule must:

- be organic. The organic molecules needed are amino acids.
- have a metabolism.
- be capable of replication (be able to reproduce).

Amino acids are molecules of carbon, hydrogen, and oxygen. These molecules are called the building blocks of life because they create proteins. **Proteins** are complex organic molecules that make up cells. They are the most abundant class of biological molecules.

Learning About the Origin of Life

To look for information regarding the origin of life, scientists:

- perform experiments to recreate the environmental conditions found at that time.
- study the living creatures that make their homes in extreme environments. These environments are most like Earthâ[U+0080][U+0099]s early days.
- seek traces of life left by ancient microorganisms, also called **microbes** (**Figure** 1.1). These include microscopic features or chemistry left by life. It is very difficult to distinguish these from non-biological features.

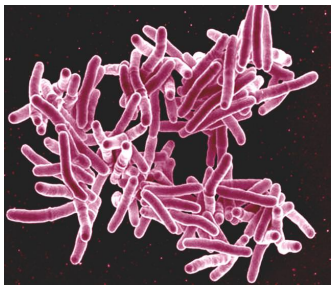

FIGURE 1.1

How can we tell where these microbes have been?

Summary

- For something to be alive it must be organic, have a metabolism, and be capable of replication.
- Amino acids create proteins. They are the building blocks of life.
- To learn about the origins of life, scientists perform experiments. They study creatures that live in extreme environments. They look for traces of life that were left by ancient microbes.

Review

1. What are the characteristics of life?
2. What are amino acids? Why are they important?
3. What are proteins? If something doesn't have proteins can it be alive?
4. How do scientists learn about the origins of life?

References

1. NIAID. Pictures of microbes . CC BY 2.0

CONCEPT 2 First Organic Molecules-Miller and Urey Experiment

How do you make large molecules?

From smaller ones. The first **organic molecules** were probably very simple carbon-based molecules made of few atoms. These molecules then combined with other simple molecules to form more complex molecules. Over many years and probably trillions and trillions of chemical reactions, more complex molecules, and more stable molecules, formed.

All living things consist of **organic molecules**, centered around the element carbon. Therefore, it is likely that organic molecules evolved before cells, perhaps as long as 4 billion years ago. How did these building blocks of life first form?

Miller and Urey Experiment

Scientists think that lightning sparked chemical reactions in Earth's early atmosphere. The early atmosphere contained gases such as ammonia, methane, water vapor, and carbon dioxide. Scientists hypothesize that this created a "soup" of organic molecules from inorganic chemicals. In 1953, scientists Stanley Miller and Harold Urey used their imaginations to test this hypothesis. They created a simulation experiment to see if organic molecules could arise in this way (see **Figure** 2.1). They used a mixture of gases to represent Earth's early atmosphere. Then, they passed sparks through the gases to represent lightning. Within a week, several simple organic molecules had formed.

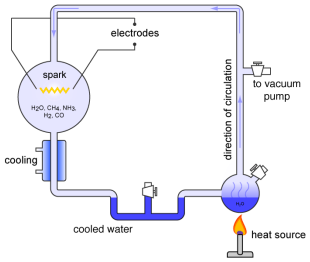

FIGURE 2.1

Miller and Urey's Experiment. Miller and Urey demonstrated that organic molecules could form under simulated conditions of early Earth. What assumptions were their simulation based upon?

Which Organic Molecule Came First?

Living things need organic molecules to store genetic information and to carry out the chemical work of cells. Modern organisms use DNA to store genetic information and proteins to catalyze chemical reactions. So, did DNA or proteins evolve first? This is like asking whether the chicken or the egg came first. DNA encodes proteins and proteins are needed to make DNA, so each type of organic molecule needs the other for its own existence. How could either of these two molecules have evolved before the other? Did some other organic molecule evolve first, instead of DNA or proteins?

RNA World Hypothesis

Some scientists speculate that RNA may have been the first organic molecule to evolve. In fact, they think that early life was based solely on RNA and that DNA and proteins evolved later. This is called the **RNA world hypothesis.** Why RNA? It can encode genetic instructions (like DNA), and some RNAs can carry out chemical reactions (like proteins). Other evidence also suggests that RNA may be the most ancient of the organic molecules. You can learn more about the RNA world hypothesis and the evidence for it at this link:

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/156139

Watch the video at: http://www.youtube.com/watch?v=sAkgb3yNgqg

Summary

- The first organic molecules formed about 4 billion years ago.
- This may have happened when lightning sparked chemical reactions in Earth's early atmosphere.
- RNA may have been the first organic molecule to form as well as the basis of early life.

Explore More

Use the time slider in this resource to answer the questions that follow.

- **Evolution** at http://johnkyrk.com/evolution.swf .

1. When did the element carbon first form?
2. When did the first elements appear in Earth's atmosphere and on its surface?
3. List 5 of these early chemicals.
4. When did the first organic molecules appear?
5. What were these first organic molecules? How did these organic molecules accumulate?

Review

1. Describe Miller and Urey's experiment. What did it demonstrate?
2. State the RNA world hypothesis.

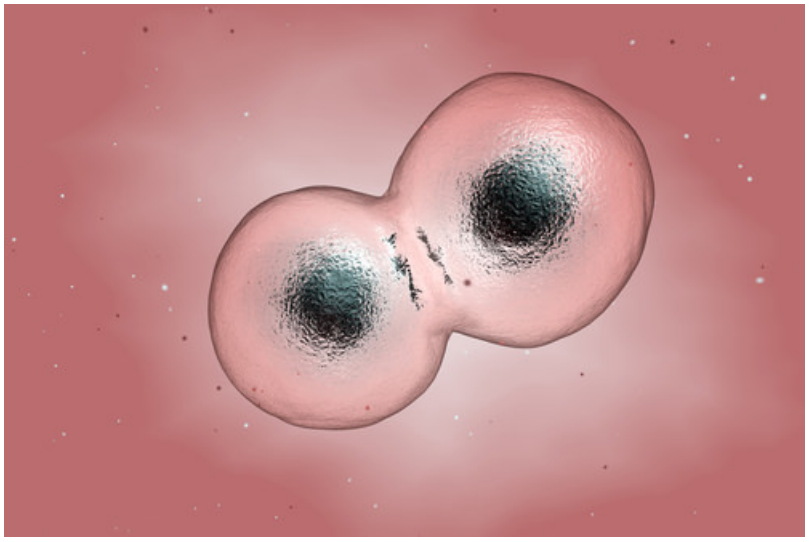
References

1. User:Carny/He.Wikipedia, modified by CK-12 Foundation. Miller-Urey experiment, forming organic molecule from simulated early Earth .

CONCEPT 3 The Cell Theory - Advanced

Learning Objectives

- Summarize the principle points of the Cell Theory.



Where do cells come from?

All cells come from other cells. It was the advent of the microscope that allowed this discovery to be made. And it is one of the three basic points of the Cell Theory. This picture represents cell division, the process of one cell dividing into two cells.

The Cell Theory

Over the next two centuries after the discoveries of Hooke and Leeuwenhoek, biologists found cells everywhere. Biologists in the early part of the 19^{th} century suggested that all living things were made of **cells**, but the role of cells as the primary building block of life was not discovered until 1839 when two German scientists, Theodor Schwann, a **zoologist**, and Matthias Jakob Schleiden, a **botanist**, suggested that cells were the basic unit of structure and function of all living things. Later, in 1858, the German doctor Rudolf Virchow observed that cells divide to produce more cells. He proposed that all cells arise only from other cells. The collective observations of all three scientists form the **Cell Theory**, which states that:

- all organisms are made up of one or more cells,
- all the life functions of an organism occur within cells,
- all cells come from preexisting cells.

Though no one point of the Cell Theory is more important than another, the theory clearly states that the functions necessary for life occur in the cell. Findings since the time of the original Cell Theory have enabled scientists to "modernize" the theory, including points related to **biochemistry** and **molecular biology**. The modern version of the Cell Theory includes:

- all known living things are made up of one or more cells,
- all living cells arise from pre-existing cells by division,
- the cell is the fundamental unit of structure and function in all living organisms,
- the activity of an organism depends on the total activity of independent cells,
- energy flow (**metabolism** and biochemistry) occurs within cells,
- cells contain hereditary information (**DNA**) which is passed from cell to cell during **cell division**,
- all cells are basically the same in chemical composition in organisms of similar species.

The Cell Theory is one of the main principles of biology. The points of the theory have been found to be true for all life. As with any scientific theory, the Cell Theory is based on observations that over many years upheld the basic conclusions of Schwann's 1839 paper. However, one of Schwann's original conclusions stated that cells formed in a similar way to crystals. This observation, which refers to **spontaneous generation** of life, was discounted when Virchow proposed that all cells arise only from other cells. The Cell Theory has withstood intense examination of cells by modern powerful microscopes and other instruments. Scientists continue to use new techniques and equipment to look into cells to discover additional explanations for how they work.

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Summary

- The Cell Theory states that all living things are made of one or more cells, that cells are the basic unit of life, and that cells come only from other cells.
- The Cell Theory has been updated to include findings based on more recent findings.

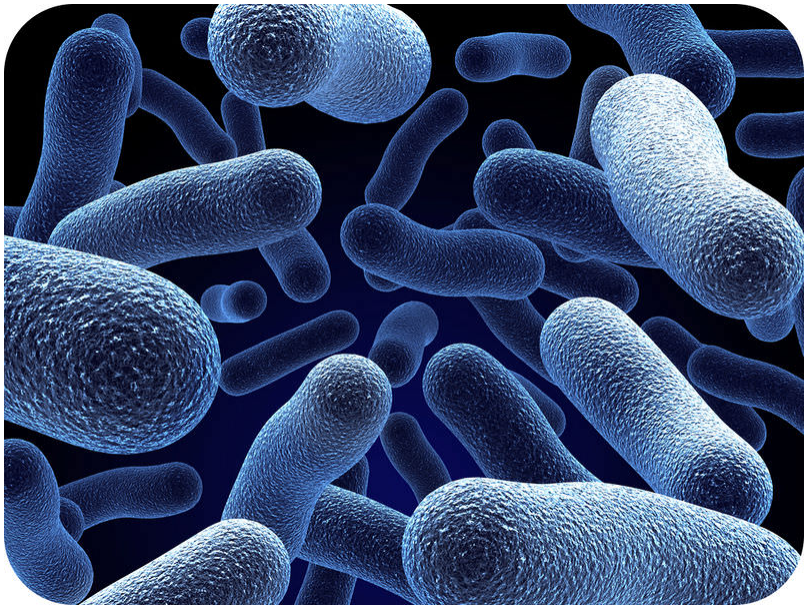
Review

1. What three things does the original Cell Theory propose?
2. Compare the modern Cell Theory to the original Cell Theory.
3. How has the theory developed?

CONCEPT 4 Prokaryotic and Eukaryotic Cells

Learning Objectives

- Distinguish between eukaryotic and prokaryotic cells.
- Define an organelle.
- Describe the main role of the nucleus



Are bacteria cells like our cells?

Yes and no. Bacteria cells are similar to our cells in some ways. Like our cells, bacteria cells have DNA and a plasma membrane. But bacteria are unique in other ways. They are called prokaryotic cells because of these differences.

Prokaryotic and Eukaryotic

There are two basic types of cells, **prokaryotic cells** and **eukaryotic cells**. The main difference between eukaryotic and prokaryotic cells is that eukaryotic cells have a **nucleus**. The nucleus is where cells store their **DNA**, which is the genetic material. The nucleus is surrounded by a membrane. Prokaryotic cells do not have a nucleus. Instead, their DNA floats around inside the cell. Organisms with prokaryotic cells are called **prokaryotes**. All prokaryotes are single-celled (unicellular) organisms. Bacteria and Archaea are the only prokaryotes. Organisms with eukaryotic cells are called **eukaryotes**. Animals, plants, fungi, and protists are eukaryotes. All multicellular organisms are eukaryotes. Eukaryotes may also be single-celled.

Both prokaryotic and eukaryotic cells have structures in common. All cells have a plasma membrane, ribosomes, cytoplasm, and DNA. The **plasma membrane**, or cell membrane, is the phospholipid layer that surrounds the cell and protects it from the outside environment. **Ribosomes** are the non-membrane bound organelles where proteins are made, a process called **protein synthesis.** The **cytoplasm** is all the contents of the cell inside the cell membrane, not including the nucleus.

Eukaryotic Cells

Eukaryotic cells usually have multiple **chromosomes**, composed of DNA and protein. Some eukaryotic species have just a few chromosomes, others have close to 100 or more. These chromosomes are protected within the nucleus. In addition to a nucleus, eukaryotic cells include other membrane-bound structures called **organelles**. Organelles allow eukaryotic cells to be more specialized than prokaryotic cells. Pictured below are the organelles of eukaryotic cells (**Figure** 4.1), including the **mitochondria**, **endoplasmic reticulum**, and **Golgi apparatus**. These will be discussed in additional concepts.

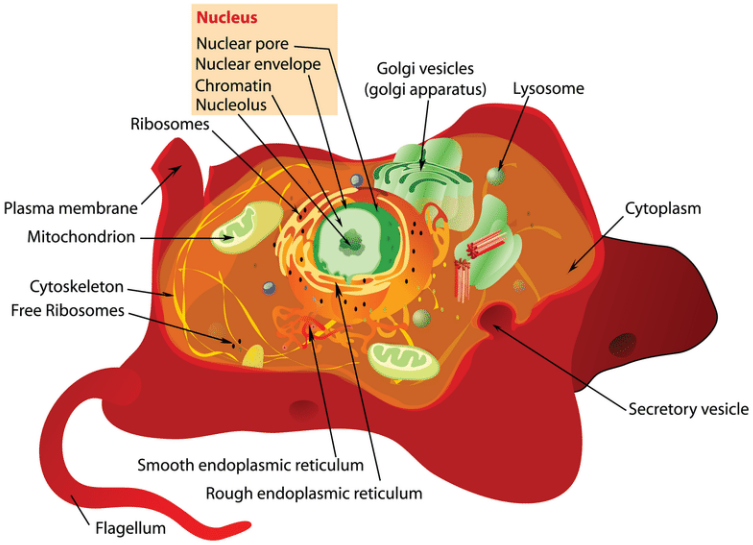


FIGURE 4.1

Eukaryotic cells contain a nucleus and various other special compartments surrounded by membranes, called organelles. The nucleus is where the DNA (chromatin) is stored. Organelles give eukaryotic cells more functions than prokaryotic cells.

Prokaryotic Cells

Prokaryotic cells (**Figure** 4.2) are usually smaller and simpler than eukaryotic cells. They do not have a nucleus or other membrane-bound organelles. In prokaryotic cells, the DNA, or genetic material, forms a single large circle that coils up on itself. The DNA is located in the main part of the cell.

TABLE 4.1: Comparison of Prokaryotic and Eukaryotic Cells

	Prokaryotic Cells	**Eukaryotic Cells**
Nucleus	No	Yes
DNA	Single circular piece of DNA	Multiple chromosomes
Membrane-Bound Organelles	No	Yes
Examples	Bacteria	Plants, animals, fungi

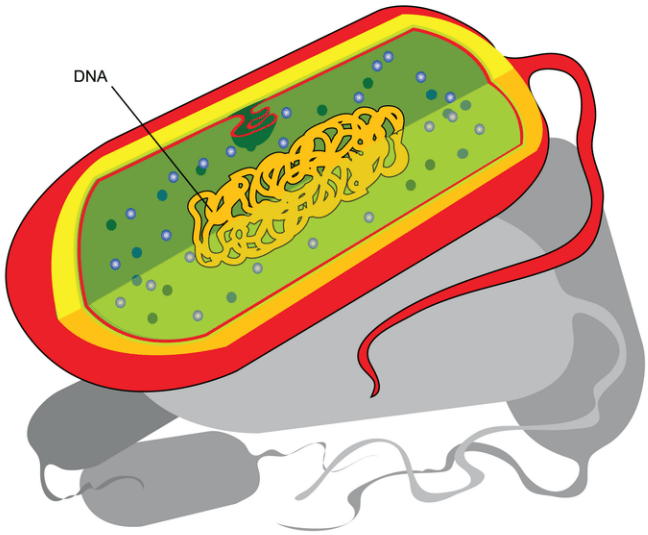


FIGURE 4.2

Prokaryotes do not have a nucleus. Instead, their genetic material is located in the main part of the cell.

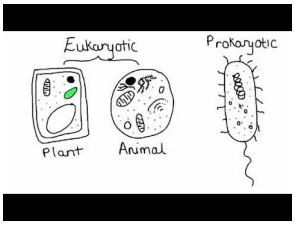
Summary

- All cells have a plasma membrane, ribosomes, cytoplasm, and DNA.
- Prokaryotic cells lack a nucleus and membrane-bound structures.
- Eukaryotic cells have a nucleus and membrane-bound structures called organelles.

Explore More

Use the resource below to answer the questions that follow.

- **Compare Prokaryotic and Eukaryotic Cells** at http://www.youtube.com/watch?v=QON4z9vo7Ag (1:55)



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1. What does "naked" DNA mean? What kinds of organisms have "naked" DNA?
2. Where do you find membrane bound organelles? Are plasmids membrane bound organelles?
3. What is the function of mitochondria in prokaryotes?

Review

1. What do all cells have in common?

2. What are organelles?
3. Compare the location of the genetic material of eukaryotic cells and prokaryotic cells.
4. What are ribosomes?
5. What are the only prokaryotes?
6. Which prokaryotes are multicellular?

References

1. Mariana Ruiz Villarreal (LadyofHats), modified by CK-12 Foundation. Organelles of a eukaryotic cell .
2. Mariana Ruiz Villarreal (LadyofHats), modified by CK-12 Foundation. Diagram of a prokaryotic cell . Public Domain

CONCEPT 5

Evolution of Eukaryotes - Advanced

Learning Objectives

- Explain the Endosymbiotic Theory of the origin of eukaryotic cells.
- Evaluate the evidence for the Endosymbiotic Theory.
- Identify the origins of the three major domains of life.
- Analyze the evolutionary potential of the eukaryotic cell.
- Discuss the pros and cons of the evolutionary "tree" as a way of depicting the evolutionary process.

Why can this fish live in these tentacles, but other fish cannot?

Sea anemones and Clown Fish have a well-known symbiotic relationship. In the ocean, the Clown Fish are protected from predatory fish by the stinging tentacles of the sea anemone and the sea anemone receives protection from polyp-eating fish, which the Clown Fish chase away. But what about symbiotic relationships at a much smaller scale? Is it possible for two single-celled organisms to have a symbiotic relationship? As you will find out, yes it is!

Eukaryotes

All **eukaryotic** cells protect DNA in chromosomes with a nuclear membrane, make ATP with mitochondria, move with flagella (in the case of sperm cells), and feed on glucose, made by cells with chloroplasts. All multicellular organisms and the unicellular protists share this cellular intricacy. Bacterial (prokaryotic) cells are orders of magnitude smaller and have much less complexity. They do not have nuclei. They do not have membrane-bound organelles and though they may move with flagella, they do not have mitochondria or chloroplasts. But some bacteria can photosynthesize and some can perform aerobic respiration. Still, there is a tremendous difference between prokaryotes and eukaryotes. What quantum leap in evolution created this vast chasm of difference?

Alliance, Invasion, or Slavery?

How did the first eukaryotic organisms form? They must have evolved from unicellular prokaryotic organisms. Once prokaryotic cells evolved to have true membrane-bound organelles, the cells, by definition, could no longer be considered prokaryotic, and must have become the first eukaryotic cells and organisms.

The widely accepted **Theory of Endosymbiosis** (or Endosymbiotic Theory), shown in **Figure** 5.1, proposes that many organelles were once independently-living, single-celled prokaryotic organisms. Larger prokaryotic cells engulfed these smaller cells but did not digest them, perhaps due to prey defenses. Alternatively, perhaps the smaller cells invaded the larger cells with the "intent" to parasitize. In either case, with their own DNA, the endosymbionts reproduced independently within the cell, and cell division passed them on to future generations of cells. Aerobic bacterial invaders would have been able to use oxygen to further break down the products of glycolysis, producing ATP. So much energy (ATP) resulted that some was available to the larger host; a mutually beneficial symbiotic relationship resulted. This intriguing story of cooperation - so different from natural selection's emphasis on competition - explains the origin of our mitochondria. A similar tale is told for chloroplasts; the benefit for a heterotrophic "host" is clear. In this case, the endosymbiont would have been a photosynthetic prokaryote. Providing the grateful host with glucose essentially reduced the host's need to consume food. Some scientists view cilia, flagella, peroxisomes, and even the cell nucleus as endosymbionts, but these ideas are less widely accepted.

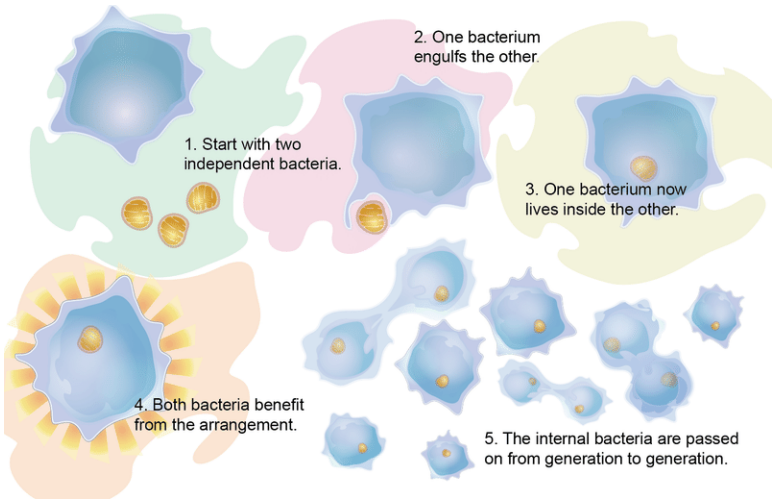

FIGURE 5.1

From an Independent Cell to an Organelle. The endosymbiotic theory explains how eukaryotic cells evolved.

Evidence of Endosymbiosis

What is the evidence for this maverick evolutionary pathway? Biochemistry and electron microscopy provide convincing support for the Endosymbiotic Theory. The mitochondria and chloroplasts which live within eukaryotic cells share the following features with prokaryotic cells:

1. Organelle DNA is both short and circular and sequences do not match DNA in the nucleus.
2. Molecules that make up organelle membranes resemble those in prokaryotic membranes and differ from those in eukaryotic membranes
3. Ribosomes in these organelles are similar to those in bacteria and different from eukaryotic ribosomes.
4. Reproduction of the organelles is by binary fission, not mitosis.
5. Biochemical pathways and structure show closer relationships to prokaryotes.
6. These organelles have internal membranes in addition to their outer membrane.

The “host” cell membrane and biochemistry are more similar to those of Archaebacteria, so scientists believe eukaryotes descended more directly from that major group (**Figure** 5.2). However, the standard evolutionary tree cannot accurately depict our ancestry, because the origin of the eukaryotes combines traditional descent from the Archaea with landmark cohabitation alliances forged with the Bacteria.

The timing of this dramatic evolutionary event (more likely a series of events) is not clear. The oldest fossil clearly related to modern eukaryotes is a red alga dating back to 1.2 billion years ago. However, many scientists place the appearance of eukaryotic cells at about 2 billion years. Some time within the Proterozoic Eon all three major groups of life - Bacteria, Archaea, and Eukaryotes - became well established. Geologists hypothesize the oldest supercontinent, Columbia (between 1.8 and 1.5 years ago), to be the backdrop for the further evolution of these three domains.

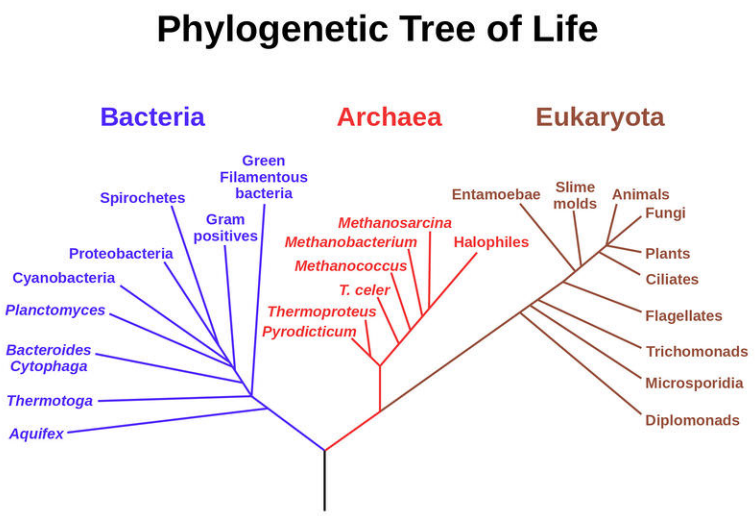

FIGURE 5.2

The three major domains of life had evolved by 1.5 billion years ago. Biochemical similarities show that we Eukaryotes share more recent common ancestors with the Archaea, but our organelles probably descended from Bacteria by endosymbiosis.

What Does It All Mean?

Eukaryotic cells, made possible by endosymbiosis, were powerful and efficient. That power and efficiency gave them the potential to evolve new "ideas": multicellularity, cell specialization, and large size. They were the key to the spectacular diversity of animals, plants, and fungi which populate our world today. And they all came from simple single-celled prokaryotic organisms.

Nevertheless, it is easy for people to consider large organisms as "life," and forget about the many more smaller organisms. Our “sizeism” sets us up to wonder at plants and animals, but to ignore bacteria. Human senses cannot directly perceive the unimaginable variety of single cells, the architecture of organic molecules, or the intricacy of biochemical pathways. But think about these unseen pathways. Cells of the most intelligent and complex organisms still share many components in common with the simplest single-celled organisms. The discussion of early evolution should provide a window into the beauty and diversity of unseen worlds, now and throughout Earth’s history. Apart from the innumerable mitochondria which call your 100 trillion cells home, a human body contains more bacterial cells than human cells. You, mitochondria, and your resident bacteria share common ancestry - a continuous history of the gift of life.

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Summary

- Eukaryotic cells probably evolved about 2 billion years ago. Their evolution is explained by the endosymbiotic theory.
- The widely accepted Endosymbiotic Theory explains the origin of eukaryotic cells as a merging of several kinds of prokaryotic cells.
- Eukaryotic cells would go on to evolve into the diversity of eukaryotes we know today.

Review

1. Discuss the evidence for the evolution of mitochondria and chloroplasts.
2. Analyze the theory which explains our current understanding of the origin of eukaryotic cells.

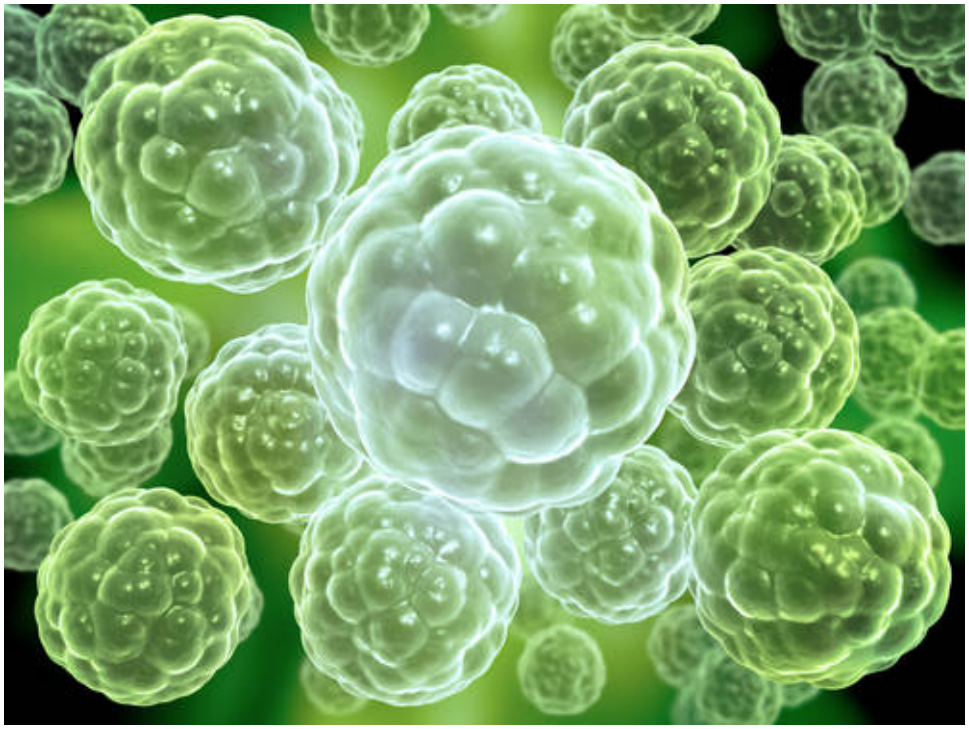
References

1. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0
2. Eric Gaba. http://commons.wikimedia.org/wiki/File:Phylogenetic_tree.svg . Public Domain

CONCEPT 6 The Evolution of Multicellular Life - Advanced

Learning Objectives

- Assess the impact of global environmental changes on the evolution of life.
- Describe the diversity of unicellular organisms which arose over 2 billion years of evolution.



Does multicellular mean eukaryotic?

Prokaryotic organisms are not multicellular, so yes, multicellular does mean eukaryotic. But not all eukaryotic organisms are multicellular. The first multicellular organisms must have been made of just cells. Tissues, organs or organ systems would not evolve for many millions of years.

Multicellular Life

Biologists estimate that 99% of the species which have ever lived on Earth are now extinct and up to 30 million species populate our world today. It is the great diversity of species that allows at least some organisms to survive major changes in the environment. **Biodiversity** can be defined as the variety of life and its processes, including the variety of living organisms, the genetic differences among them, and the communities and ecosystems which they populate. Biodiversity has evolved through billions of years of evolution, resulting in the organisms that populate the planet today.

These include the following:

4 billion years of simple, prokaryotic cells.

3 billion years of photosynthesis.

2 billion years of complex, eukaryotic (but still single) cells.

1 billion years of multicellular life.

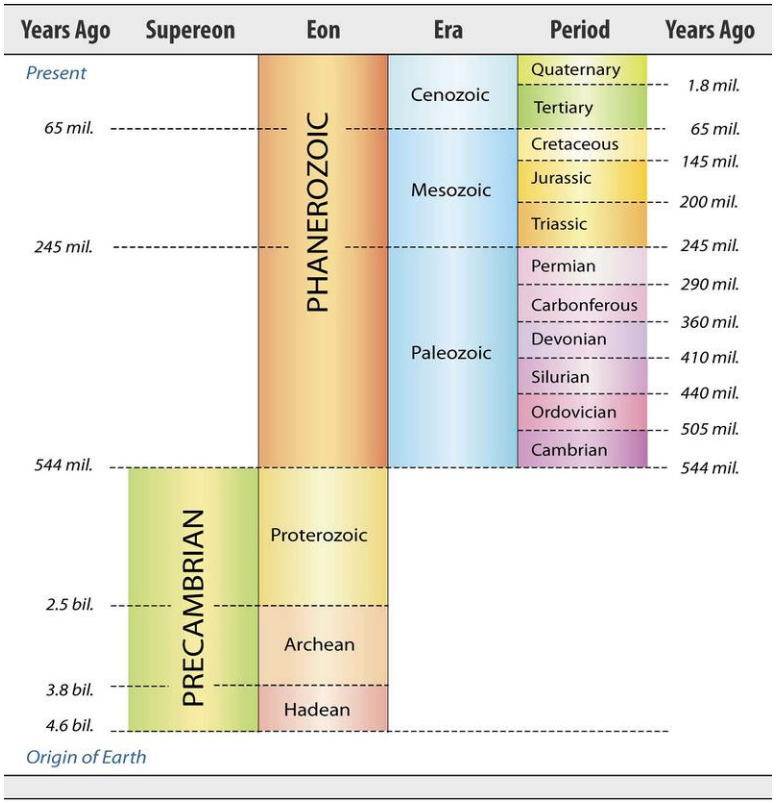


FIGURE 6.1

A linear arrangement of the **Geologic Time Scale** shows overall relationships between well-known time periods. Our knowledge of past life is concentrated in the most recent Eon, but the Phanerozoic occupies such a small proportion of the overall history of earth that eras, periods, and epochs are not precisely to scale. This diagram shows well-known time frames, but is not complete.

The history of life eclipses the last billion years of Earth's 4.6 billion-year history with no hint of the wondrous diversity of life as humans know it (**Figure** 6.1). Not until nearly 80% of Earth's history had passed did multicellular life evolve. The fossil record tells the story: millions of species of fish, amphibians, reptiles, birds, mammals, mosses, ferns, conifers, flowering plants, and fungi populated the seas and covered the Earth - as continents crashed together and broke apart, glaciers advanced and retreated, and meteors struck, causing massive extinctions. Life has had a colorful and exciting last billion years, spawning diversity almost beyond our comprehension.

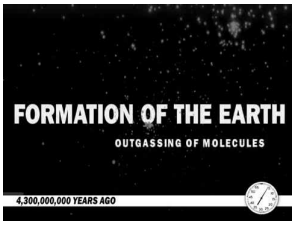
And yet, the giant steps of evolution remain back in the Precambrian. Its catalog of evolutionary innovations is long and impressive:

- Energized elements from stardust formed simple organic molecules.
- Building blocks chained together to form catalysts and self-replicating macromolecules.
- Biochemical pathways evolved.
- Protective, yet permeable membranes enclosed the catalysts, replicators, and their metabolic retinue, forming the first cells.
- Early prokaryotic cells "learned" to make ATP by splitting glucose (**glycolysis**).
- Other prokaryotic cells began to harvest sunlight energy through **photosynthesis**.
- Photosynthetic **cyanobacteria** produced vast amounts of waste in the form of oxygen, dramatically altering the Earth's atmosphere.
- The oceans rusted from iron ore deposits.
- An ozone layer formed, shielding life from UV radiation.
- The O_2 **catastrophe** killed many anaerobic prokaryotes.

- Still other prokaryotes evolved to use the new O_2 to release the energy remaining in carbohydrate products of glycolysis.
- Endosymbiosis created eukaryotes, firmly establishing the three major evolutionary lineages, which today comprise the living world (**Theory of Endosymbiosis**).

The timing and exact nature of most of these innovations is speculative; indeed, the first few may have been extraterrestrial and even deeper in time. They comprise perhaps the most important landmarks in the evolution of life, but the fossil record is sketchy due to prokaryote size, rock layer metamorphosis, and burial by more recent rocks.

Overall, we know remarkably little about Precambrian life. The **Cambrian Period** documents the greatest flowering of life of all time and gives its name - in a rather negative sense - to the 4 billion years of Earth history that preceded it. Before we dive into the famous **Cambrian "explosion,"** we will look more carefully at the last Eon of the Precambrian, which set the stage for this most famous burst of evolution.



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Summary

- All of multicellular evolution occurred within the last billion years.

Review

1. What major evolutionary steps preceded and followed the evolution of the first eukaryotic cells?
2. What is the O_2 catastrophe? Why do you think it occurred?

References

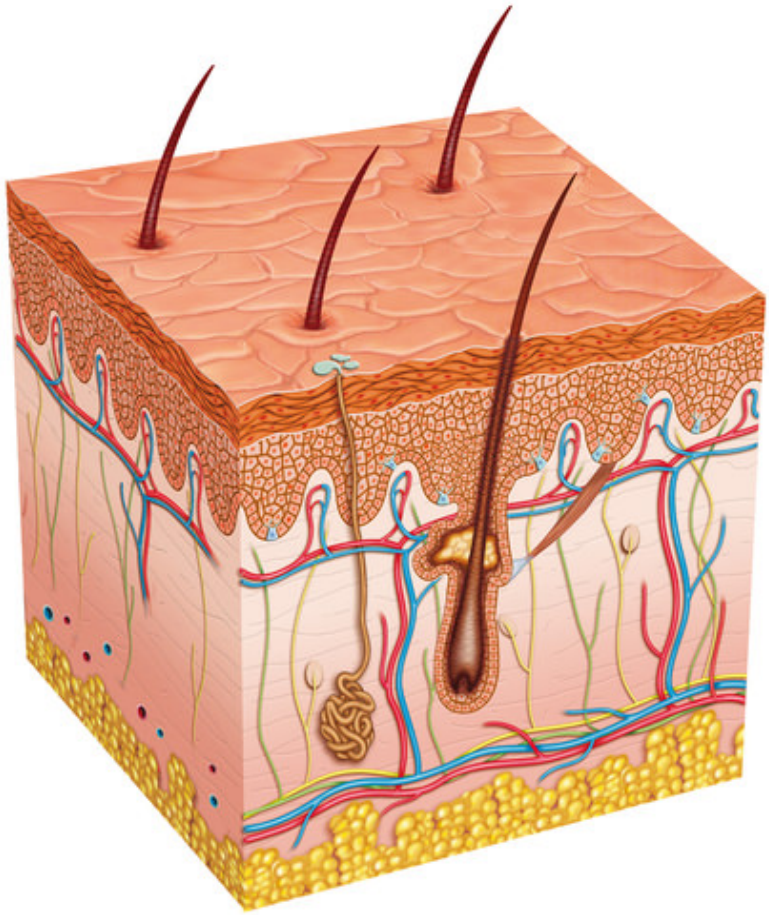
1. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0

CONCEPT 7

Cell Size and Shape - Advanced

Learning Objectives

- Identify the limitations on cell size. Describe the relationship between volume and surface area.
- Discuss cell shape and its relationship to cell function.



What determines a cell's function?

The cell's structure has a lot to do with it. Notice in the representation of skin that there are different layers. These layers have different functions. Also notice the difference in cell shape within the different layers. The structure-function relationship is a central theme running throughout biology.

Diversity of Cells

Different cells within a single organism can come in a variety of sizes and shapes. They may not be very big, but their shapes can be very different from each other. However, these cells all have common abilities, such as obtaining

and using food energy, responding to the external environment, and reproducing. In part, a cell's shape determines its function.

Cell Size

If cells are the main structural and functional unit of an organism, why are they so small? And why are there no organisms with huge cells? The answers to these questions lie in a cell's need for fast, easy food. The need to be able to pass nutrients and gases into and out of the cell sets a limit on how big cells can be. The larger a cell gets, the more difficult it is for nutrients and gases to move in and out of the cell.

As a cell grows, its volume increases more quickly than its surface area. If a cell was to get very large, the small surface area would not allow enough nutrients to enter the cell quickly enough for the cell's needs. This idea is explained in **Figure** 7.1. However, large cells have a way of dealing with some size challenges. Big cells, such as some white blood cells, often grow more nuclei so that they can supply enough proteins and RNA for the cell's requirements. Large, metabolically active cells often have lots of cell protrusions, resulting in many folds throughout the membrane. These folds increase the surface area available for transport of materials into or out of the cell. Such cell types are found lining your small intestine, where they absorb nutrients from your food through protrusions called **microvilli**.

Scale of Measurements

- 1 centimeter (cm) = 10 millimeters (mm) = 10^{-2} meters (m)
- 1 mm = 1000 micrometers (μm) = 10^{-3} m
- 1 μm = 1000 nanometers (nm) = 10^{-6} m
- 1 nm = 10^{-3} μm

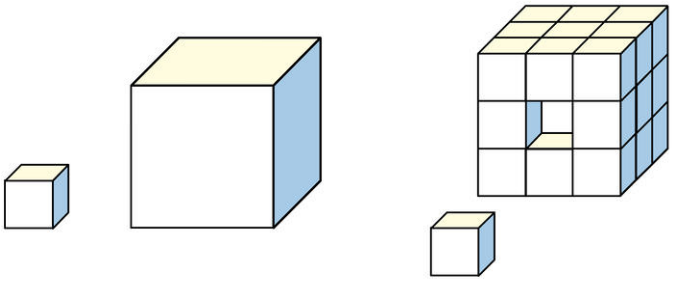


FIGURE 7.1

A small cell (left), has a larger surface-area to volume ratio than a bigger cell (center). The greater the surface-area to volume ratio of a cell, the easier it is for the cell to get rid of wastes and take in essential materials such as oxygen and nutrients. In this example, the large cell has the same area as 27 small cells, but much less surface area.

Imagine cells as little cube blocks. If a small cube cell like the one in **Figure** 7.1 is one unit (u) in length, then the total surface area of this cell is calculated by the equation:

- height $\times$ width $\times$ number of sides $\times$ number of boxes
- 1u $\times$ 1u $\times$ 6 $\times$ 1 = $6u^2$

The volume of the cell is calculated by the equation:

- height $\times$ width $\times$ length $\times$ number of boxes
- 1u $\times$ 1u $\times$ 1u $\times$ 1 = $1u^3$

The surface-area to volume ratio is calculated by the equation:

- area ÷ volume
- 6 ÷ 1 = 6

A larger cell that is 3 units in length would have a total surface area of

- $3u \times 3u \times 6 \times 1 = 54u^2$

and a volume of:

- $3u \times 3u \times 3u \times 1 = 27u^3$

The surface-area to volume ratio of the large cell is:

- 54 ÷ 27 = 2

Now, replace the three unit cell with enough one unit cells to equal the volume of the single three unit cell. This can be done with 27 one unit cells. Find the total surface area of the 27 cells:

- $1u \times 1u \times 6 \times 27 = 162u^2$

The total volume of the block of 27 cells is:

- $1 \times 1 \times 1 \times 27 = 27u^3$

The surface-area to volume ratio of the 27 cells is:

- 162 ÷ 27 = 6

An increased surface area to volume ratio means increased exposure to the environment. This means that nutrients and gases can move in and out of a small cell more easily than in and out of a larger cell.

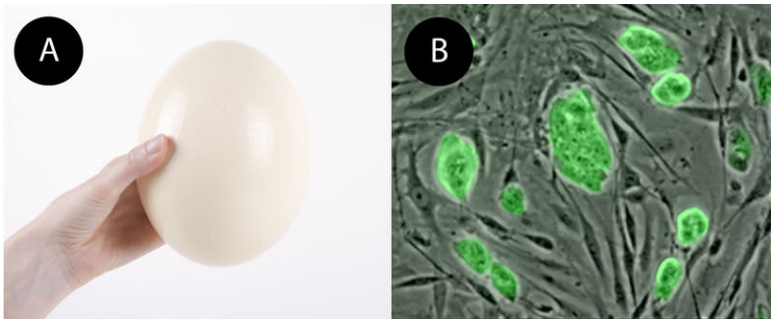


FIGURE 7.2

Ostrich eggs (A) can weigh as much as 1.5 kg and be 13 cm in diameter, whereas each of the mouse cells (B) shown at right are each about 10 μm in diameter, much smaller than the period at the end of this sentence.

The cells you have learned about so far are much smaller than the period at the end of this sentence, so they are normally measured on a very small scale. The smallest **prokaryotic cell** currently known has a diameter of only 400 nm. **Eukaryotic cells** normally range between 1- 100μm in diameter. The mouse cells in **Figure** 7.2 are about 10 μm in diameter. One exception, however, is **eggs**. Eggs contain the largest known single cell, and the ostrich egg is the largest of them all. The ostrich egg in **Figure** 7.2 is over 10,000 times larger than the mouse cell.

Cell Shape

The variety of cell shapes seen in prokaryotes and eukaryotes reflects the functions that each cell has, confirming the **structure-function relationship** seen throughout biology. Each cell type has evolved a shape that is best related to its function. For example, the **neuron** in **Figure** 7.3 has long, thin extensions (**axons** and **dendrites**) that reach out to other nerve cells. The extensions help the neuron pass chemical and electrical messages quickly through the body. The shape of the red blood cells (**erythrocytes**) enable these cells to easily move through **capillaries**. The spikes on the pollen grain help it stick to a pollinating insect or animal so that it can be transferred to and pollinate another flower. The long whip-like **flagella** (tails) of the algae *Chlamydomonas* help it swim in water.

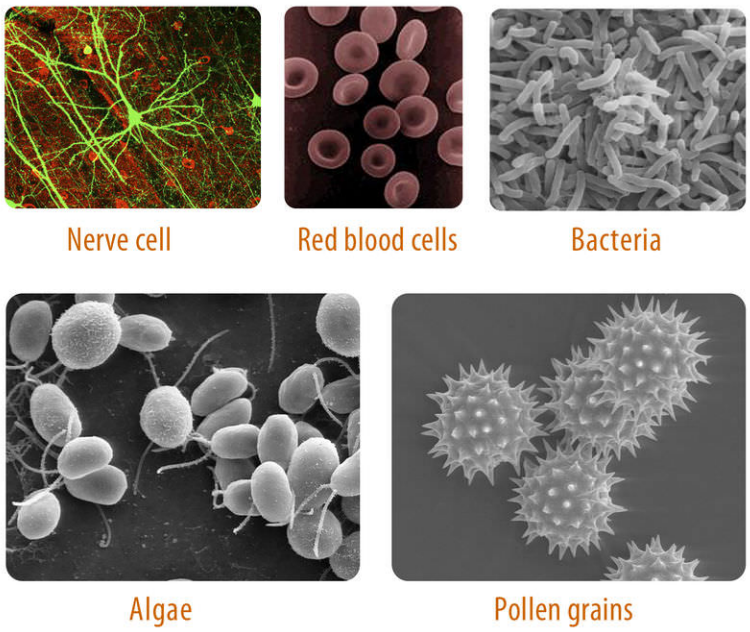


FIGURE 7.3

Cells come in very different shapes. Left to right, top row: Long, thin nerve cells; biconcave red blood cells; curved-rod shaped bacteria. Left to right, bottom row: oval, flagellated algae and round, spiky pollen grains are just a sample of the many shapes.

Summary

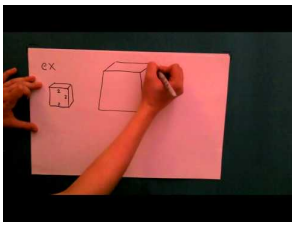
- Cell size is limited by a cell's surface area to volume ratio. A smaller cell is more effective and transporting materials, including waste products, than a larger cell.
- Cells come in many different shapes. A cell's function is determined, in part, by its shape.

Review

1. What limits the size of a cell? Why?
2. A cell has a volume of 64 units, and total surface area of 96 units. What is the cell's surface area to volume ratio?
3. What is the largest single cell?
4. Describe the relationship between cell shape and function? Give an example of cell shape influencing cell function.

Explore More

Use this resource to answer the questions that follow.



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1. Describe the relationship between the cell surface area and cell membrane.
2. Why is a smaller volume of the cell better?
3. What are ways to "get around" the SA:V ratio?

References

1. Niamh Gray-Wilson. CK-12 Foundation . CC BY-NC 3.0
2. (A) Lenore Edman (Flickr:1lenore); (B) National Science Foundation. (A) http://www.flickr.com/photos/lenore-m/6123190318/; (B) http://commons.wikimedia.org/wiki/File:Mouse_embryonic_stem_cells.jpg . (A) CC BY 2.0; (B) Public Domain
3. Nerve cell: WA Lee et al.; Blood cell: Courtesy of National Institute of Health; Bacteria: TJ Kirn, MJ Lafferty, CMP Sandoe, and RK Taylor; Algae: EF Smith and PA Lefebvre; Pollen: L Howard and C Daghlian. Nerve cell: http://en.wikipedia.org/wiki/File:GFPneuron.png; Blood cell: http://commons.wikimedia.org/wiki/File:Redbloodcells.jpg; Bacteria: http://remf.dartmouth.edu/images/bacteriaSEM/source/1.html; Algae: http://remf.dartmouth.edu/images/algaeSEM/source/1.html; Pollen: http://remf.dartmouth.edu/images/botanicalPollenSEM/source/10.html . Nerve cell: CC-BY 2.5; Blood cell: Public Domain; Bacteria: Public Domain; Algae: Public Domain; Pollen: Public Domain

CONCEPT 8

Cell Functions

Chapter 4 Test

Name_____ Class_____ Date_____

Multiple Choice

Circle the letter of the correct choice.

1. Endocytosis is an example of
    a. facilitated diffusion
    b. passive transport
    c. simple diffusion
    d. none of the above
2. Small hydrophilic molecules are transported through a cell membrane by
    a. channel proteins
    b. carrier proteins
    c. active transport
    d. vesicle transport
3. Which substance can cross a cell membrane without added energy?
    a. sodium ions
    b. potassium ions
    c. water molecules
    d. none of the above
4. What is the first stage of photosynthesis?
    a. Krebs cycle
    b. Calvin cycle
    c. light reactions
    d. electron transport
5. Plants exchange gases with the air through their
    a. chloroplasts
    b. stroma
    c. stomata
    d. mitochondria
6. What is the maximum number of ATP molecules produced during the final stage of cellular respiration?
    a. 38
    b. 36
    c. 34
    d. 32
7. Cellular respiration takes place in
    a. mitochondria
    b. chloroplasts

c. the cytoplasm
d. two of the above

True or False

Write true if the statement is true or false if the statement is false.

8. _____ Transport with the help of transport proteins always requires energy.
9. _____ A channel protein binds with a diffusing substance to transport it across a cell membrane.
10. _____ The surface of a cell membrane is water "loving."
11. _____ Facilitated diffusion is like a ball rolling up a hill.
12. _____ It takes many molecules of glucose to store as much energy as a single molecule of ATP.
13. _____ During the Calvin cycle, carbon dioxide is used to produce glucose.
14. _____ Lactic acid fermentation takes place only in anaerobic bacteria.
15. _____ A waste product of the Krebs cycle is water.

Fill in the Blank

Fill in the blank with the appropriate term.

16. Whenever the transport of a substance through a cell membrane requires energy, it is called _____-transport.
17. The sodium-potassium pump transports _____ ions into the cell.
18. The waste product of photosynthesis is _____.
19. During photosynthesis, _____ energy is changed to chemical energy.
20. The only anaerobic stage of cellular respiration is called _____.

Short Answer

Answer the following questions in complete sentences.

21. Explain how plants change energy from one form to another.
22. Relate the processes of cellular respiration and photosynthesis.

CONCEPT 9

Cell Transport and Homeostasis

Lesson Objectives

- Describe different types of passive transport.
- Explain how different types of active transport occur.
- Outline the role of cell transport in homeostasis.

Vocabulary

- active transport
- diffusion
- endocytosis
- exocytosis
- facilitated diffusion
- osmosis
- passive transport
- sodium-potassium pump
- transport protein
- vesicle transport

Introduction

Imagine living in a house that has walls without any windows or doors. Nothing could enter or leave the house. Now imagine living in a house with holes in the walls instead of windows and doors. Things could enter or leave the house, but you wouldn't be able to control what came in or went out. Only if a house has walls with windows and doors that can be opened or closed can you control what enters or leaves. For example, windows and doors allow you to let the dog in and keep the bugs out.

Transport Across Membranes

If a cell were a house, the plasma membrane would be walls with windows and doors. Moving things in and out of the cell is an important role of the plasma membrane. It controls everything that enters and leaves the cell. There are two basic ways that substances can cross the plasma membrane: passive transport and active transport.

Passive Transport

Passive transport occurs when substances cross the plasma membrane without any input of energy from the cell. No energy is needed because the substances are moving from an area where they have a higher concentration to an area where they have a lower concentration. Concentration refers to the number of particles of a substance per unit of volume. The more particles of a substance in a given volume, the higher the concentration. A substance always moves from an area where it is more concentrated to an area where it is less concentrated. It's a little like a ball rolling down a hill. It goes by itself without any input of extra energy.

There are several different types of passive transport, including simple diffusion, osmosis, and facilitated diffusion. Each type is described below.

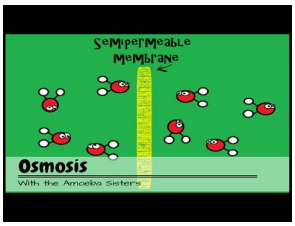
Simple Diffusion

Diffusion is the movement of a substance across a membrane, due to a difference in concentration, without any help from other molecules. The substance simply moves from the side of the membrane where it is more concentrated to the side where it is less concentrated. **Figure** 9.1 shows how diffusion works. Substances that can squeeze between the lipid molecules in the plasma membrane by simple diffusion are generally very small, hydrophobic molecules, such as molecules of oxygen and carbon dioxide.

Osmosis

Osmosis is a special type of diffusion — the diffusion of water molecules across a membrane. Like other molecules, water moves from an area of higher concentration to an area of lower concentration. Water moves in or out of a cell until its concentration is the same on both sides of the plasma membrane.

Osmosis is discussed at https://www.youtube.com/watch?v=IaZ8MtF3C6M



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Facilitated Diffusion

Water and many other substances cannot simply diffuse across a membrane. Hydrophilic molecules, charged ions, and relatively large molecules such as glucose all need help with diffusion. The help comes from special proteins in the membrane known as **transport proteins**. Diffusion with the help of transport proteins is called **facilitated diffusion**. There are several types of transport proteins, including channel proteins and carrier proteins. Both are shown in **Figure** 9.2.

- Channel proteins form pores, or tiny holes, in the membrane. This allows water molecules and small ions to pass through the membrane without coming into contact with the hydrophobic tails of the lipid molecules in the interior of the membrane.

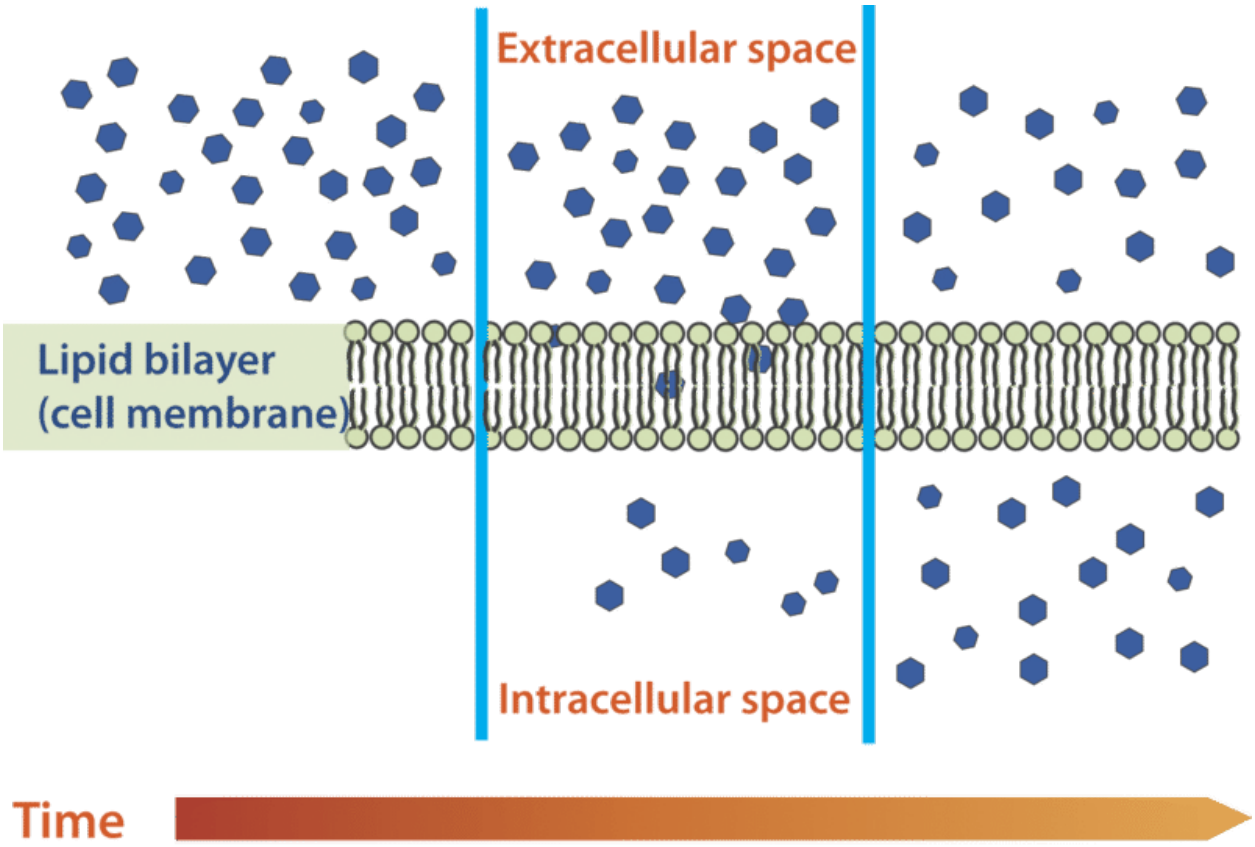


FIGURE 9.1

Diffusion Across a Cell Membrane. Molecules diffuse across a membrane from an area of higher concentration to an area of lower concentration until the concentration is the same on both sides of the membrane.

- Carrier proteins bind with specific ions or molecules, and in doing so, they change shape. As carrier proteins change shape, they carry the ions or molecules across the membrane.

Active Transport

Active transport occurs when energy is needed for a substance to move across a plasma membrane. Energy is needed because the substance is moving from an area of lower concentration to an area of higher concentration. This is a little like moving a ball uphill; it can't be done without adding energy. The energy for active transport comes from the energy-carrying molecule called ATP. Like passive transport, active transport may also involve transport proteins.

Sodium-Potassium Pump

An example of active transport is the **sodium-potassium pump**. When this pump is in operation, sodium ions are pumped out of the cell, and potassium ions are pumped into the cell. Both ions move from areas of lower to higher

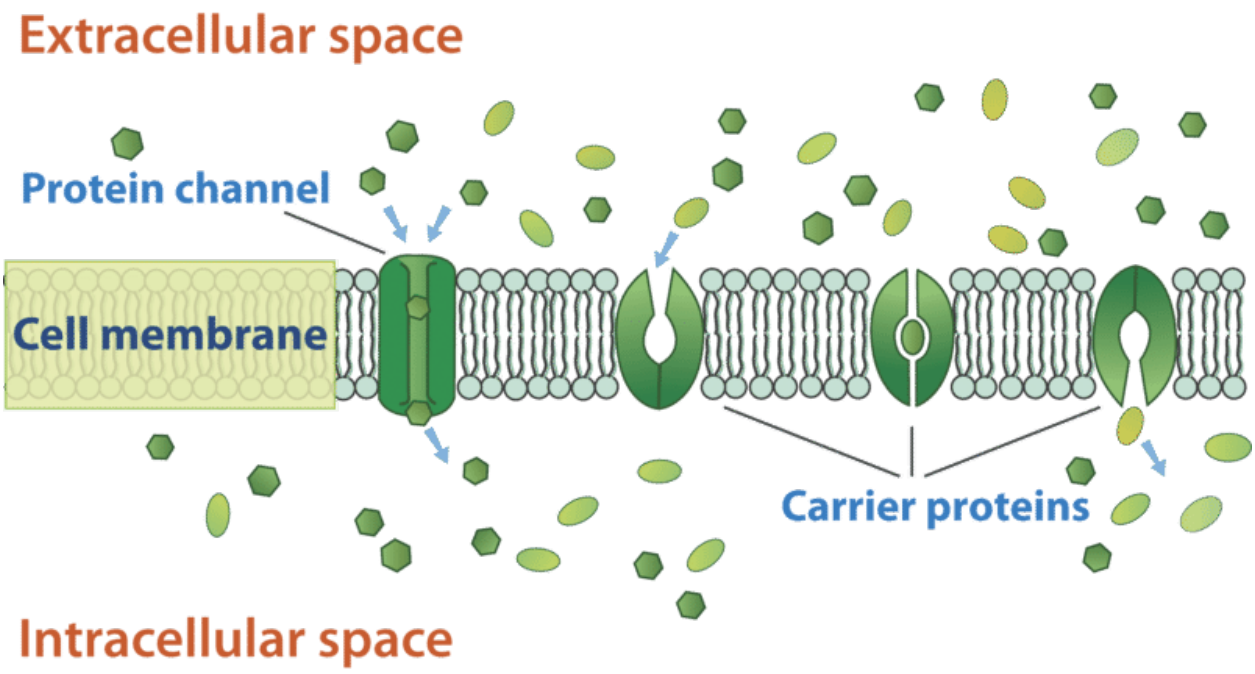
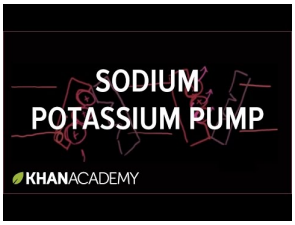


FIGURE 9.2

Facilitated Diffusion Across a Cell Membrane. Channel proteins and carrier proteins help substances diffuse across a cell membrane. In this diagram, the channel and carrier proteins are helping substances move into the cell (from the extracellular space to the intracellular space).

concentration, so ATP is needed to provide energy for this "uphill" process. **Figure** 9.3 explains in more detail how this type of active transport occurs.

A more detailed look at the sodium-potassium pump is available at http://www.youtube.com/watch?v=C_H-ONQFjpQ and http://www.youtube.com/watch?v=ye3rTjLCvAU .



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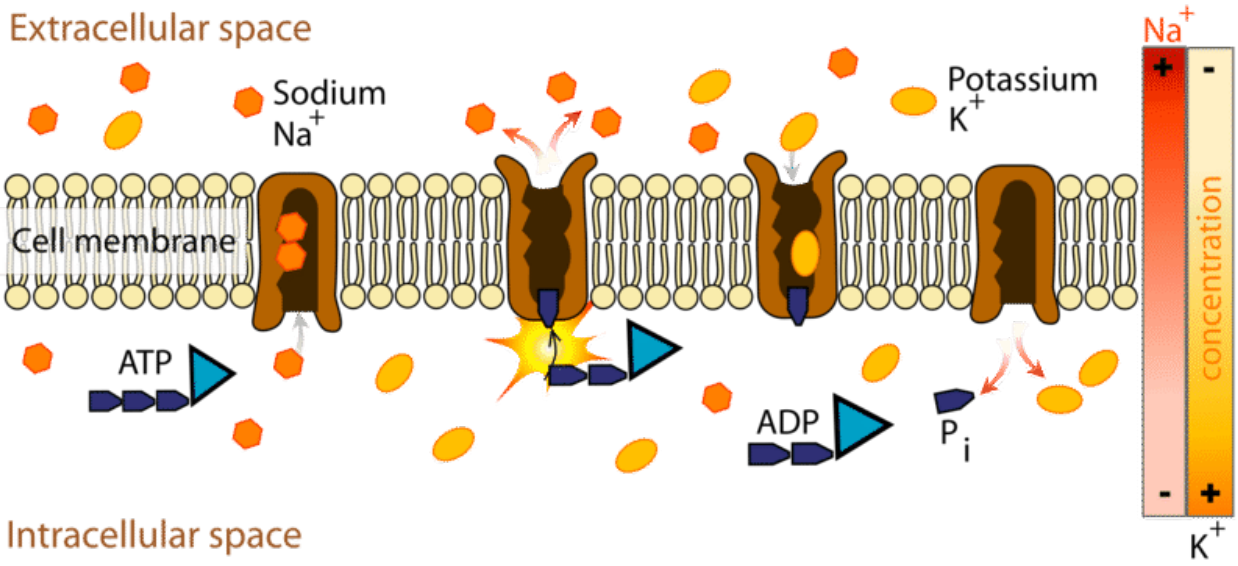

FIGURE 9.3

The sodium-potassium pump. The sodium-potassium pump moves sodium ions (Na^+) out of the cell and potassium ions (K^+) into the cell. First, three sodium ions bind with a carrier protein in the cell membrane. Then, the carrier protein receives a phosphate group from ATP. When ATP loses a phosphate group, energy is released. The carrier protein changes shape, and as it does, it pumps the three sodium ions out of the cell. At that point, two potassium ions bind to the carrier protein. The process is reversed, and the potassium ions are pumped into the cell.

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Vesicle Transport

Some molecules, such as proteins, are too large to pass through the plasma membrane, regardless of their concentration inside and outside the cell. Very large molecules cross the plasma membrane with a different sort of help, called **vesicle transport**. Vesicle transport requires energy, so it is also a form of active transport. There are two types of vesicle transport: endocytosis and exocytosis. Both types are shown in **Figure** 9.4 and described below.

- **Endocytosis** is the type of vesicle transport that moves a substance into the cell. The plasma membrane completely engulfs the substance, a vesicle pinches off from the membrane, and the vesicle carries the substance into the cell. When an entire cell is engulfed, the process is called phagocytosis. When fluid is engulfed, the process is called pinocytosis.

- **Exocytosis** is the type of vesicle transport that moves a substance out of the cell. A vesicle containing the substance moves through the cytoplasm to the cell membrane. Then, the vesicle membrane fuses with the cell membrane, and the substance is released outside the cell. You can watch an animation of exocytosis at the link below.

http://www.stanford.edu/group/Urchin/GIFS/exocyt.gif

FIGURE 9.4

Illustration of the two types of vesicle transport, exocytosis and endocytosis.

Homeostasis and Cell Function

For a cell to function normally, a stable state must be maintained inside the cell. For example, the concentration of salts, nutrients, and other substances must be kept within a certain range. The process of maintaining stable conditions inside a cell (or an entire organism) is homeostasis. Homeostasis requires constant adjustments, because conditions are always changing both inside and outside the cell. The processes described in this lesson play important roles in homeostasis. By moving substances into and out of cells, they keep conditions within normal ranges inside the cells and the organism as a whole.

Lesson Summary

- A major role of the plasma membrane is transporting substances into and out of the cell. There are two major types of cell transport: passive transport and active transport.
- Passive transport requires no energy. It occurs when substances move from areas of higher to lower concentration. Types of passive transport include simple diffusion, osmosis, and facilitated diffusion.
- Active transport requires energy from the cell. It occurs when substances move from areas of lower to higher concentration or when very large molecules are transported. Types of active transport include ion pumps, such as the sodium-potassium pump, and vesicle transport, which includes endocytosis and exocytosis.
- Cell transport helps cells maintain homeostasis by keeping conditions within normal ranges inside all of an organism's cells.

Lesson Review Questions

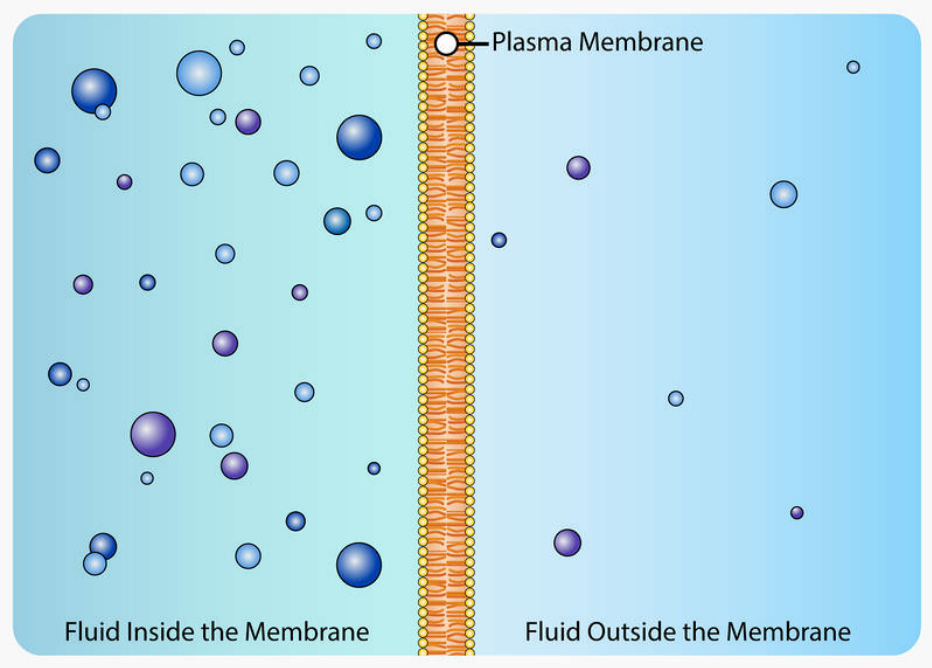
Recall

1. What is osmosis? What type of transport is it?
2. Describe the roles of transport proteins in cell transport.
3. What is the sodium-potassium pump?
4. Name two types of vesicle transport. Which type moves substances out of the cell?

Apply Concepts

5. Assume a molecule must cross the plasma membrane into a cell. The molecule is a very large protein. How will it be transported into the cell? Explain your answer.

6. The drawing below shows the fluid inside and outside a cell. The dots represent molecules of a substance needed by the cell. The molecules are very small and hydrophobic. What type of transport will move the molecules into the cell?



Think Critically

7. Compare and contrast simple diffusion and facilitated diffusion. For each type of diffusion, give an example of a molecule that is transported that way.

8. Explain how cell transport helps an organism maintain homeostasis.

Points to Consider

All cells share some of the same structures and basic functions, but cells also vary.

- Plant cells have structures that animal cells lack. What important process takes place in plant cells but not in animal cells that might explain their differences?
- All cells, including both plant and animal cells, need energy for processes such as active transport. How do cells obtain the energy they need?

References

1. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons), modified by Hana Zavadska. http://commons.wikimedia.org/wiki/File:Scheme_simple_diffusion_in_cell_membrane-en.svg . Public Domain
2. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons), Hana Zavadska. http://commons.wikimedia.org/wiki/File:Scheme_facilitated_diffusion_in_cell_membrane-en.svg . Public Domain
3. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons), Hana Zavadska. http://commons.wikimedia.org/wiki/File:Scheme_sodium-potassium_pump-en.svg . Public Domain
4. Mariana Ruiz Villarreal (LadyofHats) for the CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0

CONCEPT 10 Cells of the Human Body - Advanced

Learning Objectives

- Outline the role of a specialized cell.
- Understand the difference between cells and stem cells.
- Understand the process of cell differentiation, and determine which types of cells undergo differentiation.
- List three types of stem cells.

How is the human body similar to a well-tuned machine?

Over and over, the human body is compared to a complex piece of machinery. Like any common machine, the human body is composed of a variety of parts, each working separately, but also working together.

Cells

Cells are the most basic units of life in your body, and each cell is specialized, with a specific function. Nerve cells transmit electrical messages around the body, and white blood cells attack invading bacteria throughout the body. Other cells include specialized cells in the kidney (such as kidney glomerulus parietal cells), brain (such as astrocytes), stomach (such as parietal cells), and muscles (such as red and white skeletal muscle fibers). Cells group together to form tissues; different tissues work together to form organs. This grouping of cells and tissues is referred to as levels of organization. Complex multicellular organisms, which include flatworms and humans, have different levels of organization. The human body's levels begin with cells and conclude with the entire organism. Flatworms, though they lack specialized circulatory and respiratory systems, also have levels of organization ranging from cells to the entire organism.

Differentiation

Every cell in the body originates from a single fertilized egg called a zygote. The zygote divides repeatedly to produce an embryo. These embryonic cells continue to divide, differentiating into all the cell types present in the body of all humans (and other mammals), from a new-born baby to an elderly adult. **Differentiation** is the process by which an unspecialized cell, such as a fertilized egg cell, divides many times to produce specialized cells. During differentiation, certain genes are turned on, or become activated, while other genes are switched off, becoming inactivated. This process is regulated by the cell. A differentiated cell will develop specific structures and perform certain functions.

A cell that is able to differentiate into all cell types within a body is called **totipotent.** They have "total potential" to differentiate into any cell type. In mammals, only the zygote and early embryonic cells are totipotent. A cell that is able to differentiate into many, but not all, cell types is called **pluripotent.** Such cells have "plural potential" (but not "total potential") to differentiate into *most* cell types. **Figure** 10.2 gives a visual representation of cell differentiation.

Stem Cells

An unspecialized cell that can divide and give rise to different specialized cells is called a **stem cell** (**Figure** 10.2). Zygotes and embryonic cells are both types of stem cells. These stem cells, called **embryonic stem cells,** can divide indefinitely and can specialize into any cell type. They are totipotent. In contrast, **adult stem cells,** also known as

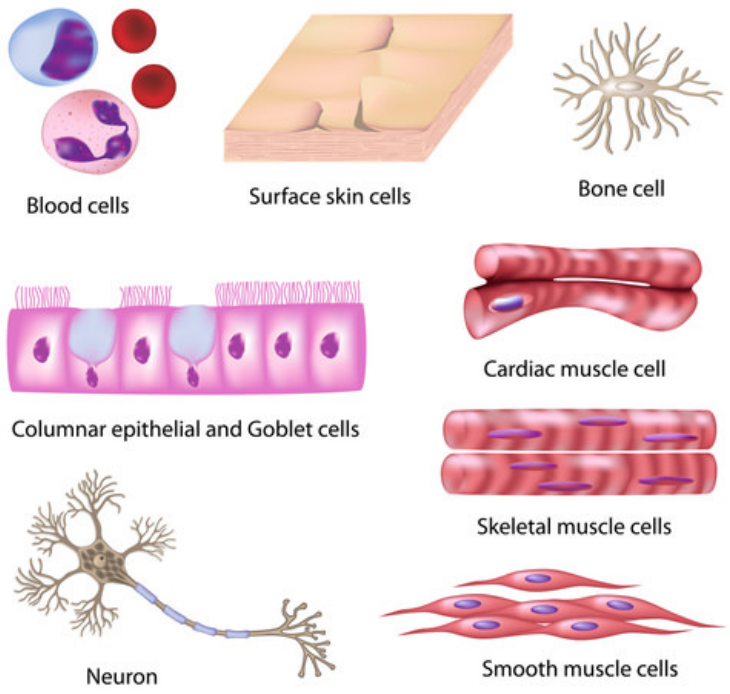


FIGURE 10.1

Different types of cells in the human body are specialized for specific jobs. Do you know the functions of any of the cell types shown here?

somatic stem cells, are undifferentiated cells found within the body that divide to replace dying cells and damaged tissues. Adult stem cells can divide indefinitely and generate all the cell types of the organ from which they originate. They can potentially re-grow the entire organ from just a few cells. A third type of stem cell is found in both the blood from the umbilical cord of a new-born baby and the placenta. These "cord blood stem cells" are considered to be adult stem cells because they cannot generate all body cell types, just different types of blood cells. Adult stem cells and cord blood stem cells are pluripotent.

Stem Cells in Medicine

Stem cells are of great interest to researchers because of their ability to both divide indefinitely and differentiate into many cell types. Stem cells have many existing and even more potential therapeutic applications. Such therapies include treatments for cancer, blood disorders, brain or spinal cord injuries, and blindness.

Embryonic stem cells, shown in **Figure** 10.3, are taken from eggs that were donated to research and fertilized in the laboratory. These stem cells may have the greatest potential because they are totipotent and thus have the most potential medical applications. However, embryonic stem cells are relatively controversial. Some individuals and groups have objections to the harvesting of embryonic stem cells because harvesting the stem cells involves the destruction of the embryo. Some researchers are looking into methods of extracting embryonic stem cells without destroying the actual embryo. Other researchers have claimed success in harvesting embryonic stem cells from the embryonic fluid that surrounds a growing fetus. Additionally, stem cells harvested from a donated embryo differ from a potential patient's tissue type. Therefore, just as in organ transplantation, there is a risk that the patient's body may reject the transplanted embryonic stem cells.

Adult stem cells, including cord blood stem cells, have already been used to treat diseases of the blood such as sickle-cell anemia and certain types of cancer. Unlike embryonic stem cells, the use of adult stem cells in research and therapy is not controversial because the production of adult stem cells does not require the destruction of an embryo. Adult stem cells can be isolated from tissue samples, such as bone marrow, of a patient. Scientists have

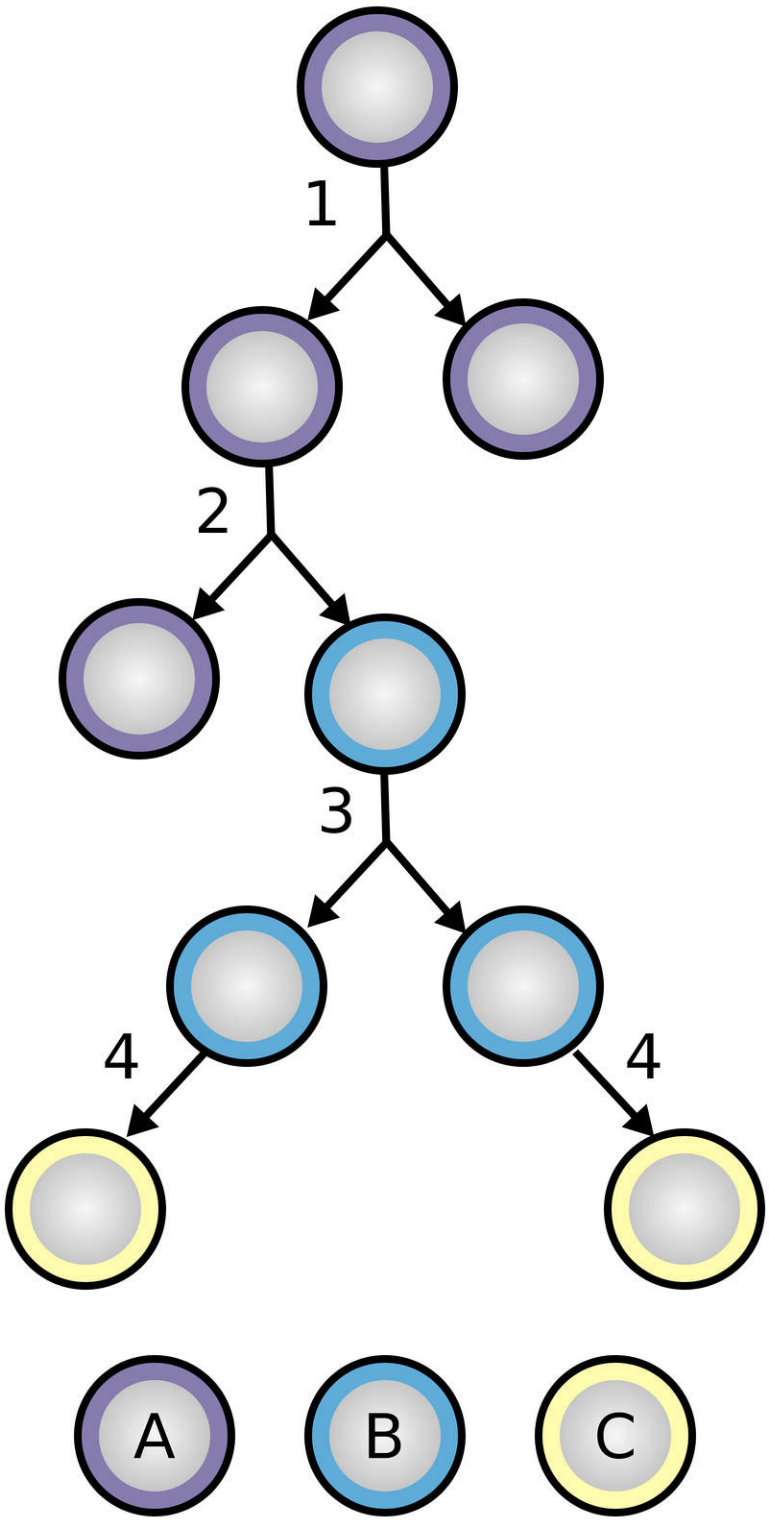


FIGURE 10.2

Division and differentiation of stem cells into specialized cells.

recently discovered more sources of adult stem cells in the body including in body fat, the inside lining of the nose, and the brain. Some researchers are investigating ways to revert adult stem cells back to a totipotent stage.

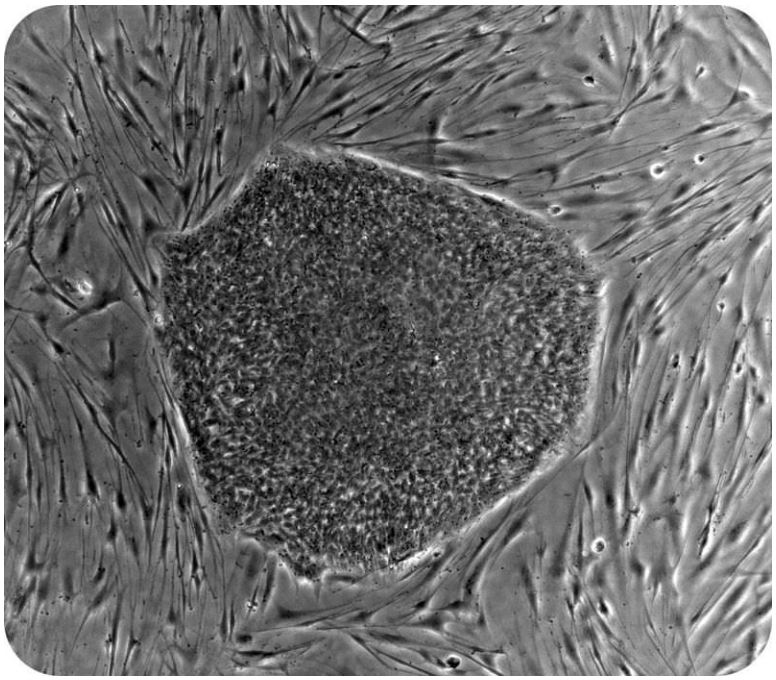


FIGURE 10.3

A human embryonic stem cell colony, which was grown in a laboratory on a feeder layer of mouse cells.

Summary

- Cells are the most basic units of life found in the human body and any living organism.
- Stem cells undergo the process of differentiation to become specialized cells.

Review

1. What are totipotent and pluripotent cells?
2. What are stem cells? Where do they come from?

Explore More

MEDIA

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Use the video above to answer the following questions:

1. When did scientists first understand the idea of differentiation?
2. What changes in a totipotent cell to make it specialize?
3. Can a blood stem cell become a muscle, brain, and/or liver cell?

References

1. Image copyright Alila Sao Mai, 2011. http://www.shutterstock.com . Used under license from Shutterstock.com
2. Wykis. http://en.wikipedia.org/wiki/Image:Stem_cell_division_and_differentiation.svg . Public Domain
3. Original uploader was Id711 at en.wikipedia. http://en.wikipedia.org/wiki/Image:Human_embryonic_stem_cell_colony_phase.jpg . Public Domain

CONCEPT 11

Cellular Respiration Overview - Advanced

Learning Objectives

- Trace the flow of energy from food molecules through ATP to its use in cellular work.
- Compare cellular respiration to burning.
- Analyze the chemical equation for cellular respiration.
- Briefly describe the role of mitochondria in producing ATP.
- Compare cellular respiration to photosynthesis.

Why eat?

Because we're hungry. Not necessarily. Biologically speaking, we eat to get energy. The food we eat is broken down, the glucose extracted, and that energy is converted into ATP. And this happens most efficiently in the presence of oxygen.

An Overview of Cellular Respiration

Another way to think about the role of oxygen in your body - and a good starting point for understanding the whole process of cellular respiration - is to recall (or imagine) the last time you sat by a campfire (see **Figure** 11.1) and noticed that it was "dying." Often people will blow on a campfire to keep it from "dying out." How does blowing help? What happens in a campfire?

FIGURE 11.1

Analyzing what happens when wood burns in a campfire is a good way to begin to understand cellular respiration.

You know that a fire produces light and heat energy. However, it cannot create energy (remember that energy cannot be created or destroyed). Fire merely transforms the energy stored in its fuel - chemical energy - into light and heat. Another way to describe this energy transformation is to say that burning releases the energy stored in fuel. As energy is transformed, so are the compounds that make up the fuel. In other words, burning is a chemical reaction. We could write our understanding of this energy-releasing chemical reaction up to this point as:

$$\underset{\text{Stored chemical Energy}}{\text{Wood Fuel}} \xrightarrow{\text{Spark or match}} \text{light energy} + \text{heat energy}$$

Now return to what happens when you blow on a fire. The fire was "dying out," so you blew on it to get it going again. Was it movement or something in the air that promoted the chemical reaction? If you have ever "smothered" a fire, you know that a fire needs something in the air to keep burning. That something turns out to be oxygen. Oxygen gas is a **reactant** in the burning process. At this point, our equation is:

$$O_2 + \underset{\text{Stored chemical Energy}}{\text{Wood Fuel}} \xrightarrow{\text{Spark or match}} \text{light energy} + \text{heat energy}$$

To complete this equation, we need to know what happens to matter, to the atoms of oxygen, and to the atoms of the fuel during the burning. If you collect the gas rising above a piece of burning wood in an inverted test tube, you will notice condensation - droplets appearing on the sides of the tube. To identify the **products**, the experiment shown below can be performed. Cobalt chloride paper will change from blue to pink, confirming that these droplets are water. If you add bromothymol blue (BTB) to a second tube of collected gases, the blue solution will change

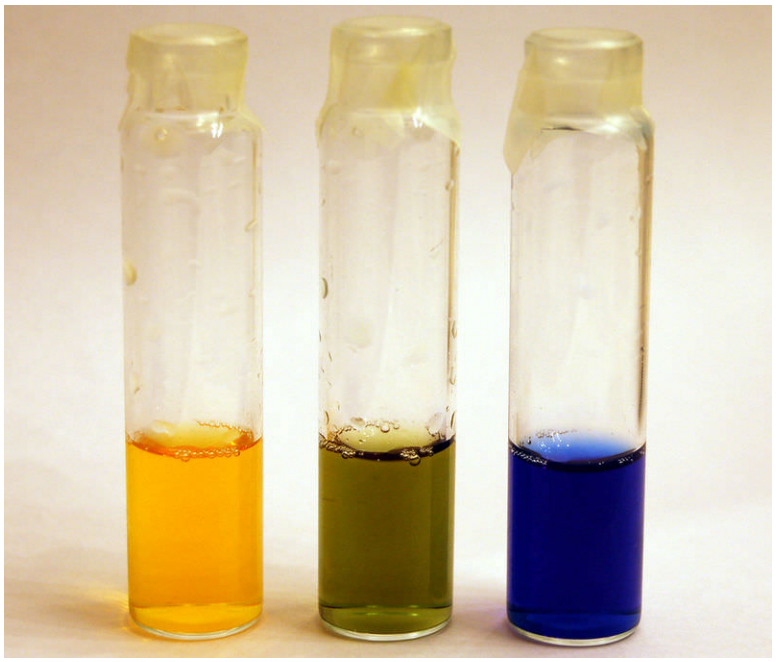

FIGURE 11.2

Bromothymol blue (BTB) changes from blue to green to yellow as carbon dioxide is added. Thus, it is a good indicator for this product of burning or cellular respiration.

to green or yellow (**Figure** 11.2), indicating the presence of carbon dioxide. Thus, carbon dioxide and water are products of burning wood fuel. The oxygen atoms have been incorporated into carbon dioxide and water.

$$O_2 + \underset{\text{Stored chemical Energy}}{\text{Wood Fuel}} \xrightarrow{\text{Spark or match}} CO_2 + H_2O + \text{light energy} + \text{heat energy}$$

The oxygen atoms have been incorporated into carbon dioxide and water, but what are the sources of the carbon atoms in the CO_2 and of the hydrogen atoms in the water? These atoms make up the wood fuel - and nearly all fuels we burn, from coal to propane to candle wax to gasoline. Overall, burning is the combining of oxygen with hydrogen and carbon atoms in a fuel (combustion or oxidation) to release the stored chemical energy as heat and light. Products of combustion are CO_2 (oxidized carbon) and H_2O (oxidized hydrogen). The equation can be modified to:

$$O_2 + \underset{\text{Stored chemical Energy}}{C_x\text{-}H_y} \xrightarrow{\text{Spark or match}} CO_2 + H_2O + \text{light energy} + \text{heat energy}$$

Cellular Respiration

Recall that breathing rate and oxygen intake relates to energy use. Burning consumes oxygen as it releases stored chemical energy, transforming it into light and heat. **Cellular respiration** is actually a slow burn. Your cells absorb the oxygen carried by your blood from your lungs, and use the O_2 to release stored chemical energy so that you can use it.

Stages of Cellular Respiration

Cellular respiration involves many chemical reactions. As you saw earlier, the reactions can be summed up in this equation:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Chemical Energy (in ATP)

The reactions of cellular respiration can be grouped into three stages: glycolysis, the Krebs cycle (also called the citric acid cycle), and electron transport.

However, releasing energy within cells does not produce light or intense heat. Cells run on chemical energy - specifically, the small amount temporarily stored in **ATP** molecules. Cellular respiration transfers chemical energy from a "deliverable" fuel molecule - **glucose** - to many "usable" molecules of ATP. Like oxygen, glucose is delivered by your blood to your cells. If ATP were delivered to cells, more than 60,221,417,930,000,000,000,000,000 of these large molecules (which contain relatively small amounts of energy) would clog your capillaries each day. Pumping them across cell membranes would "cost" a great deal of energy. A molecule of glucose contains a larger amount of chemical energy in a smaller package. Therefore, glucose is much more convenient for bloodstream delivery, but too "powerful" to work within the cell. The process of cellular respiration uses oxygen to help transfer the chemical energy from glucose to ATP, which can be used to do work in the cell. This chemical equation expresses what we have worked out:

O_2 + $C_6H_{12}O_6$ (stored chemical energy, deliverable) ⟶ ATP (stored chemical energy, usable)

As with burning, we must trace what happens to atoms during cellular respiration. You can readily see that when the carbon atoms in glucose are combined with oxygen, they again form carbon dioxide. And when the hydrogen atoms in glucose are oxidized, they form water, as in burning. You can detect these products of cellular respiration in your breath on a cold day (as water condensation) and in the lab (BTB turns yellow when you blow into it through a straw).

O_2 + $C_6H_{12}O_6$ (stored chemical energy, deliverable) ⟶ ATP (stored chemical energy, usable) + CO_2 + H_2O

This equation accounts for the energy transfer and the carbon, hydrogen, and oxygen atoms, but it does not show the "raw materials" or reactants which build ATP. Recall that the energy temporarily stored in ATP is released for use when the bond between the second and third phosphate is broken. The resulting ADP can be recycled within the cell by recombining it with inorganic phosphate (P_i).

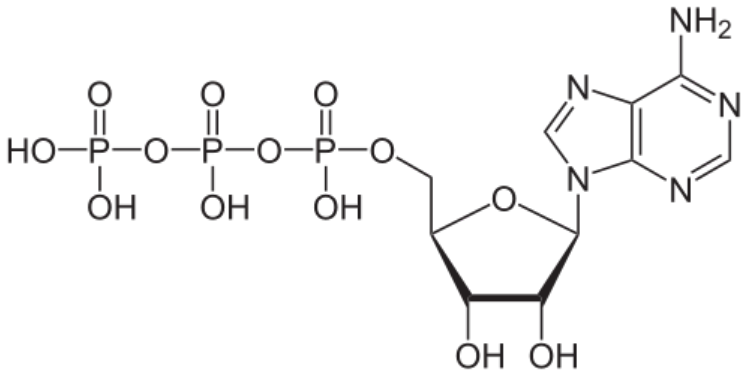

FIGURE 11.3

Like recharging batteries, cells recycle ATP and ADP (and AMP) molecules by combining them with inorganic phosphate. When the high-energy bond between phosphate groups in ATP breaks, its chemical energy can do cellular work. The bonds between phosphate groups can be broken and reformed, recycling this cellular energy.

The source of energy for re-attaching the phosphate and making ATP is the chemical energy in glucose. Materials cycle and recycle, but energy gets used up and must be replaced. That is the key to understanding cellular respiration:

it is a "recharging of the batteries" - ATP molecules - which power cellular work. How many ATP can be made by harnessing the energy in a single glucose molecule? Although this number varies under certain conditions, most cells can capture enough energy from one molecule of glucose to build 38 molecules of ATP. Our equation becomes:

$$O_2 + \underset{\text{stored chemical energy, deliverable}}{C_6H_{12}O_6} + 38ADP + 38P_i \longrightarrow \underset{\text{stored chemical energy, usable}}{38\ ATP} + CO_2 + H_2O$$

Mitochondria

This equation for cellular respiration is not quite complete, however, because we can easily mix air and glucose sugar (even adding ADP and P_i) and nothing will happen. For the campfire, we indicated above the arrow that a necessary condition was a spark or match to start the reaction. A spark or match would damage or destroy living tissue. What necessary condition initiates the slow burn that is cellular respiration? Recall that **enzymes** are highly specific proteins which "speed up" or catalyze chemical reactions in living cells. More than 20 different enzymes are necessary to carry out cellular respiration. Recall also that membranes within organelles often sequence enzymes for efficiency, as in chloroplasts for photosynthesis, you will not be surprised that a specific organelle, the **mitochondrion** (**Figure** 11.4), is also a necessary condition of cellular respiration - at least in eukaryotes.

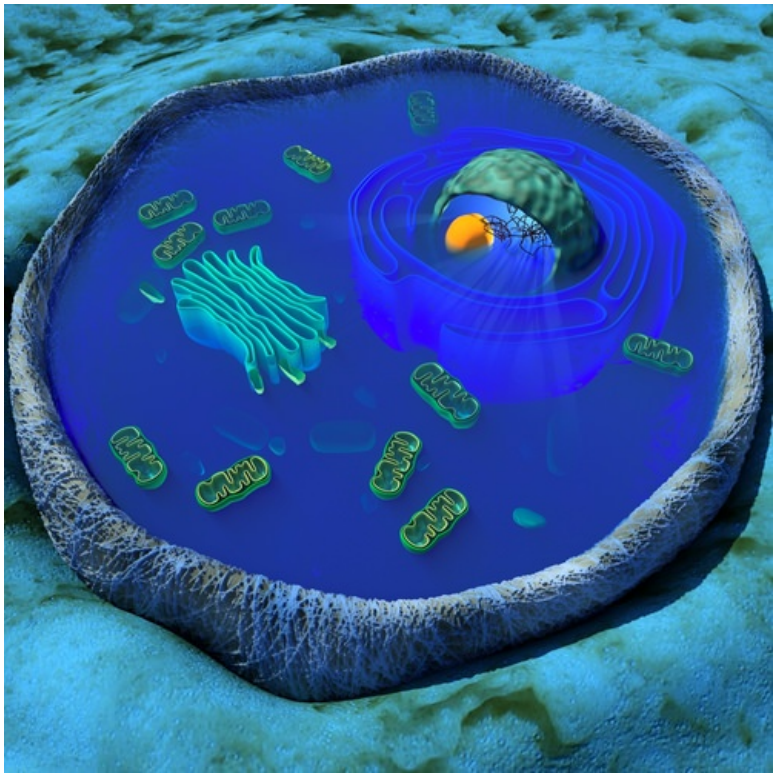

FIGURE 11.4

Mitochondria, shown here as the green ovals in this animal cell, are membranous organelles which sequence enzyme and electron carrier molecules to make cellular respiration highly efficient. Mitochondria have both an inner and outer membrane, with a matrix inside the inner membrane. The inner membrane has many internal folds, increasing the surface area for proteins and molecules involved in cellular respiration.

Within each eukaryotic cell, the membranes of a few to a few thousand mitochondria sequence enzymes and electron carriers and compartmentalize ions so that cellular respiration proceeds efficiently. Mitochondria, like chloroplasts, contain their own DNA and ribosomes and resemble certain bacteria. The **Theory of Endosymbiosis** holds that mitochondria, like chloroplasts, were once independently living prokaryotes. Larger prokaryotes engulfed (or enslaved) these smaller aerobic cells, forming eukaryotic cells. Many prokaryotes today can perform cellular respiration; perhaps they and mitochondria have common ancestors. Their expertise in generating ATP made mitochondria highly valued **symbionts**.

Including these necessary conditions and balancing numbers of atoms on both sides of the arrow, our final equation for the overall process of cellular respiration is:

$$\underset{\text{stored chemical energy, deliverable}}{6O_2 + C_6H_{12}O_6} + 38ADP + 38P_i \xrightarrow[\text{mitochondria}]{\text{enzymes}} \underset{\text{stored chemical energy, usable}}{38ATP} + 6CO_2 + 6H_2O$$

In words, cellular respiration uses oxygen gas to break apart the carbon-hydrogen bonds in glucose and release their energy to build 38 molecules of ATP. Most of this process occurs within the mitochondria of the cell. Carbon dioxide and water are waste products. This is similar to burning, in which oxygen breaks the carbon-hydrogen bonds in a fuel and releases their chemical energy as heat and light. Again, carbon dioxide and water are waste.

Cellular Respiration and Photosynthesis

Comparing this process to that of photosynthesis, the similarity between the two processes is striking. Both are processes within the cell which make chemical energy available for life. Photosynthesis transforms light energy into chemical energy stored in glucose, and cellular respiration releases the energy from glucose to build ATP, which does the work of life. Moreover, photosynthesis reactants CO_2 and H_2O are products of cellular respiration. And the reactants of respiration, $C_6H_{12}O_6$ and O_2, are the products of photosynthesis. This interdependence is the basis of the **carbon-oxygen cycle** (**Figure** 11.5), which connects producers to consumers and their environment. At first glance, the cycle merely seems to show mitochondria undoing what chloroplasts do; but the cycle's energy transformations power all the diversity, beauty, and mystery of life.

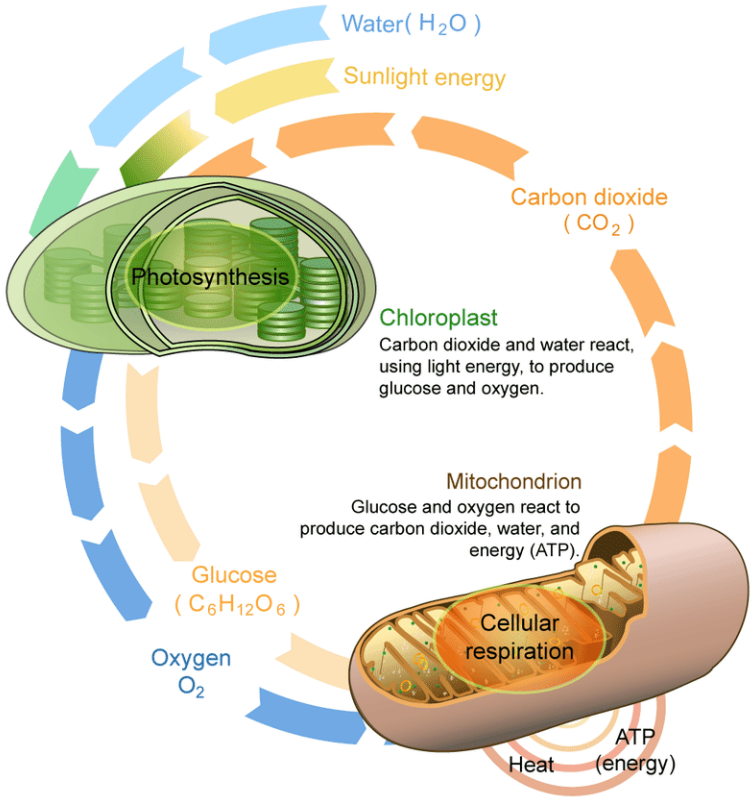

FIGURE 11.5

Photosynthesis in the chloroplast and cellular respiration in the mitochondrion show the interdependence of producers and consumers, the flow of energy from sunlight to heat, and the cycling of carbon and oxygen between living world and environment.

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Summary

- Cellular respiration is a series of chemical reactions which transfer energy from glucose (deliverable or fuel energy) to ATP (usable energy).
- Analyzing a campfire can clarify your understanding of cellular respiration. A campfire breaks chemical bonds in wood, releasing stored energy as light and heat; respiration breaks chemical bonds in glucose, releasing stored energy and transferring some to 38 ATP; some energy is lost as heat.
- This equation summarizes the process of cellular respiration:

$$6O_2 + \underset{\text{stored chemical energy, deliverable}}{C_6H_{12}O_6} + 38ADP + 38P_i \xrightarrow{\substack{\text{enzymes} \\ \text{mitochondria}}} \underset{\text{stored chemical energy, usable}}{38ATP} + 6CO_2 + 6H_2O$$

- In eukaryotic cells, mitochondria organize enzymes and electron carriers and compartmentalize ions so that cellular respiration proceeds efficiently.
- Cellular respiration, in many ways the opposite of photosynthesis, shows the interdependence of producers and consumers. Combined, the two equations demonstrate how energy flows and the carbon and oxygen cycle between organisms and environment.

Review

1. What source of energy do cells use to build ATP by cellular respiration?
2. Compare the purpose and energy content of glucose to the function and energy content of ATP; in other words, why do organisms need both kinds of energy-rich molecules?
3. Compare the process of burning gasoline in your automobile's engine to the process of cellular respiration in terms of reactants, products, and necessary conditions.
4. Write out the chemical reaction which summarizes the overall process of cellular respiration, first in symbols as a chemical equation, and then in words in a complete sentence.
5. In what eukaryote organelle does cellular respiration take place? Does this mean that prokaryotes cannot carry out the entire process of cellular respiration? Explain.
6. Compare and contrast cellular respiration and photosynthesis.

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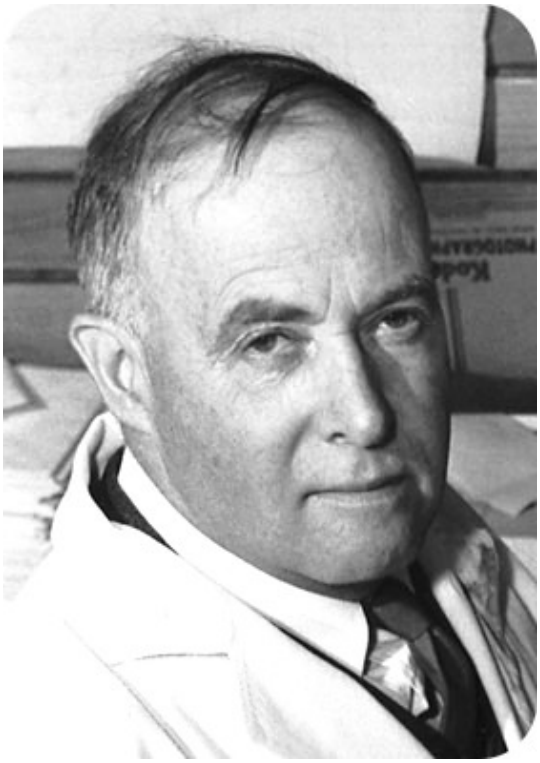
CONCEPT 12 Enzymes

Learning Objectives

- Define enzyme.
- Define active site.
- Describe the process of an enzyme reaction.
- Describe the process by which a competitive inhibitor alters the rate of an enzyme reaction.
- Describe the process by which a non-competitive inhibitor alters the rate of an enzyme reaction.
- Explain the role of cofactors in enzyme reactions.



What did he discover?

The first enzyme to be isolated was discovered in 1926 by American chemist James Sumner, who crystallized the protein. The enzyme was urease, which catalyzes the hydrolytic decomposition of urea, a component of urine, into ammonia and carbon dioxide.

$$H_2NCONH_2(aq) + H_2O(l) \xrightarrow{\text{urease}} 2NH_3(g) + CO_2(g)$$

His discovery was ridiculed at first because nobody believed that enzymes would behave the same way that other chemicals did. Sumner was eventually proven right and won the Nobel Prize in Chemistry in 1946.

Enzymes

An **enzyme** is a protein that acts as a biological catalyst. Recall that a catalyst is a substance that increases the rate of a chemical reaction without itself being consumed in the reaction. Cellular processes consist of many chemical reactions that must occur quickly in order for the cell to function properly. Enzymes catalyze most of the chemical reactions that occur in a cell. A **substrate** is the molecule or molecules on which the enzyme acts. In the urease catalyzed reaction above, urea is the substrate. **Figure** 12.1 diagrams a typical enzymatic reaction.

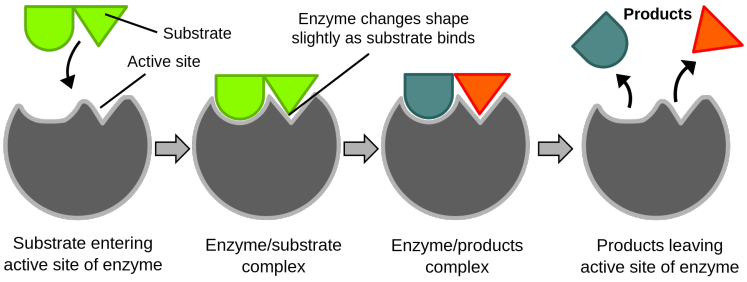


FIGURE 12.1

The sequence of steps for a substrate binding to an enzyme in its active site, reacting, then being released as products.

The first step in the reaction is that the substrate binds to a specific part of the enzyme molecule. The binding of the substrate is dictated by the shape of each molecule. Side chains on the enzyme interact with the substrate in a specific way, resulting in the making and breaking of bonds. The **active site** is the place on an enzyme where the substrate binds. An enzyme folds in such a way that it typically has one active site, usually a pocket or crevice formed by the folding pattern of the protein. Because the active site of an enzyme has such a unique shape, only one particular substrate is capable of binding to that enzyme. In other words, each enzyme catalyzes only one chemical reaction with only one substrate. Once the enzyme/substrate complex is formed, the reaction occurs and the substrate is transformed into products. Finally, the product molecule or molecules are released from the active site. Note that the enzyme is left unaffected by the reaction and is now capable of catalyzing the reaction of another substrate molecule.

Inhibitors

An **inhibitor** is a molecule which interferes with the function of an enzyme, either by slowing or stopping the chemical reaction. Inhibitors can work in a variety of ways, but one of the most common is illustrated in **Figure** 12.2.

The inhibitor binds competitively at the active site and blocks the substrate from binding. Since no reaction occurs with the inhibitor, the enzyme is prevented from catalyzing the reaction. Cyanide is a potent poison which acts as a competitive inhibitor. It binds to the active site of the enzyme *cytochrome c oxidase* and interrupts cellular respiration. The binding of the cyanide to the enzyme is irreversible and the affected organism dies quickly.

Non-competitive Inhibition

A non-competitive inhibitor does not bind at the active site. It attaches at some other site on the enzyme and changes the shape of the protein. This shift in three-dimensional structure alters the shape of the active site so that the substrate will no longer fit in the site properly (see **Figure** 12.3).

Co-factors

Some enzymes require the presence of a non-protein molecule called a cofactor in order to function properly. Cofactors can be inorganic metal ions or small organic molecules. Many vitamins, such as B vitamins, act as

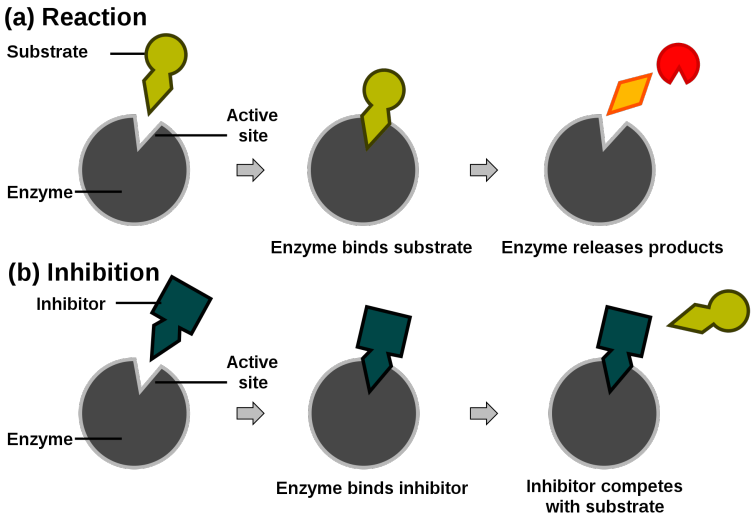


FIGURE 12.2

A competitive inhibitor is a molecule that binds to the active site of an enzyme without reacting, thus preventing the substrate from binding.

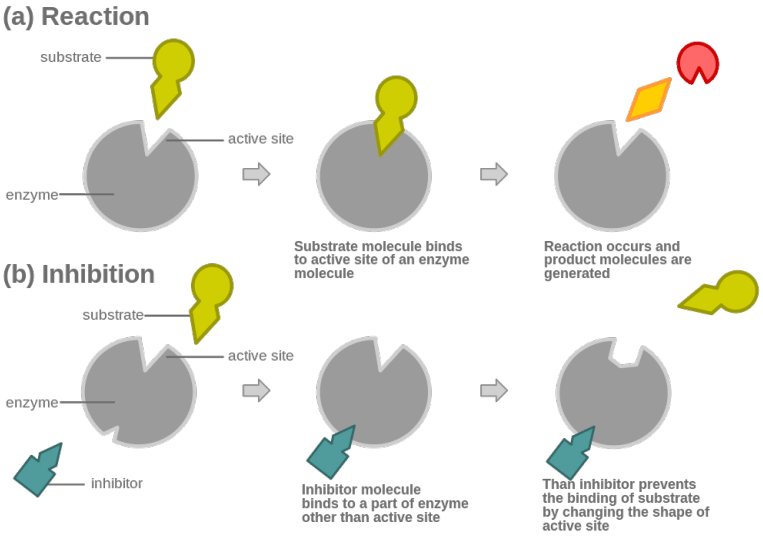
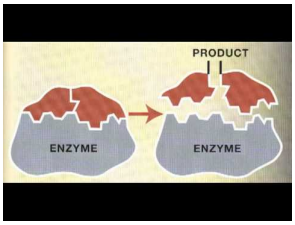


FIGURE 12.3

Non-competitive inhibition

cofactors. Some metal ions which function as cofactors for various enzymes include zinc, magnesium, potassium, and iron.



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Science Friday: Stained Glass Conservation

Stained glass from the Middle Ages is often hundreds of years old. Unfortunately, many of these relics are in need of cleaning and maintenance. In this video by Science Friday, conservator Mary Higgins discusses the methods used to protect the stained glass.

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Review

1. What is the substrate?
2. How does a competitive inhibitor work?
3. How does a non-competitive inhibitor work?

Vocabulary

- **active site:** The place on an enzyme where the substrate binds.
- **enzyme:** A protein that acts as a biological catalyst.
- **inhibitor:** A molecule which interferes with the function of an enzyme, either slowing or stopping the chemical reaction.
- **substrate:** The molecule or molecules on which the enzyme acts.

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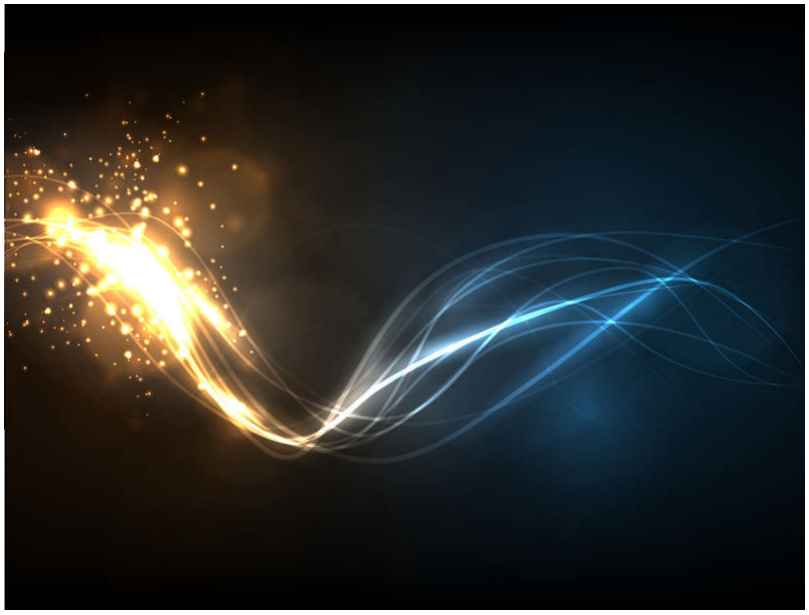
CONCEPT 13

Enzymes and Activation Energy - Advanced

Learning Objectives

- Explain the importance of enzymes in organisms, and describe how enzymes work.
- State factors that affect the rate of chemical reactions.

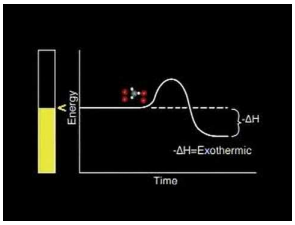


What is the energy needed for biochemical reactions?

Is it light or heat? It could be either. But whatever form energy takes, every single biochemical reaction in your body - and there are trillions of these reactions (or more) every split second, needs energy to start or activate. And that is known as activation energy.

Activation Energy

Regardless of whether reactions are **exothermic reactions** or **endothermic reactions**, they all need energy to get started. This energy is called **activation energy**. Activation energy is like the push you need to start moving down a slide. The push gives you enough energy to start moving. Once you start, you keep moving without being pushed again. Activation energy is defined as the energy that must be overcome in order for a chemical reaction to occur, or the minimum energy required to start a chemical reaction. The concept of activation energy is illustrated in **Figure** 13.1.



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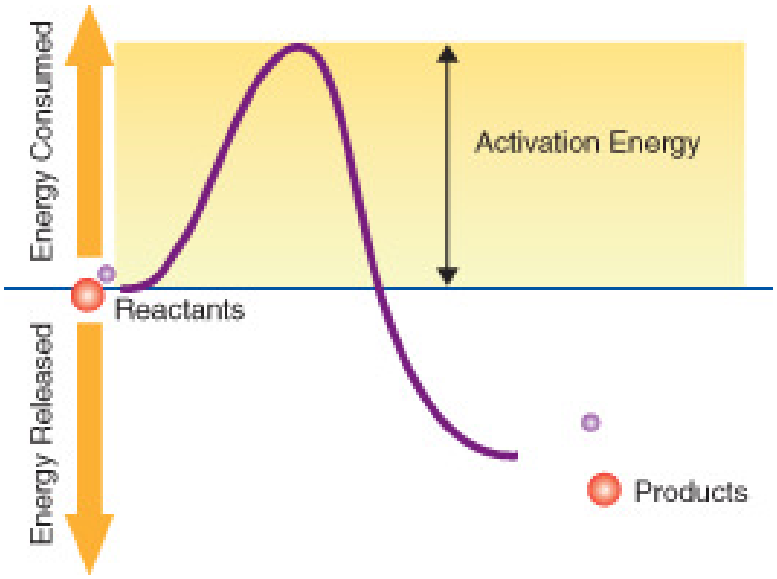


FIGURE 13.1

To start this reaction, a certain amount of energy is required, called the activation energy. How much activation energy is required depends on the nature of the reaction and the conditions under which the reaction takes place. Activation energy can be thought of as the height of the energy barrier between the **reactants** and the **products**.

Why do reactions need energy to get started? In order for reactions to occur, three things must happen, and they all require energy:

- Reactant molecules must collide. To collide, they must move, so they need kinetic energy.
- Unless reactant molecules are positioned correctly, intermolecular forces may push them apart. To overcome these forces and move together requires more energy.
- If reactant molecules collide and move together, there must be enough energy left for them to react.

Rates of Chemical Reactions

The rates at which chemical reactions take place in organisms are very important. Chemical reactions in organisms are involved in processes ranging from the contraction of muscles to the digestion of food. For example, when you wave goodbye, it requires repeated contractions of muscles in your arm over a period of a couple of seconds. A huge number of reactions must take place in that time, so each reaction cannot take longer than a few milliseconds. If the reactions took much longer, you might not finish waving until sometime next year.

Factors that help reactant molecules collide and react speed up chemical reactions. These factors include the concentration of reactants and the temperature at which the reactions occur.

- Reactions are usually faster at higher concentrations of reactants. The more reactant molecules there are in a given space, the more likely they are to collide and react.
- Reactions are usually faster at higher temperatures. Reactant molecules at higher temperatures have more energy to move, collide, and react.

Summary

- All chemical reactions require activation energy, which is the energy needed to get a reaction started.
- Rates of chemical reactions depend on factors such as the concentration of reactants and the temperature at which reactions occur. Both factors affect the ability of reactant molecules to react.

Review

1. What is activation energy?
2. Why do all chemical reactions require activation energy?

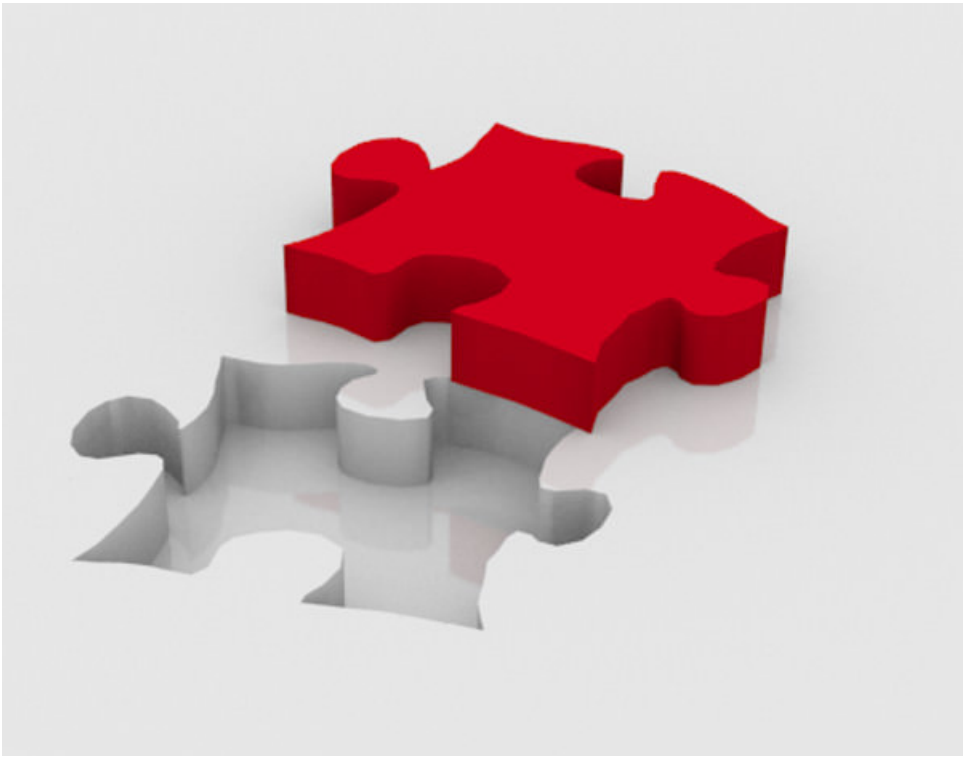
References

1. CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0

CONCEPT 14 Enzyme Function

Learning Objectives

- Summarize the importance of enzymes to living organisms.
- Define substrate and active site.
- Describe how enzymes function.
- Differentiate between a biochemical reaction in the presence or absence of an enzyme.
- Describe the effects of temperature and pH on enzyme activity.

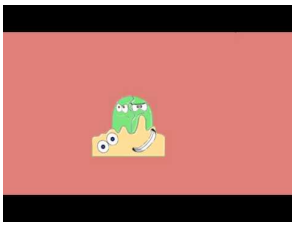


Do cells have one enzyme with lots of functions, or many enzymes, each with just one function?

Enzymes. Vital proteins necessary for life. So how do enzymes work? How do they catalyze just one specific biochemical reaction? In a puzzle, only two pieces will fit together properly. Understanding that is one of the main steps in understanding how enzymes work.

Enzyme Function

How do **enzymes** speed up biochemical reactions so dramatically? Like all **catalysts**, enzymes work by lowering the **activation energy** of chemical reactions. Activation energy is the energy needed to start a chemical reaction. This is illustrated in **Figure** 14.1. The biochemical reaction shown in the figure requires about three times as much activation energy without the enzyme as it does with the enzyme.



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As you view *Enzyme Animation,* focus on this concept:

1. how enzymes function.

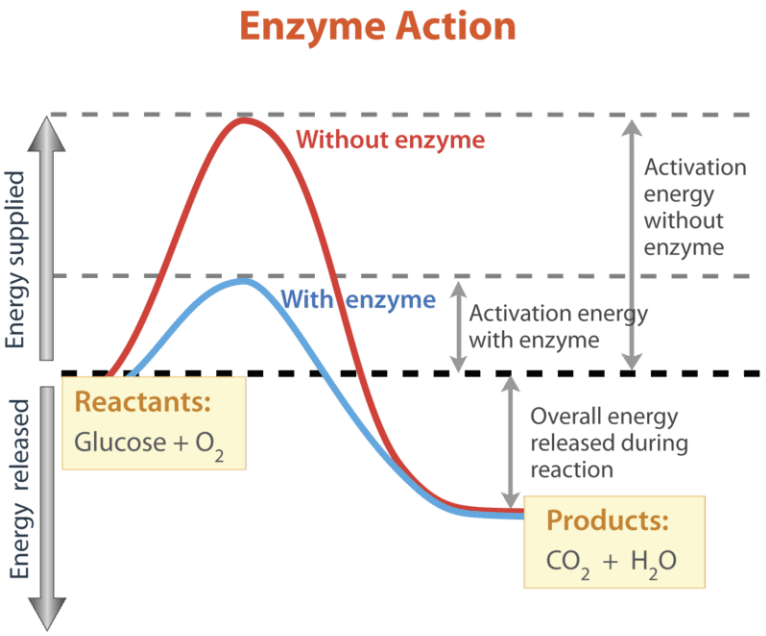

FIGURE 14.1

The reaction represented by this graph is a combustion reaction involving the reactants glucose ($C_6H_{12}O_6$) and oxygen (O_2). The products of the reaction are carbon dioxide (CO_2) and water (H_2O). Energy is also released during the reaction. The enzyme speeds up the reaction by lowering the activation energy needed for the reaction to start. Compare the activation energy with and without the enzyme.

Enzymes generally lower activation energy by reducing the energy needed for reactants to come together and react. For example:

- Enzymes bring reactants together so they don't have to expend energy moving about until they collide at random. Enzymes bind both reactant molecules (called the **substrate**), tightly and specifically, at a site on the enzyme molecule called the **active site** (**Figure** 14.2).
- By binding reactants at the active site, enzymes also position reactants correctly, so they do not have to overcome intermolecular forces that would otherwise push them apart. This allows the molecules to interact with less energy.
- Enzymes may also allow reactions to occur by different pathways that have lower activation energy.

The active site is specific for the reactants of the biochemical reaction the enzyme catalyzes. Similar to puzzle pieces fitting together, the active site can only bind certain substrates.

The activities of enzymes also depend on the temperature, ionic conditions, and the pH of the surroundings. Some enzymes work best at acidic pHs, while others work best in neutral environments.

- Digestive enzymes secreted in the acidic environment (low pH) of the stomach help break down proteins into smaller molecules. The main digestive enzyme in the stomach is **pepsin**, which works best at a pH of about

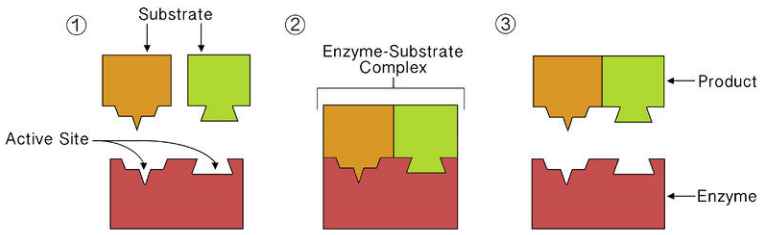

FIGURE 14.2

This enzyme molecule binds reactant molecules—called substrate—at its active site, forming an enzyme-substrate complex. This brings the reactants together and positions them correctly so the reaction can occur. After the reaction, the products are released from the enzyme's active site. This frees up the enzyme so it can catalyze additional reactions.

1.5. These enzymes would not work optimally at other pHs. Trypsin is another enzyme in the digestive system, which breaks protein chains in food into smaller parts. Trypsin works in the small intestine, which is not an acidic environment. Trypsin's optimum pH is about 8.

- Biochemical reactions are optimal at physiological temperatures. For example, most biochemical reactions work best at the normal body temperature of 98.6°F. Many enzymes lose function at lower and higher temperatures. At higher temperatures, an enzyme's shape deteriorates. Only when the temperature comes back to normal does the enzyme regain its shape and normal activity.

Summary

- Enzymes work by lowering the activation energy needed to start biochemical reactions.
- The activities of enzymes depend on the temperature, ionic conditions, and the pH of the surroundings.

Review

1. How do enzymes speed up biochemical reactions?
2. Where is the active site located? Explain the role of the active site?
3. Complete this sentence: The activities of enzymes depends on the _____, _____ conditions, and the _____ of the surroundings.
4. Distinguish between the conditions needed for the proper functioning of pepsin and trypsin.

References

1. Hana Zavadska. How enzyme changes activation energy . CC BY-NC 3.0
2. Laura Guerin. Enzyme binding reactant at active site . CC BY-NC 3.0

CONCEPT 15

Aerobic vs Anaerobic Respiration

Learning Objectives

- Distinguish aerobic from anaerobic.
- Define aerobic and anaerobic respiration.

How long can you hold your breath?

With or without air? In terms of producing energy, that is the key question. Can cellular respiration occur without air? It can, but it does have limitations.

The Presence of Oxygen

There are two types of cellular respiration (see *Cellular Respiration* concept): aerobic and anaerobic. One occurs in the presence of oxygen (**aerobic**), and one occurs in the absence of oxygen (**anaerobic**). Both begin with **glycolysis** - the splitting of glucose.

Glycolysis (see "Glycolysis" concept) is an **anaerobic** process - it does not need oxygen to proceed. This process produces a minimal amount of ATP. The Krebs cycle and electron transport do need oxygen to proceed, and in the presence of oxygen, these process produce much more ATP than glycolysis alone.

Scientists think that glycolysis evolved before the other stages of cellular respiration. This is because the other stages need oxygen, whereas glycolysis does not, and there was no oxygen in Earthâ[U+0080][U+0099]s atmosphere when life first evolved about 3.5 to 4 billion years ago. Cellular respiration that proceeds without oxygen is called **anaerobic respiration**.

Then, about 2 or 3 billion years ago, oxygen was gradually added to the atmosphere by early photosynthetic bacteria (cyanobacteria). After that, living things could use oxygen to break down glucose and make ATP. Today, most organisms make ATP with oxygen. They follow glycolysis with the Krebs cycle and electron transport to make more ATP than by glycolysis alone. Cellular respiration that proceeds in the presence of oxygen is called **aerobic respiration**.

Summary

- Cellular respiration always begins with glycolysis, which can occur either in the absence or presence of oxygen.
- Cellular respiration that proceeds in the absence of oxygen is anaerobic respiration.
- Cellular respiration that proceeds in the presence of oxygen is aerobic respiration.
- Anaerobic respiration evolved prior to aerobic respiration.

Review

1. Define aerobic and anaerobic respiration.
2. What process is common to both aerobic and anaerobic respiration?
3. Why do scientists think that glycolysis evolved before the other stages of cellular respiration?

CONCEPT 16

Cellular Respiration Process

Learning Objectives

- Describe the structure of a mitochondrion.
- List the three steps of cellular respiration.
- Write the chemical reaction of cellular respiration.
- Explain the process of cellular respiration.

Why do you need to breathe?

Of course if you didn't breathe, you couldn't survive. Why do you need air to live? You need the gas oxygen to perform cellular respiration to get energy from your food.

The Process of Cellular Respiration

Cellular respiration is the process of extracting energy in the form of **ATP** from the glucose in the food you eat. How does cellular respiration happen inside of the cell? Cellular respiration is a three step process. Briefly:

1. In stage one, glucose is broken down in the cytoplasm of the cell in a process called **glycolysis**.
2. In stage two, the pyruvate molecules are transported into the mitochondria. The **mitochondria** are the organelles known as the energy "powerhouses" of the cells (**Figure** 16.1). In the mitochondria, the pyruvate, which have been converted into a 2-carbon molecule, enter the **Krebs cycle.** Notice that mitochondria have an inner membrane with many folds, called **cristae**. These cristae greatly increase the membrane surface area where many of the cellular respiration reactions take place.

3. In stage three, the energy in the energy carriers enters an **electron transport chain**. During this step, this energy is used to produce ATP.

Oxygen is needed to help the process of turning glucose into ATP. The initial step releases just two molecules of ATP for each glucose. The later steps release much more ATP.

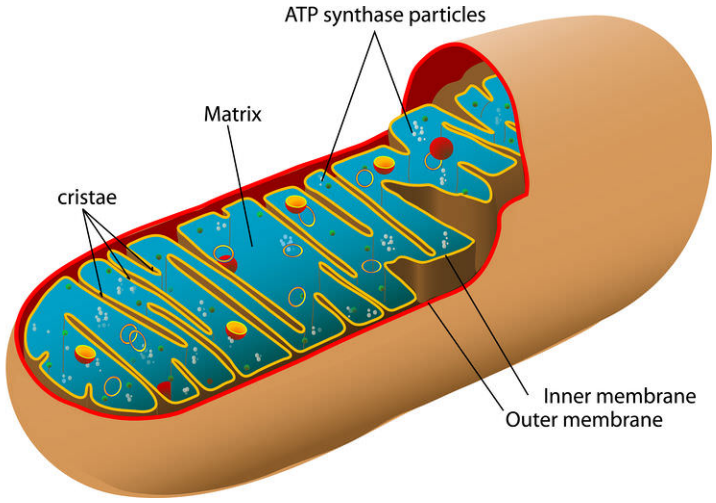

FIGURE 16.1
Most of the reactions of cellular respiration are carried out in the mitochondria.

The Reactants

What goes into the cell? Oxygen and glucose are both **reactants** of cellular respiration. Oxygen enters the body when an organism breathes. Glucose enters the body when an organism eats.

The Products

What does the cell produce? The **products** of cellular respiration are carbon dioxide and water. Carbon dioxide is transported from your mitochondria out of your cell, to your red blood cells, and back to your lungs to be exhaled. ATP is generated in the process. When one molecule of glucose is broken down, it can be converted to a net total of 36 or 38 molecules of ATP. This only occurs in the presence of oxygen.

The Chemical Reaction

The overall chemical reaction for cellular respiration is one molecule of glucose ($C_6H_{12}O_6$) and six molecules of oxygen (O_2) yields six molecules of carbon dioxide (CO_2) and six molecules of water (H_2O). Using chemical symbols the equation is represented as follows:

$C_6H_{12}O_6 + 6O_2$ â[U+0086][U+0092] $6CO_2 + 6H_2O$

ATP is generated during the process. Though this equation may not seem that complicated, cellular respiration is a series of chemical reactions divided into three stages: glycolysis, the Krebs cycle, and the electron transport chain.

Glycolysis

Stage one of cellular respiration is glycolysis. Glycolysis is the splitting, or *lysis* of glucose. Glycolysis converts the 6-carbon glucose into two 3-carbon **pyruvate** molecules. This process occurs in the cytoplasm of the cell, and

it occurs in the presence or absence of oxygen. During glycolysis a small amount of NADH is made as are four ATP. Two ATP are used during this process, leaving a net gain of two ATP from glycolysis. The NADH temporarily holds energy, which will be used in stage three.

The Krebs Cycle

In the presence of oxygen, under **aerobic** conditions, pyruvate enters the mitochondria to proceed into the Krebs cycle. The second stage of cellular respiration is the transfer of the energy in pyruvate, which is the energy initially in glucose, into two energy carriers, NADH and $FADH_2$. A small amount of ATP is also made during this process. This process occurs in a continuous cycle, named after its discover, Hans Krebs. The Krebs cycle uses a 2-carbon molecule (acetyl-CoA) derived from pyruvate and produces carbon dioxide.

The Electron Transport Chain

Stage three of cellular respiration is the use of NADH and $FADH_2$ to generate ATP. This occurs in two parts. First, the NADH and $FADH_2$ enter an electron transport chain, where their energy is used to pump, by active transport, protons (H^+) into the intermembrane space of mitochondria. This establishes a proton gradient across the inner membrane. These protons then flow down their concentration gradient, moving back into the matrix by facilitated diffusion. During this process, ATP is made by adding inorganic phosphate to ADP. Most of the ATP produced during cellular respiration is made during this stage.

For each glucose that starts cellular respiration, in the presence of oxygen (aerobic conditions), 36-38 ATP are generated. Without oxygen, under **anaerobic** conditions, much less (only two!) ATP are produced.

Summary

- Most of the steps of cellular respiration take place in the mitochondria.
- Oxygen and glucose are both reactants in the process of cellular respiration.
- The main product of cellular respiration is ATP; waste products include carbon dioxide and water.

Explore More

Use the resources below to answer the following questions

Explore More I

- **Glycolysis** at http://www.youtube.com/watch?v=piIrBw24c8M (0:44)

MEDIA

Click image to the left or use the URL below.

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1. Where does glycolysis occur?
2. When glucose is broken down what is produced?
3. Does glycolysis require oxygen?

Explore More II

- **Krebs Cycle** at http://www.youtube.com/watch?v=O6bInBQXtmM (5:30)

MEDIA

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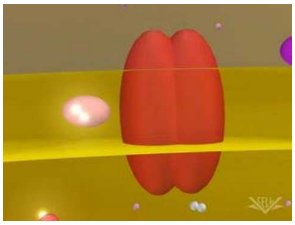
1. Which types of cells have mitochondria?
2. What is the cristae? Where does it occur? Why is this structure important?
3. What high energy electron carriers are produced by the Krebs cycle? Where do they carry their electrons?
4. What is the role of acetyl-CoA? Where does it fit into the Krebs cycle?
5. How much ATP is made by the Krebs cycle for every molecule of Pyruvate that enter the cycle?

Explore More III

- **Electron Transport Chain** at http://www.youtube.com/watch?v=xbJ0nbzt5Kw (3:50)



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1. What is the name of the protein complex that makes ATP?
2. What is the final electron acceptor at the end of the electron transport chain?
3. What is a "mobile transfer molecule"? What is their function?
4. How is the hydrogen ion gradient formed?
5. What is the purpose of the proton (hydrogen ion) gradient?

Review

1. Where is glucose broken down to form ATP? What is this process called? Does this process need oxygen?
2. Write the chemical reaction for the overall process of cellular respiration.
3. What is necessary for the Krebs cycle to proceed?
4. What happens during the Krebs cycle?
5. What is pyruvate?
6. What happens during the electron transport chain?
7. How is ATP made during the third stage of cellular respiration?

References

1. Mariana Ruiz Villarreal (LadyofHats), modified by CK-12 Foundation. Diagram of the mitochondria . Public Domain

CONCEPT 17 Identifying Redox Reactions

Learning Objectives

- List criteria for determining whether or not a given reaction involves oxidation and reduction.

Whatâ [U+0080] [U+0099]s that blue stuff?

The reaction of copper wire with nitric acid produces a colorful mix of products that include copper(II) nitrate, nitrogen dioxide, and water. Copper salts are blue in solution, reflecting the rather unique arrangements of electrons in the *d* orbital as the copper ionizes from metallic copper.

Identifying Reaction Types

A redox reaction must involve a change in oxidation number for two of the elements involved in the reaction. The oxidized element increases in oxidation number, while the reduced element decreases in oxidation number.

Single-replacement reactions are redox reactions because two different elements appear as free element (oxidation number of zero) on one side of the equation and as part of a compound on the other side. Therefore, its oxidation number must change.

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$

Zn is oxidized from Zn^0 to Zn^{2+} and the H is reduced from H^+ to H^0

Combustion reactions are redox reactions because elemental oxygen (O_2) acts as the oxidizing agent and is itself reduced.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Most combination and decomposition reactions are redox reactions since elements are usually transformed into compounds and vice-versa. The thermite reaction involves ferric oxide and metallic aluminum:

$$Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2Fe$$

FIGURE 17.1
Thermite grenade demonstration.

We see that the iron is reduced and the aluminum oxidized during the course of the reaction.

Watch a video of the thermite reaction:

MEDIA
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So what types of reactions are not redox reactions? Double-replacement reactions such as the one below are not redox reactions because ions are simply recombined without any transfer of electrons.

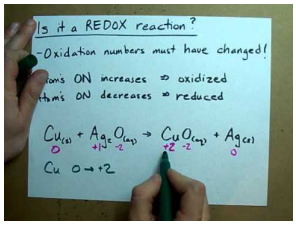
$$\overset{+1}{Na_2}\overset{+6}{S}\overset{-2}{O_4}\ (aq) + \overset{+2}{Ba}\ \overset{+5}{(N}\overset{-2}{O_3)_2}(aq) \rightarrow 2\ \overset{+1}{Na}\overset{+5}{N}\overset{-2}{O_3}\ (aq) + \overset{+2}{Ba}\overset{+6}{S}\overset{-2}{O_4}\ (s)$$

Note that the oxidation numbers for each element remain unchanged in the reaction.

Acid-base reactions involve a transfer of a hydrogen ion instead of an electron. Acid-base reactions, like the one below, are also not redox reactions.

$$\overset{+1-1}{\mathrm{HF}}\,(aq) + \overset{-3+1}{\mathrm{NH_3}}\,(aq) \rightarrow \overset{-3+1}{\mathrm{NH_4}}{}^{+}(aq) + \overset{-1}{\mathrm{F}}{}^{-}(aq)$$

Again, the transfer of an H^+ ion leaves the oxidation numbers unaffected. In summary, redox reactions can always be recognized by a change in oxidation number of two of the atoms in the reaction. Any reaction in which no oxidation numbers change is not a redox reaction.



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Review

1. Why is the Zn + HCl reaction a redox reaction?
2. Why is the sodium sulfate + barium nitrate reaction not a redox reaction?
3. Does the transfer of H^+ affect oxidation numbers?

References

1. User:The mad scientist/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:CopperReaction.JPG .
2. Courtesy of the U.S. Marines. http://commons.wikimedia.org/wiki/File:USMC-07509.jpg .

CONCEPT 18 Glycolysis - Advanced

Learning Objectives

- Recognize that glycolysis is the first and most universal of three stages in cellular respiration.
- Explain why biologists consider glycolysis to be one of the oldest energy production pathways.
- Describe how some of the energy in glucose is transferred to ATP in the cytoplasm, without oxygen.

How do you slice a molecule of glucose in half?

With sharp knives? Not really. But you lyse it with enzymes during a process named glycolysis. Glucose is sliced right in half from a 6-carbon molecule to two 3-carbon molecules. This is the first step and an extremely important part of cellular respiration. It happens all the time, both with and without oxygen. And in the process, transfers some energy to ATP.

Glycolysis: A Universal and Ancient Pathway for Making ATP

When was the last time you enjoyed yogurt on your breakfast cereal, or had a tetanus shot? These experiences may appear unconnected, but both relate to bacteria which do not use oxygen to make ATP. In fact, tetanus bacteria cannot survive if oxygen is present. However, *Lactobacillus acidophilus* (bacteria which make yogurt) and *Clostridium tetani* (bacteria which cause tetanus or lockjaw) share with nearly all organisms the first stage of cellular respiration, **glycolysis** (**Figure** 18.1). Because glycolysis is universal, whereas aerobic (oxygen-requiring) cellular respiration is not, most biologists consider it to be the most fundamental and primitive pathway for making ATP.

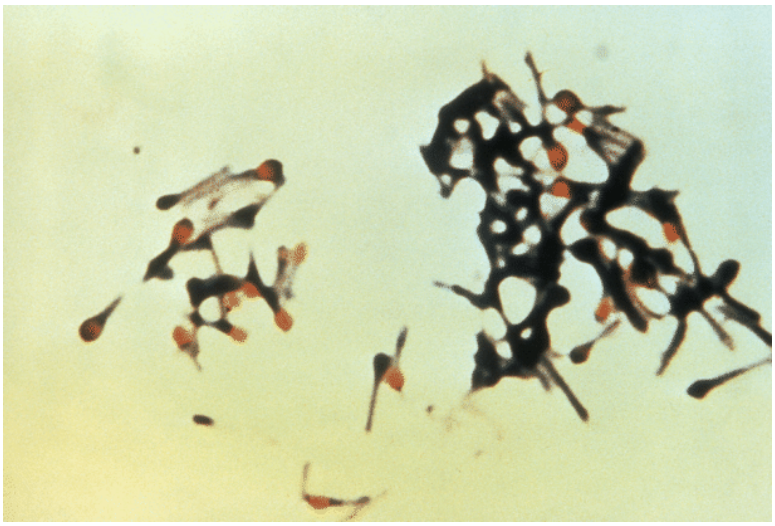


FIGURE 18.1

Clostridium tetani bacteria are obligate anaerobes, which cannot grow in the presence of oxygen and use a variation of glycolysis to make ATP. Because they can grow in deep puncture wounds and secrete a toxin, which can cause muscle spasms, seizures, and death, most people receive tetanus vaccinations at least every ten years throughout life.

Return to the overall equation for cellular respiration:

$$\underset{\text{stored chemical energy, deliverable}}{6O_2 + C_6H_{12}O_6} + 38ADP + 38P_i \xrightarrow[\text{mitochondria}]{\text{enzymes}} \underset{\text{stored chemical energy, usable}}{38ATP} + 6CO_2 + 6H_2O$$

Like photosynthesis, the process represented by this equation is actually many small, individual chemical reactions. We grouped the reactions of photosynthesis into two stages, the light reactions and the Calvin Cycle. We will divide the reactions of cellular respiration into three stages: glycolysis, the **Krebs Cycle**, and the **electron transport chain** (**Figure** 18.2). In this concept, Stage 1, glycolysis, the oldest and most widespread pathway for making ATP, is discussed. Before diving into the details, we must note that this first stage of cellular respiration is unique among the three stages: it does not require oxygen, and it does not take place in the mitochondrion. The chemical reactions of glycolysis occur without oxygen in the cytosol of the cell (**Figure** 18.3).

The name for Stage 1 clearly indicates what happens during that stage: *glyco-* refers to glucose, and *-lysis* means "splitting." In glycolysis, within the cytosol of the cell, a minimum of eight different enzymes break apart glucose into two 3-carbon molecules. The energy released in breaking those bonds is transferred to carrier molecules, ATP and NADH. **NADH** temporarily holds small amounts of energy which can be used later to build ATP. The 3-carbon product of glycolysis is **pyruvate**, or pyruvic acid (**Figure** 18.4). (The difference between them is actually a sole hydrogen atom. Pyruvic acid: $CH_3COCOOH$, pyruvate: CH_3COCOO^-.) Overall, glycolysis can be represented as:

$$C_6H_{12}O_6 + 2NAD^+ + 2P_i + 2ADP \rightarrow 2 \text{ pyruvate} + 2NADH + 2ATP$$

However, even this equation is deceiving. Just the splitting of glucose requires many steps, each transferring or capturing small amounts of energy. Individual steps appear in **Figure** 18.6. Studying the pathway in detail reveals that cells must "spend" or "invest" two ATP in order to begin the process of breaking glucose apart. Note that the phosphates produced by breaking apart ATP join with glucose, making it unstable and more likely to break

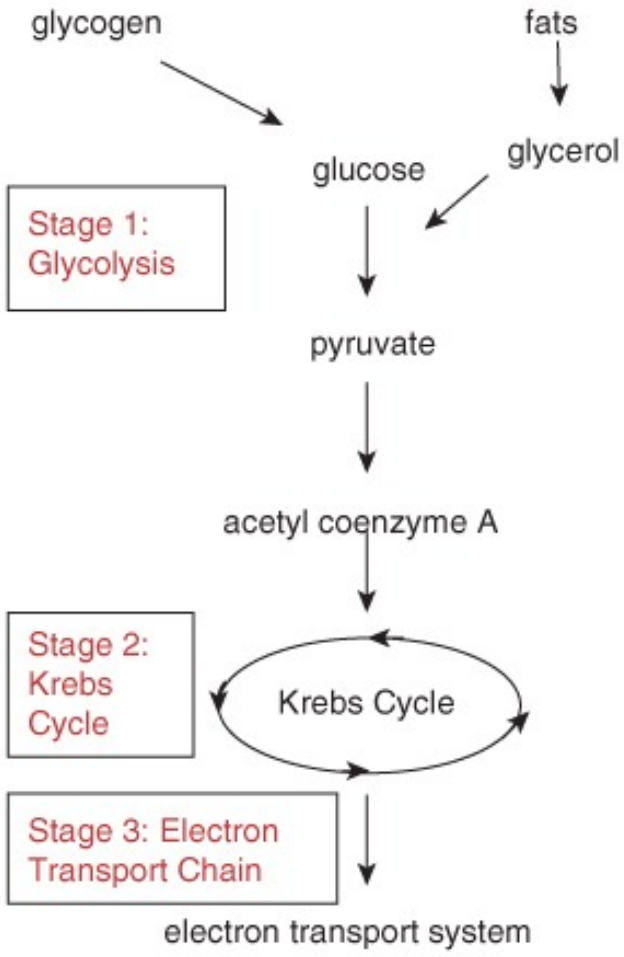
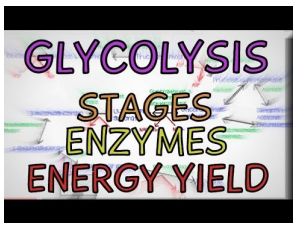


FIGURE 18.2

The many steps in the process of aerobic cellular respiration can be divided into three stages. The first stage, glycolysis, produces ATP without oxygen. Because this part of the cellular respiration pathway is universal, biologists consider it the oldest segment. Note that **glycogen** and fats can also enter the glycolysis pathway. The second stage is the Krebs Cycle, and the third stage is the electron transport chain. It is during the third stage that chemiosmosis produces numerous ATP molecules.

apart. Later steps harness the energy released when glucose splits, and use it to build "hot hydrogens" (NAD^+ is reduced to NADH) and ATP (ADP + P_i $\rightarrow$ ATP). If you count the ATP produced, you will find a net yield of two ATP per glucose (4 produced - 2 spent). Remember to double the second set of reactions to account for the two 3-carbon molecules which follow that pathway! The "hot hydrogens" can power other metabolic pathways, or in many organisms, provide energy for further ATP synthesis.



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To summarize: In the cytosol of the cell, glycolysis transfers some of the chemical energy stored in one molecule of glucose to two molecules of ATP and two NADH. This makes (some of) the energy in glucose, a universal fuel

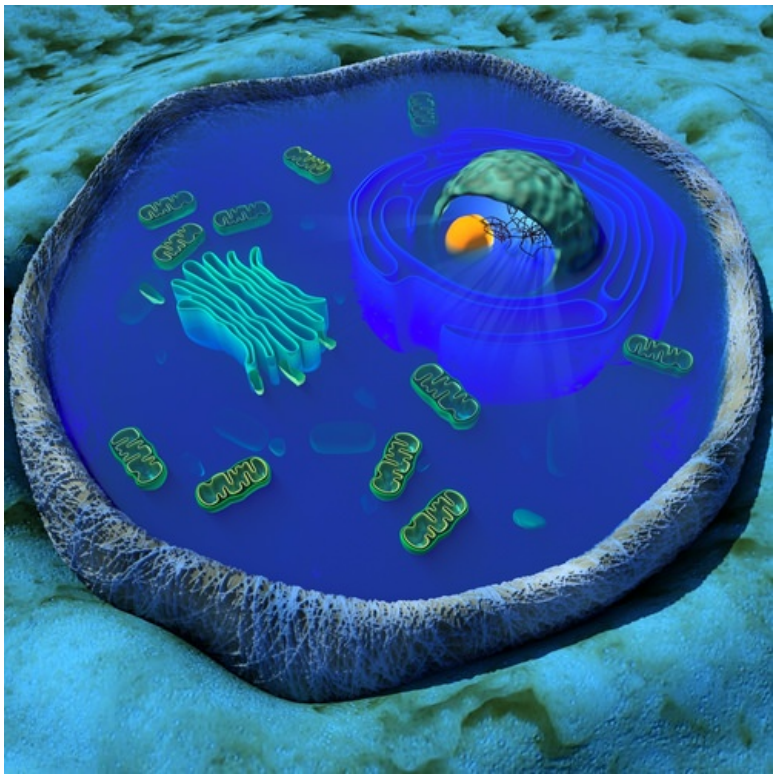


FIGURE 18.3

Glycolysis, unlike the latter two stages of cellular respiration, takes place without oxygen in the cytosol (blue) of the cell. For many organisms, aerobic respiration continues with the Krebs cycle and the electron transport chain in the mitochondria (green). To enter the mitochondria, glucose must first be lysed into smaller molecules.

molecule for cells, available to use in cellular work - moving organelles, transporting molecules across membranes, or building large organic molecules.

Although glycolysis is universal, pathways leading away from glycolysis vary among species depending on the availability of oxygen. If oxygen is unavailable, pyruvate may be converted to lactic acid or ethanol and carbon dioxide in order to regenerate NAD^+, ending anaerobic respiration. **Anaerobic respiration** is also called **fermentation**, which will be discussed in another concept.

If oxygen is present, pyruvate enters the mitochondria for further breakdown, releasing far more energy and producing many additional molecules of ATP in the latter two stages of **aerobic respiration** - the Krebs cycle and electron transport chain. We will explore these, too, in a later section.

Summary

- The process of cellular respiration is actually many separate reactions, which can be divided into three stages: glycolysis, the Krebs Cycle, and the electron transport chain.
- During glycolysis, glucose is split into two 3-carbon pyruvate molecules, using 2 ATP but generating 4 ATP, for a net gain of 2 ATP.
- During glycolysis, 2 NADH are also produced.

Review

1. List the three stages of cellular respiration, and contrast the first stage with the other two in terms of distribution throughout the living world, location within the cell, and use of oxygen.
2. Summarize the overall process of glycolysis, following both the path of carbon atoms and chemical energy.
3. What molecules can enter the glycolysis pathway, besides glucose?

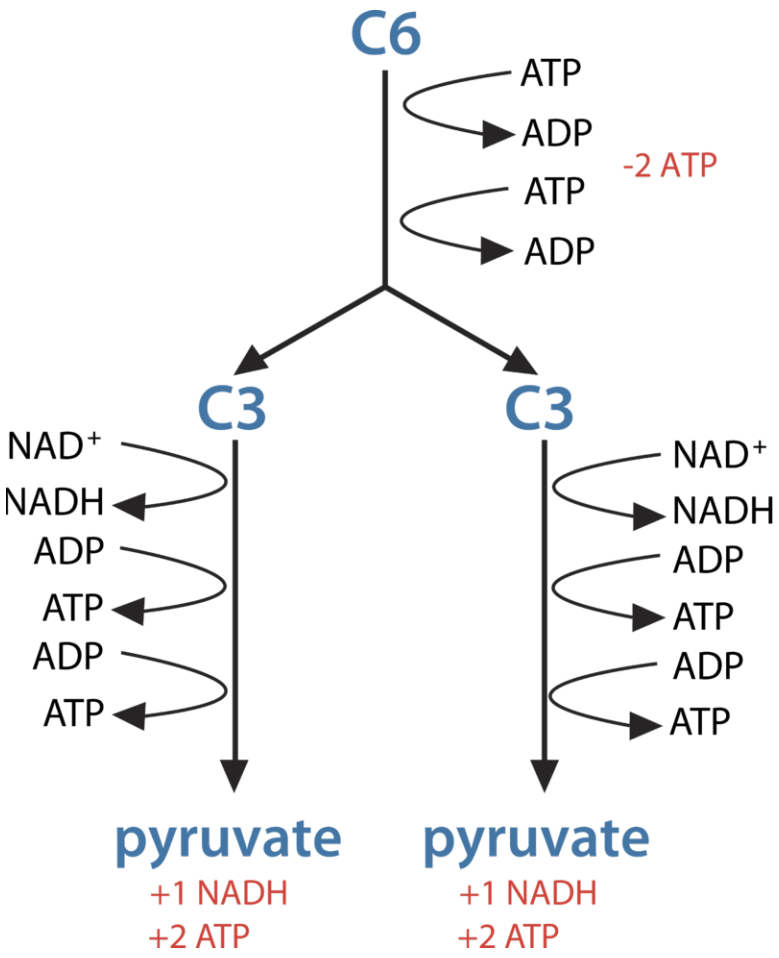


FIGURE 18.4

In glycolysis, glucose (C6) is split into two 3-carbon (C3) pyruvate molecules. This releases energy, which is transferred to ATP. How many ATP molecules are made during this stage of cellular respiration?

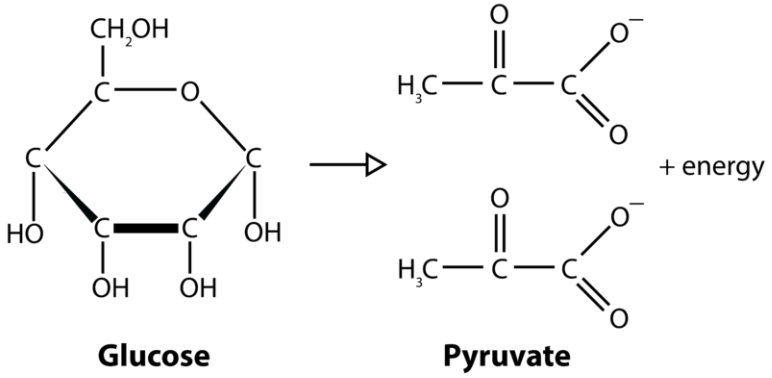


FIGURE 18.5

Glycolysis breaks the 6-carbon molecule glucose into two 3-carbon pyruvate molecules, releasing some of the chemical energy which had been stored in glucose.

References

1. Courtesy of the Centers for Disease Control and Prevention. http://commons.wikimedia.org/wiki/File:Clostridium_tetani_01.png . Public Domain
2. User:Mikm/Wikipedia. http://commons.wikimedia.org/wiki/File:Cellular_respiration_flowchart_%28en%29.svg . Public Domain

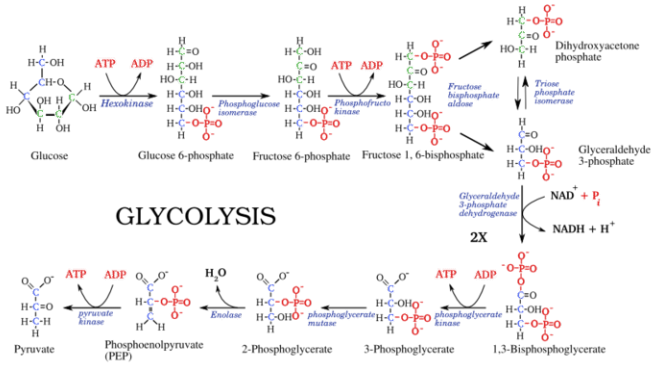


FIGURE 18.6

3. Image copyright somersault1824, 2014. Illustration of an animal cell in cross section . Used under license from Shutterstock.com
4. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
5. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0

CONCEPT 19 The Krebs Cycle - Advanced

Learning Objectives

- Relate the history of oxygen in the atmosphere to the evolution of photosynthesis, aerobic respiration, mitochondria, and life on earth.
- Describe the fate in eukaryotic cells of the pyruvate molecules produced by glycolysis if oxygen is present.
- Recognize that for most organisms, if oxygen is present, the products of glycolysis enter the mitochondria for stage 2 of cellular respiration - the Krebs Cycle.
- Trace carbon and hydrogen atoms through the Krebs Cycle.
- Analyze the importance of the Krebs Cycle to cellular respiration by following the pathway taken by chemical energy.

What type of acid do these fruits contain?

Citric acid. Citric acid is also the first product formed in the Krebs cycle, and therefore this acid occurs in the metabolism of virtually all living things.

Aerobic Respiration

Enticing clues - volcanic gases, vast iron ore sediments, and bubbles of ancient air trapped in amber - suggest dramatic changes during the history of earth's atmosphere. Correlating these clues with the fossil record leads to two major conclusions: that early life evolved in the absence of oxygen, and that oxygen first appeared between 2 and 3 billion years ago (**Figure** 19.1) because of photosynthesis by the blue green bacteria, cyanobacteria. The chemistry of cellular respiration reflects this history. Its first stage, **glycolysis**, is universal and does not use oxygen.

Absolutely dependent on oxygen gas, we find it difficult to imagine that its appearance must have been disastrous for the anaerobic organisms that evolved in its absence. But oxygen is highly reactive, and at first, its effect on evolution was so negative that some have named this period the "oxygen catastrophe." However, as oxygen gradually formed a protective **ozone layer**, life rebounded. After the first organisms evolved to use oxygen to their advantage, the diversity of aerobic organisms exploded. According to the **Theory of Endosymbiosis**, engulfing of some of

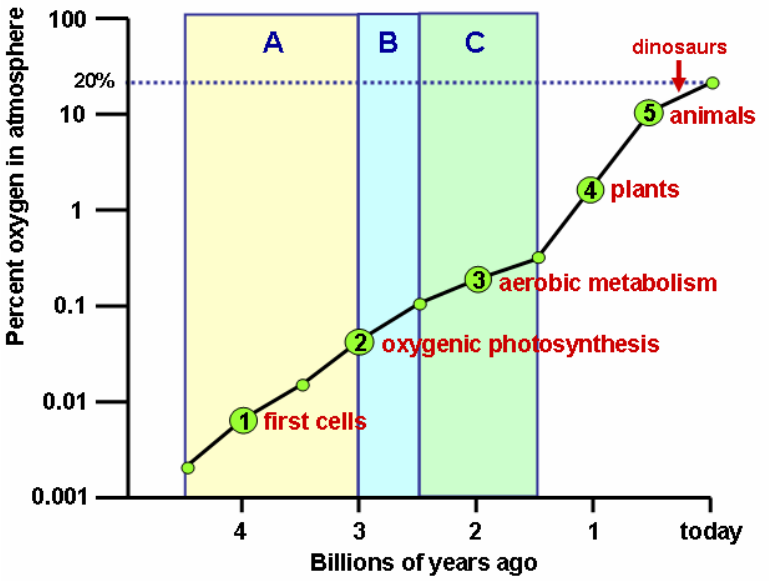


FIGURE 19.1

Oxygen has increased in the atmosphere throughout the history of the earth. Note the logarithmic scale, which indicates great increases after first photosynthesis (in bacteria) and then land plants evolved. Related geological events: A = no oxidized iron; B = oxidized iron bands in seabed rock - evidence for O_2 in the oceans; C = oxidized iron bands on land and ozone layer formation- evidence for O_2 in the atmosphere.

these aerobic bacteria led to eukaryotic cells with mitochondria, and **multicellularity**, the evolution of multicellular eukaryotic organisms, followed. Today, we live in an atmosphere which is 21% oxygen, and most of life follows glycolysis with the last two, aerobic stages of cellular respiration.

Recall the purpose of cellular respiration: to release energy from glucose to make ATP, the universal molecule of energy for cellular work. The following equation describes the overall process, although it summarizes many individual chemical reactions.

$$6O_2 + \underset{\text{stored chemical energy, deliverable}}{C_6H_{12}O_6} + 38ADP + 38P_i \xrightarrow[\text{mitochondria}]{\text{enzymes}} \underset{\text{stored chemical energy, usable}}{38ATP} + 6CO_2 + 6H_2O$$

Once again, the first stage of this process, glycolysis, is ancient, universal, and anaerobic. In the cytoplasm of most cells, glycolysis breaks each 6-carbon molecule of glucose into two 3-carbon molecules of **pyruvate**. Chemical energy, which had been stored in the now broken bonds, is transferred to 2 ATP and 2 NADH molecules.

The fate of pyruvate depends on the species and the presence or absence of oxygen. If oxygen is present to drive subsequent reactions, pruvate enters the mitochondrion, where the **Krebs Cycle** (Stage 2) and **electron transport chain** (Stage 3) break it down and oxidize it completely to CO_2 and H_2O. The energy released builds many more ATP molecules, though of course some is lost as heat. Let's explore the details of how mitochondria use oxygen to make more ATP from glucose by aerobic respiration.

The Krebs Cycle: Capturing Energy from Pyruvate

Aerobic respiration begins with the entry of the product of glycolysis, pyruvate, into the mitochondria. For each initial glucose molecules, two pyruvate molecules will enter the mitochondria. Pyruvate, however, is not the molecule that enters the Krebs cycle. Prior to entry into this cycle, pyruvate must be converted into a 2-carbon acetyl-CoenzymeA (acetyl-CoA) unit. The conversion of pyruvate into acetyl-CoA is referred to as the pyruvate dehydrogenase reaction. It is catalyzed by the pyruvate dehydrogenase complex. This process produces one NADH electron carrier while releasing a CO_2 molecule. This step is also known as the link reaction or transition step, as it links glycolysis and the Krebs cycle. Of course, as two pyruvates result from glycolysis, two acetyl-CoAs are produced as are 2 NADH molecules.

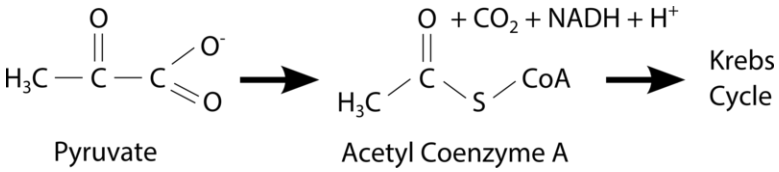


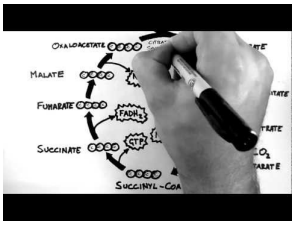
FIGURE 19.2

After glycolysis, two 3-carbon pyruvates enter the mitochondrion, where they are converted to two 2-carbon acetyl-CoenzymeA (CoA) molecules. Acetyl-CoA then enters the Krebs Cycle. Note that the carbons removed become carbon dioxide, accounting for two of the six such end products of glucose oxidation. The energy released by this breakdown is carried by NADH.

1. Within the mitochondria, each pyruvate is broken apart and combined with a coenzyme known as CoA to form a 2-carbon molecule, Acetyl-CoA, which can enter the Krebs Cycle. A single atom of carbon (per pyruvate) is "lost" as carbon dioxide. The energy released in this breakdown is captured in two NADH molecules. See **Figure** 19.2. Fatty acids can also break down into Acetyl-CoA. By this means, lipids, like fats, can be "burned" to make ATP using the Krebs Cycle.
2. The Krebs Cycle (**Figure** 19.3) begins by combining each Acetyl-CoA with a four-carbon carrier molecule to make a 6-carbon molecule of citric acid (or citrate, its ionized form). For this reason, the Krebs Cycle, named for a scientist who worked out its details, is also called the **Citric Acid Cycle**.
3. The cycle carries citric acid through a series of chemical reactions which gradually release energy and capture it in several carrier molecules. For each Acetyl-CoA which enters the cycle, 3 NAD^+ are reduced to NADH, one molecule of FAD (another temporary energy carrier) is reduced to $\mathbf{FADH_2}$, and one molecule of ATP (actually a precursor, GTP, guanine triphosphate) is produced. Study **Figure** 19.3 to locate each of these energy-capturing events.
4. Note what happens to carbon atoms (black dots in **Figure** 19.3). For each 2-carbon Acetyl-CoA which enters the cycle, two molecules of carbon dioxide are released, completing the breakdown of the original 6-carbon glucose molecule. The final step regenerates the original 4-carbon molecule which began the cycle, so that another Acetyl-CoA can enter the cycle.

In summary, the Krebs Cycle completes the breakdown of glucose which began with glycolysis. Its chemical reactions oxidize all six of the original carbon atoms to CO_2, and capture the energy released in 2 ATP, 6 NADH, and 2 $FADH_2$. These energy carriers join the 2 ATP and 2 NADH produced in glycolysis and the 2 NADH produced in the conversion of 2 pyruvates to 2 Acetyl-CoA molecules.

At the conclusion of the Krebs Cycle, glucose is completely broken down, yet only four ATP have been produced. Moreover, although oxygen is required to drive the Krebs Cycle, the cycle's chemical reactions do not themselves consume O_2. The conclusion of cellular respiration, stage 3, produces the majority of the ATP.



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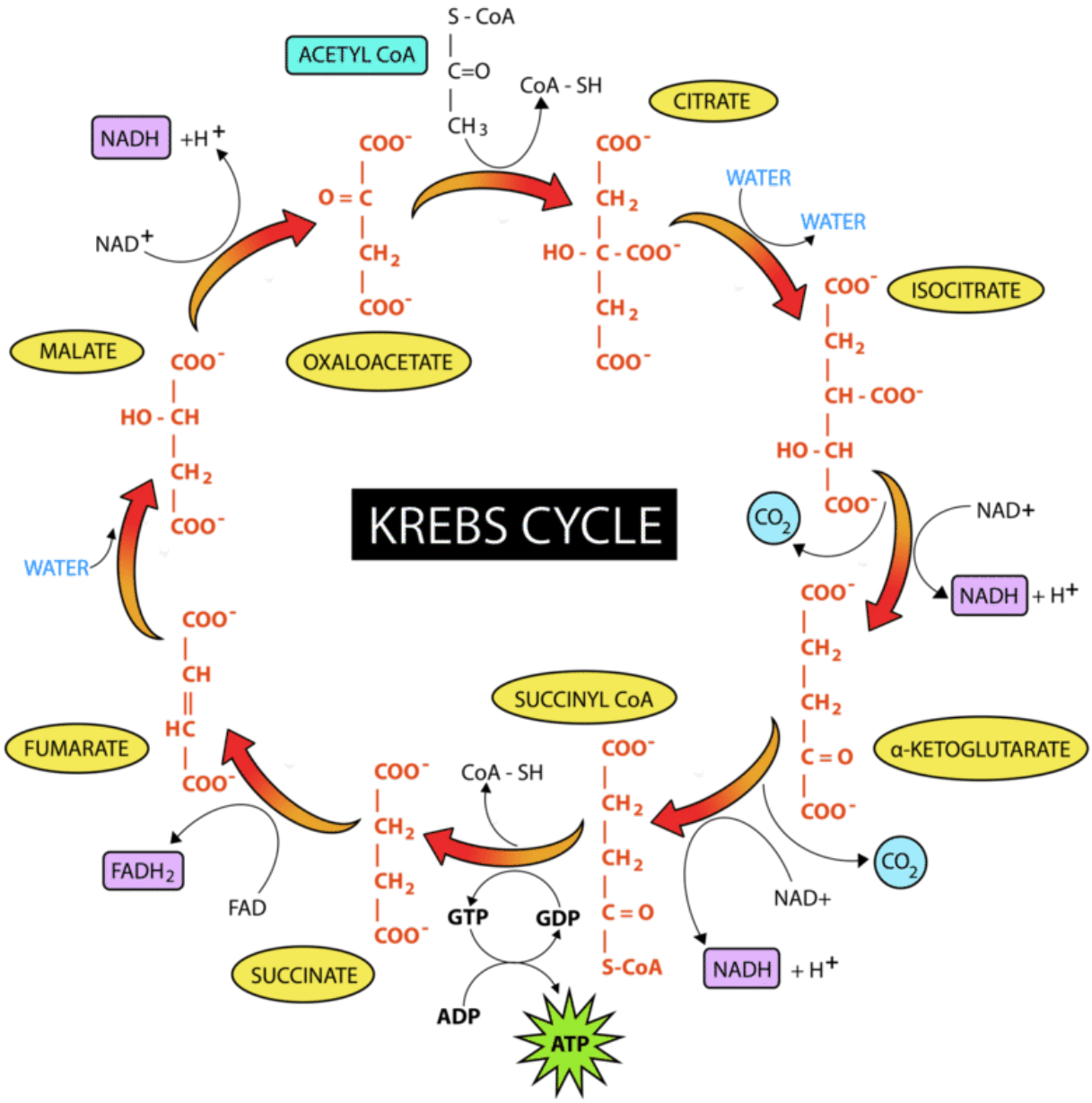


FIGURE 19.3

The Krebs cycle completes the breakdown of glucose begun in glycolysis. If oxygen is present, pyruvate enters the mitochondria and is converted to AcetylCoA. AcetylCoA enters the cycle by combining with 4-carbon oxaloacetate. Study the diagram to confirm that each turn of the cycle (two for each glucose) stores energy in 3 $NADH+H^+$, one $FADH_2$, and one ATP (from GTP), and releases 2 CO_2. The Krebs cycle is also known as the Citric Acid Cycle or the tricarboxylic acid cycle (TCA cycle).

Summary

- Oxygen produced by the first photosynthetic organisms was probably toxic to early anaerobic life forms, but later organisms evolved a way to harness the power of oxygen to make ATP.
- In eukaryotic cells, if oxygen is present, the pyruvate molecules produced by glycolysis in the cytoplasm enter the mitochondria for further breakdown and energy release. The Krebs Cycle harnesses the energy which remains in pyruvate after glycolysis.
- The Krebs Cycle removes energy from citric acid in small steps, storing it in diverse energy carrier molecules: ATP, NADH and $FADH_2$.
- The Krebs Cycle produces two molecules of CO_2 per Acetyl-CoA, completing the breakdown of glucose.

Review

1. Explain why the appearance of oxygen in the atmosphere between two and three billions of years ago was both "good news and bad news" for life on Earth.
2. In eukaryotic cells when oxygen is present, what is the fate of the pyruvate produced in glycolysis?
3. Define the Krebs cycle.
4. Trace the six carbon atoms originally from acetyl-CoA through the Krebs Cycle. Trace the flow of energy from the pyruvates produced in glycolysis through the Krebs Cycle.
5. How many energy carriers are produced during the Krebs cycle per acetyl-CoA?

References

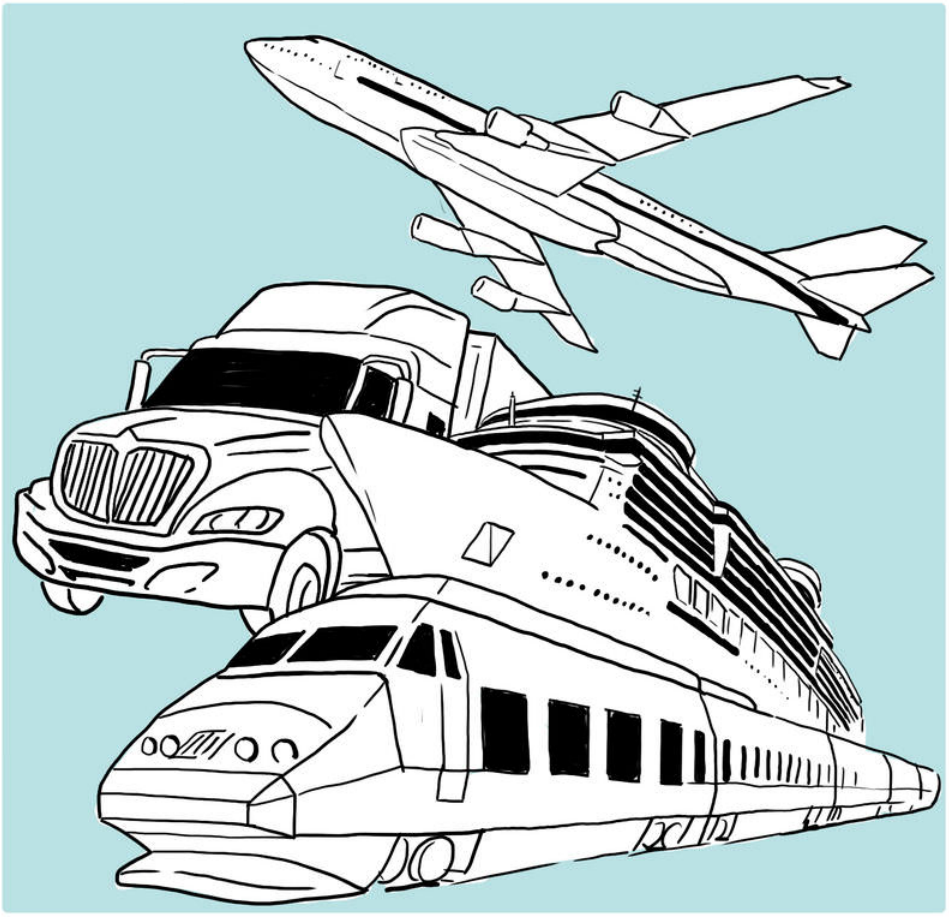
1. User:Tameeria/Wikipedia. http://commons.wikimedia.org/wiki/File:Oxygen_atmosphere.png . Public Domain
2. Joy Sheng. CK-12 Foundation . CC BY-NC 3.0
3. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0

CONCEPT 20

The Electron Transport Chain - Advanced

Learning Objectives

- Recognize that electron transport chain is the third and final stage of aerobic cellular respiration.
- Describe how chemiosmotic gradients in mitochondria store energy to produce ATP.
- Identify the role of oxygen in making stored chemical-bond energy available to cells.



Train, truck, boat, or plane?

What do these have in common? They are ways to transport. And they all use a lot of energy. To make ATP, energy must be "transported" - first from glucose to NADH, and then somehow passed to ATP. How is this done? With an electron transport chain, the third stage of aerobic respiration. This third stage uses energy to make energy.

The Electron Transport Chain: ATP for Life in the Fast Lane

At the end of the Krebs Cycle, energy from the chemical bonds of glucose is stored in diverse energy carrier molecules: four ATPs, but also two $FADH_2$ and ten NADH molecules. The primary task of the last stage of

cellular respiration, the **electron transport chain**, is to transfer energy from the electron carriers to even more ATP molecules, the "batteries" which power work within the cell.

Pathways for making ATP in stage 3 of aerobic respiration closely resemble the electron transport chains used in photosynthesis. In both electron transport chains, energy carrier molecules are arranged in sequence within a membrane so that energy-carrying electrons cascade from one to another, losing a little energy in each step. In both photosynthesis and aerobic respiration, the energy lost is harnessed to pump hydrogen ions into a compartment, creating an **electrochemical gradient** or **chemiosmotic gradient** across the enclosing membrane. And in both processes, the energy stored in the chemiosmotic gradient is used with **ATP synthase** to build ATP.

For aerobic respiration, the electron transport chain or "respiratory chain" is embedded in the inner membrane of the mitochondria (**Figure** 20.1). The $FADH_2$ and NADH molecules produced in glycolysis and the Krebs Cycle, donate high-energy electrons to energy carrier molecules within the membrane. As they pass from one carrier to another, the energy they lose is used to pump hydrogen ions into the mitochondrial intermembrane space, creating an electrochemical gradient. Hydrogen ions flow "down" the gradient - from outer to inner compartment - through the ion channel/enzyme ATP synthase, which transfers their energy to ATP. Note the paradox that it requires energy to create and maintain a concentration gradient of hydrogen ions that are then used by ATP synthase to create stored energy (ATP). In broad terms, it takes energy to make energy. Coupling the electron transport chain to ATP synthesis with a hydrogen ion gradient is **chemiosmosis**, first described by Nobel laureate Peter D. Mitchell. This process, the use of energy to phosphorylate ADP and produce ATP is also known as **oxidative phosphorylation.**

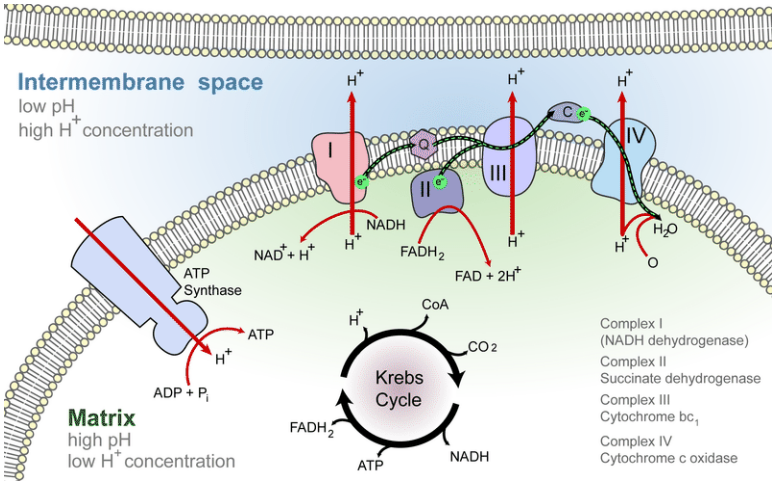


FIGURE 20.1

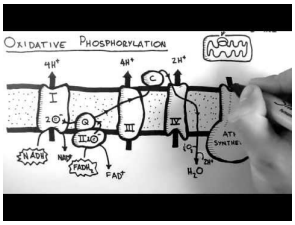
The third stage of cellular respiration uses the energy stored during the earlier stages in NADH and $FADH_2$ to make ATP. Electron transport chains embedded in the mitochondrial inner membrane capture high-energy electrons from the carrier molecules and use them to concentrate hydrogen ions in the intermembrane space. Hydrogen ions flow down their electrochemical gradient back into the matrix through ATP synthase channels which capture their energy to convert ADP to ATP. Notice that the process regenerated NAD^+, supplying the electron acceptor molecule needed in glycolysis.

After passing through the electron transport chain, low-energy electrons and low-energy hydrogen ions combine with oxygen to form water. Thus, oxygen's role is to drive the entire set of ATP-producing reactions within the mitochondrion by accepting "spent" hydrogens. Oxygen is the final electron acceptor; no part of the process - from the Krebs Cycle through electron transport chain - can happen without oxygen.

The electron transport chain can convert the energy from one glucose molecule's worth of $FADH_2$ and NADH + H^+ into as many as 34 ATP. When the four ATP produced in glycolysis and the Krebs Cycle are added, the total 0f 38 ATP fits the overall equation for aerobic cellular respiration:

$$6O_2 + \underbrace{C_6H_{12}O_6}_{\text{stored chemical energy, deliverable}} + 38ADP + 38P_i \longrightarrow \underbrace{38ATP}_{\text{stored chemical energy, usable}} + 6CO_2 + 6H_2O$$

Aerobic respiration is complete. If oxygen is available, cellular respiration transfers the energy from one molecule of glucose to 38 molecules of ATP, releasing carbon dioxide and water as waste. "Deliverable" food energy has become energy which can be used for work within the cell - transport within the cell, pumping ions and molecules across membranes, and building large organic molecules. Can you see how this could lead to "life in the fast lane" compared to anaerobic respiration (glycolysis alone)?



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Summary

- The third and final stage of aerobic cellular respiration, the electron transport chain, accounts for most of the ATP.
- Stage 3 transfers the energy from NADH and $FADH_2$ to make ATP.
- During electron transport, energy is used to pump hydrogen ions across the mitochondrial inner membrane, from the matrix into the intermembrane space.
- A chemiosmotic gradient causes hydrogen ions to flow back across the mitochondrial membrane into the matrix, through ATP synthase, producing ATP.
- When ATP from glycolysis and the Krebs Cycle are added, a total of 38 ATP result from aerobic respiration of one molecule of glucose.

Review

1. Summarize the overall task of Stage 3 of aerobic respiration.
2. Explain the principle of chemiosmosis.
3. Name the three stages of aerobic cellular respiration. Then write the overall equation, and identify which stage:
    a. Uses each reactant.
    b. Requires each necessary condition.
    c. Produces each product.

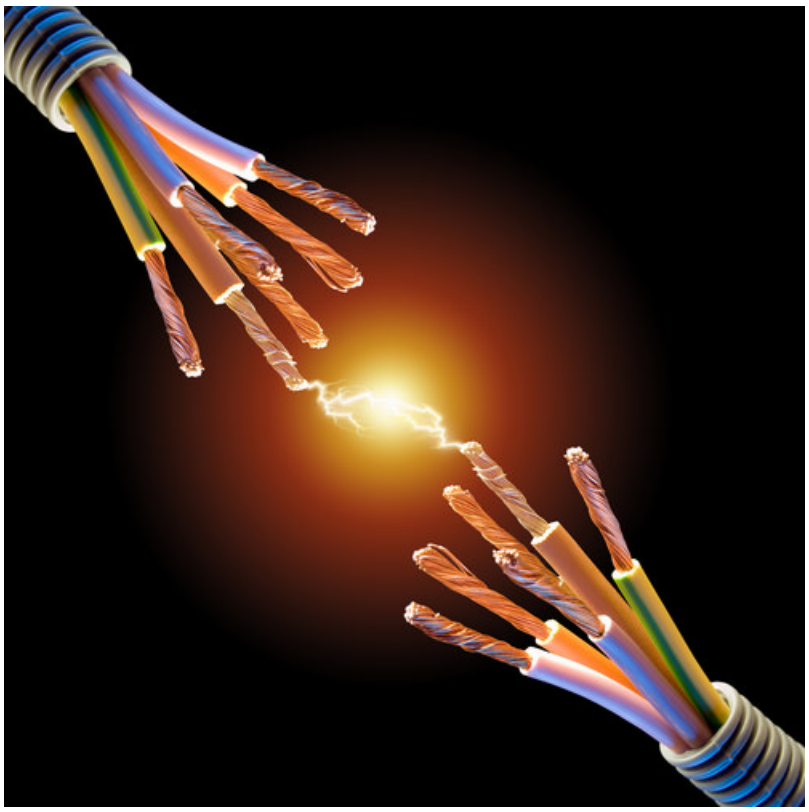
References

1. Mariana Ruiz Villarreal (LadyofHats) for the CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0

CONCEPT 21 The Electrochemical Gradient - Advanced

Learning Objectives

- Describe the electrochemical gradient.



Do you really have electricity flowing through your body?

Yes, you do. These electrical signals allow information to flow through the nervous system extremely rapidly. And it all starts with the formation of an electrochemical gradient.

The Electrochemical Gradient

The active transport of ions across the cell membrane causes an electrical gradient to build up across this membrane. The number of positively charged ions outside the cell is usually greater than the number of positively charged ions in the cytosol. This results in a relatively negative charge on the inside of the membrane, and a positive charge on the outside. This difference in charges causes a voltage to exist across the membrane. **Voltage** is electrical potential energy that is caused by a separation of opposite charges, in this case across the membrane. The voltage across a membrane is the **membrane potential**. Membrane potential is very important for the conduction of electrical impulses along nerve cells. The membrane potential of a cell at rest is known as its **resting potential**, and is discussed below. A non-excited nerve cell is an example of a cell at rest.

Because of the ion gradient, there are less positive ions inside the cell, the inside of the cell is negative compared to outside the cell. This resulting membrane potential favors the movement of positively charged ions (cations) into the cell, and the movement of negative ions (anions) out of the cell. So, there are two forces that drive the diffusion of ions across the plasma membrane—a chemical force (the ions' concentration gradient), and an electrical force (the effect of the membrane potential on the ions' movement). These two forces working together are called an **electrochemical gradient**.

The electrochemical gradient determines the direction an ion moves by diffusion or active transport across a membrane. In mitochondria and chloroplasts, **proton gradients** are used to generate a **chemiosmotic potential** that is also known as a **proton motive force**, due to both the proton gradient and voltage gradient across the membrane. This potential energy is used for the synthesis of ATP by **oxidative phosphorylation**.

The Resting Potential

In order to maintain the membrane potential, cells maintain a low concentration of sodium ions (Na^+) and high levels of potassium ions (K^+) within the cell (intracellular). The sodium-potassium pump moves three Na^+ ions out of the cell and brings two K^+ ions into the cell. This essentially removes one positive charge from the intracellular space. The resulting membrane potential is known as the resting potential.

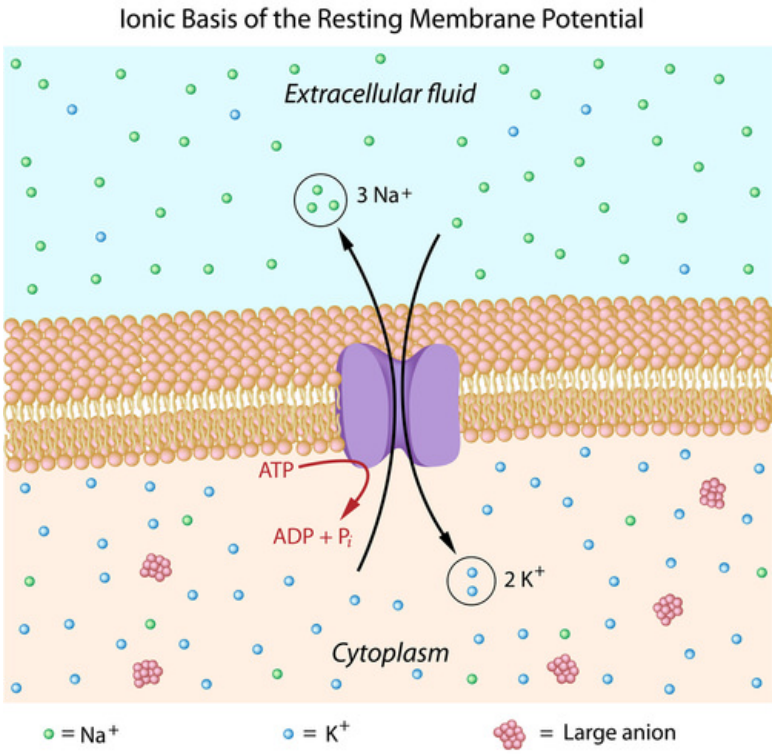


FIGURE 21.1

This diagram shows how ions maintain the membrane potential. The sodium-potassium pump is shown in the membrane, transporting three Na^+ ions (green) out of the cell and bringing two K^+ ions (blue) into the cell.

The Ion Gradient

The electrochemical potential across a membrane determines the tendency of an ion to cross the membrane. The membrane may be that of a cell or organelle or other sub cellular compartment. The electrochemical potential arises from three factors:

1. the difference in the concentration of the ions on either side of the membrane,

2. the charge of the ions (for example Na^+, Ca^{++}, Cl^-), and
3. the difference in voltage between the two sides of the membrane (the transmembrane potential).

Cotransport of ions by symporters and antiporter carriers is commonly used to actively move ions across biological membranes. Transmembrane ATPases are often involved in maintaining ion gradients. The Na+/K+ ATPase uses ATP to build and maintain a sodium ion gradient and a potassium ion gradient.

Proton Gradients and ATP synthase

One particular ion gradient with biological significance is the proton (H^+) gradient. This type of gradient is established through active transport involving proton pumps. The proton gradient is used during photosynthesis and cellular respiration to generate a chemiosmotic potential, or proton motive force. This potential energy is used for the synthesis of ATP by oxidative phosphorylation. The proton gradient can also be used to store energy for heat production and flagellar rotation.

The energy held within the proton gradient can be used to synthesize ATP. **ATP synthase** is a transmembrane enzyme that provides energy for the cell to use by producing ATP. The protein has two distinct regions, F_0 and F_1. The F_0 domain is embedded within the membrane, while the F_1 domain is above the membrane, inside the matrix of the mitochondria, or the stroma of the chloroplast. The F_0 region is the proton pore, allowing hydrogen ions to diffuse across the membrane. The F_1 region of the protein has ATP synthesis activity, catalyzing the formation of ATP from ADP and inorganic phosphate. Hence, ATP synthase is both an ion channel protein and enzyme. The synthesis reaction is driven by the proton flow, which forces the rotation of a part of the enzyme; the ATP synthase is a rotary mechanical motor. Bacteria may also have a version of this enzyme, where it, of course, is embedded in the cell membrane.

During electron transport within the mitochondria (during cellular respiration) or chloroplast (during photosynthesis) (discussed in the *Concept Metabolism (Advanced)* concept), a proton gradient is formed when protons are pumped across the membrane by active transport. These hydrogen ions flow back across the membrane by facilitated diffusion through ATP synthase, releasing energy which is then used to convert ADP to ATP (by phosphorylation). **Chemiosmosis** is the diffusion of protons across the biological membrane through ATP synthase, due to a proton gradient that forms across the membrane during electron transport.

Summary

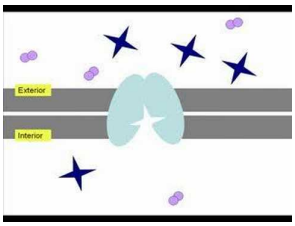
- The voltage across a membrane is the membrane potential and the membrane potential of a cell at rest is the resting potential.
- The electrochemical gradient is composed of a chemical force (the ions' concentration gradient) and an electrical force (the effect of the membrane potential on the ions' movement).
- Chemiosmosis is the diffusion of protons across the biological membrane through ATP synthase, due to a proton gradient that forms across the membrane.

Review

1. Define the electrochemical gradient.
2. Describe the role of ATP synthase.
3. What is chemiosmosis?

Explore More

Use this resource to answer the questions that follow.



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1. Why does an electrochemical gradient form across a cell membrane?
2. Why are positive ions attracted to the inside of a cell?
3. How do ions flow in and out of a cell?

References

1. Image copyright Alila Medical Media, 2014. Ionic basis of resting membrane potential . Used under license from Shutterstock.com

CONCEPT 22 Diversity in the Living World

Organization of Living Things

How would you classify a horse?

It's easy enough to classify the horse in the animal kingdom. That's one level of classification. But what other groups does the horse belong to? Horses also belong to a class—the mammals. These animals all have fur and nurse their young.

Classification of Life

When you see an organism that you have never seen before, you probably put it into a group without even thinking. If it is green and leafy, you probably call it a plant. If it is long and slithers, you probably call it as a snake. How do you make these decisions? You look at the physical features of the organism and think about what it has in common with other organisms.

Scientists do the same thing when they **classify**, or put into categories, living things. Scientists classify organisms not only by their physical features, but also by how closely related they are. Lions and tigers look like each other more than they look like bears, but are lions and tigers related? Evolutionarily speaking, yes. **Evolution** is the change in a **species** over time. Lions and tigers both evolved from a common ancestor. So it turns out that the two cats are actually more closely related to each other than to bears. How an organism looks and how it is related to other organisms determines how it is classified.

Linnaean System of Classification

People have been concerned with classifying organisms for thousands of years. Over 2,000 years ago, the Greek philosopher Aristotle developed a classification system that divided living things into several groups that we still use today, including mammals, insects, and reptiles.

Carolus (Carl) Linnaeus (1707-1778) (**Figure** 26.1) built on Aristotle's work to create his own classification system. He invented the way we name organisms today, with each organism having a two word name. Linnaeus is considered the inventor of modern **taxonomy**, the science of naming and grouping organisms.

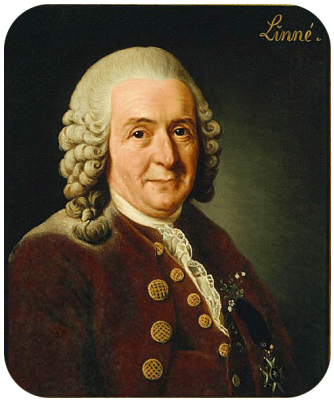

FIGURE 22.1

In the 18th century, Carl Linnaeus invented the two-name system of naming organisms (genus and species) and introduced the most complete classification system then known.

Linnaeus developed **binomial nomenclature**, a way to give a scientific name to every organism. In this system, each organism receives a two-part name in which the first word is the **genus** (a group of species), and the second word refers to one species in that genus. For example, a coyote's species name is *Canis latrans*. *Latrans* is the species and *Canis* is the genus, a larger group that includes dogs, wolves, and other dog-like animals. Here is another example: the red maple, *Acer rubra*, and the sugar maple, *Acer saccharum*, are both in the same genus and they look similar (**Figure** 26.2). Notice that the genus is capitalized and the species is not, and that the whole scientific name is in italics. The names may seem strange, but the names are written in a language called Latin.

FIGURE 22.2

These leaves are from two different species of trees in the *Acer*, or maple, genus. The green leaf (*far left*) is from the sugar maple, and the red leaf (*center*) are from the red maple. One of the characteristics of the maple genus is winged seeds (*far right*).

Modern Classification

Modern taxonomists have reordered many groups of organisms since Linnaeus. The main categories that biologists use are listed here from the most specific to the least specific category (**Figure** 22.3). All organisms can be classified into one of three **domains**, the least specific grouping. The three domains are Bacteria, Archaea, and Eukarya. The Kingdom is the next category after the **Domain**. All life is divided among six kingdoms: Kingdom Bacteria, Kingdom Archaea, Kingdom Protista, Kingdom Plantae, Kingdom Fungi, and Kingdom Animalia.

Defining a Species

Even though naming species is straightforward, deciding if two organisms are the same species can sometimes be difficult. Linnaeus defined each species by the distinctive physical characteristics shared by these organisms. But

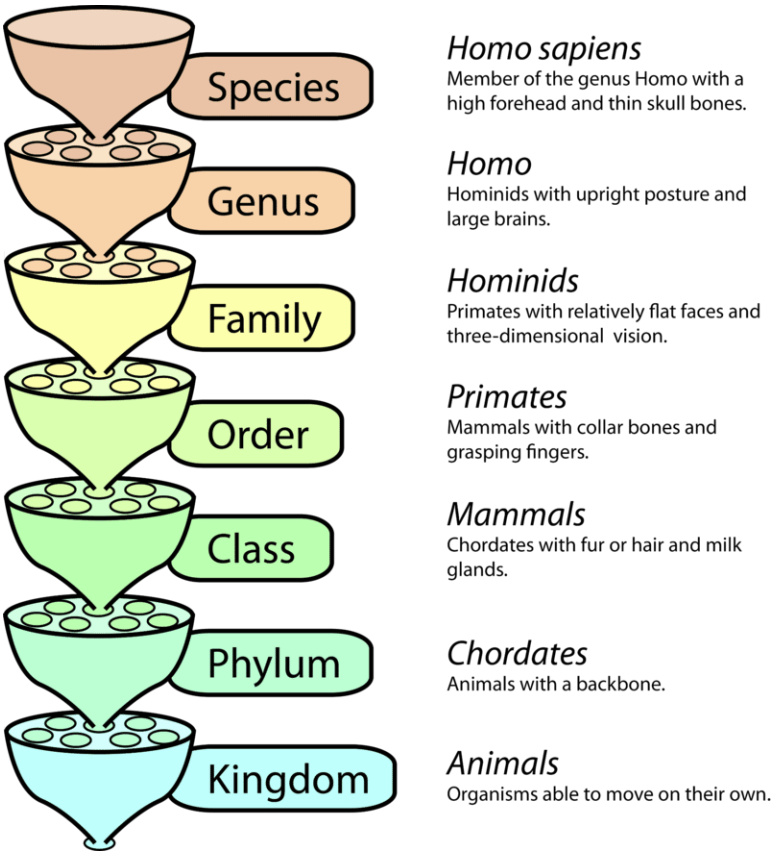

FIGURE 22.3

This diagram illustrates the classification categories for organisms, with the broadest category (kingdom) at the bottom, and the most specific category (species) at the top. We are *Homo sapiens. Homo* is the genus of great apes that includes modern humans and closely related species, and *sapiens* is the only living species of the genus.

two members of the same species may look quite different. For example, people from different parts of the world sometimes look very different, but we are all the same species (**Figure** 22.4).

So how is a species defined? A **species** is defined as a group of similar individuals that can interbreed with one another and produce fertile offspring. A species does not produce fertile offspring with other species.

FIGURE 22.4

These children are all members of the same species, *Homo sapiens.*

Summary

- Scientists have defined several major categories for classifying organisms: domain, kingdom, phylum, class, order, family, genus, and species.
- The scientific name of an organism consists of its genus and species.

Explore More I

1. What do taxonomists study? How does their work help other scientists?
2. Who was the first person we know of who developed a system to categorize things? How was this done? Is his system still used today?
3. What contribution to taxonomy did Carolus Linnaeus make?

Explore More II

Use the below activity to see specific examples of how organisms are categorized. Make sure you go through all three types of organisms so you can gain a good understanding of the level at which different types of organisms separate from each other.

- **Nova: Classifying Life** at: http://www.pbs.org/wgbh/nova/nature/classifying-life.html

Review

1. Who is the inventor of the modern classification system?
2. List the classification categories for organisms from the broadest category to the most specific.
3. What is meant by binomial nomenclature?
4. Define a species.

Taxonomy

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/163433

Watch the video at: https://vimeo.com/37353051

References

1. Alexander Roslin. Portrait of Carl Linnaeus, the inventor of modern taxonomy .
2. Left to right: Evelyn Fitzgerald; Liz West; Flickr:DaraKero_F. Leaves from the green and red maple tree, and a maple seed .
3. Peter Halasz, modified by CK-12 Foundation. Diagram of the classification categories for organisms .
4. Image copyright Monkey Business Images, 2014. This group of children are all members of the same species .

CONCEPT 23 Classification

Learning Objectives

- Define taxonomy and binomial nomenclature.
- Explain the importance of classifying organisms.
- Outline the Linnaean classification system.
- Describe a domain and list the three domains of life.

In biology, what is classification?

There are millions and millions of species, so classifying organisms into proper categories can be a difficult task. To make it easier for all scientists to do, a classification system had to be developed.

Linnaean Classification

The evolution of life on Earth over the past 4 billion years has resulted in a huge variety of species. For more than 2,000 years, humans have been trying to classify the great diversity of life. The science of classifying organisms is called **taxonomy.** Classification is an important step in understanding the present diversity and past evolutionary history of life on Earth.

All modern classification systems have their roots in the **Linnaean classification** system. It was developed by Swedish botanist Carolus Linnaeus in the 1700s. He tried to classify all living things that were known at his time. He grouped together organisms that shared obvious physical traits, such as number of legs or shape of leaves. For his contribution, Linnaeus is known as the "father of taxonomy."

The Linnaean system of classification consists of a hierarchy of groupings, called **taxa** (singular, taxon). Taxa range from the kingdom to the species (see **Figure** 24.1). The **kingdom** is the largest and most inclusive grouping. It

consists of organisms that share just a few basic similarities. Examples are the plant and animal kingdoms. The **species** is the smallest and most exclusive grouping. It consists of organisms that are similar enough to produce fertile offspring together. Closely related species are grouped together in a **genus.**

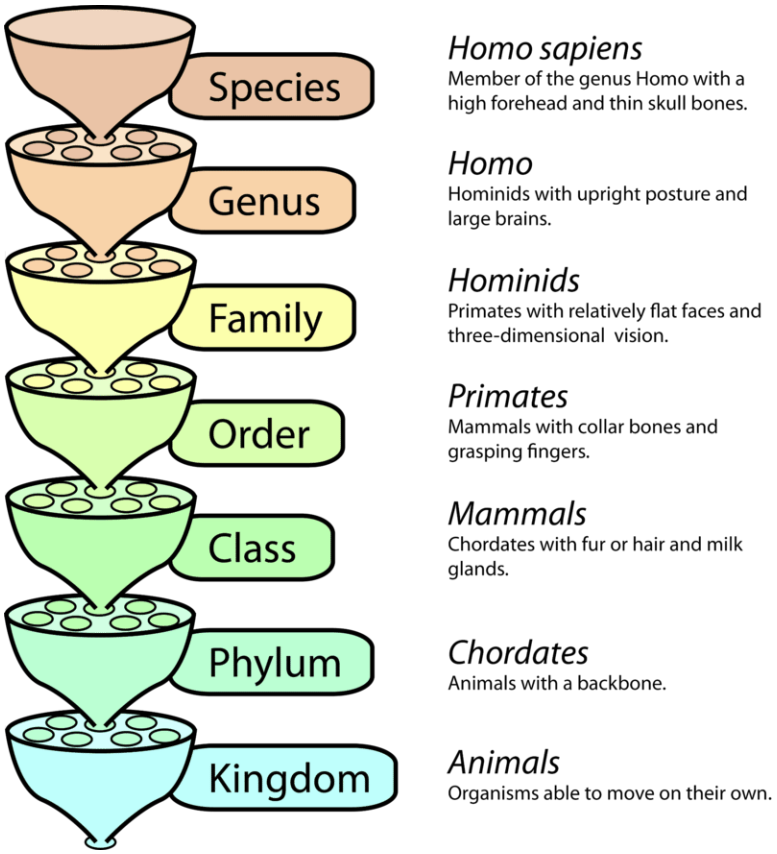

FIGURE 23.1

Linnaean Classification System: Classification of the Human Species. This chart shows the taxa of the Linnaean classification system. Each taxon is a subdivision of the taxon below it in the chart. For example, a species is a subdivision of a genus. The classification of humans is given in the chart as an example.

Binomial Nomenclature

Perhaps the single greatest contribution Linnaeus made to science was his method of naming species. This method, called **binomial nomenclature**, gives each species a unique, two-word Latin name consisting of the genus name and the species name. An example is *Homo sapiens*, the two-word Latin name for humans. It literally means "wise human." This is a reference to our big brains.

Why is having two names so important? It is similar to people having a first and a last name. You may know several people with the first name Michael, but adding Michael's last name usually pins down exactly whom you mean. In the same way, having two names uniquely identifies a species.

Revisions in Linnaean Classification

Linnaeus published his classification system in the 1700s. Since then, many new species have been discovered. The biochemistry of many organisms has also become known. Eventually, scientists realized that Linnaeus's system of classification needed revision.

A major change to the Linnaean system was the addition of a new taxon called the domain. A **domain** is a taxon that is larger and more inclusive than the kingdom. Most biologists agree there are three domains of life on Earth: Bacteria, Archaea, and Eukaryota (see **Figure** below). Both Bacteria and Archaea consist of single-celled

prokaryotes. Eukaryota consists of all eukaryotes, from single-celled protists to humans. This domain includes the Animalia (animals), Plantae (plants), Fungi (fungi), and Protista (protists) kingdoms.

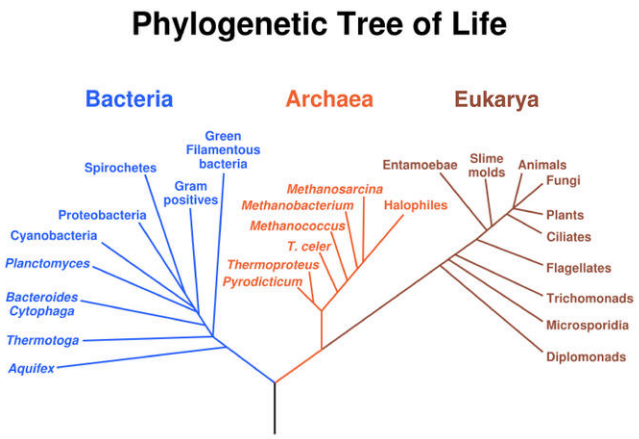

FIGURE 23.2

This phylogenetic tree is based on comparisons of ribosomal RNA base sequences among living organisms. The tree divides all organisms into three domains: Bacteria, Archaea, and Eukarya. Humans and other animals belong to the Eukarya domain. From this tree, organisms that make up the domain Eukarya appear to have shared a more recent common ancestor with Archaea than Bacteria.

MEDIA

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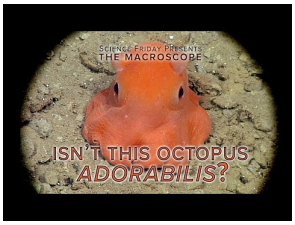
Science Friday: Isn't this Octopus Adorable?

What do you call a tiny octopus with big eyes, gelatinous skin and is cute as a button? Nobody knows quite yet! In this video by Science Friday, Stephanie Bush aims to classify and name this presently undescribed deep-sea cephalopod.



MEDIA

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Summary

- Classification is an important step in understanding life on Earth.
- All modern classification systems have their roots in the Linnaean classification system.
- The Linnaean system is based on similarities in obvious physical traits. It consists of a hierarchy of taxa, from the kingdom to the species.
- Each species is given a unique two-word Latin name.
- The recently added domain is a larger and more inclusive taxon than the kingdom.

Review

1. What is taxonomy?
2. Define taxon and give an example.
3. What is binomial nomenclature? Why is it important?
4. What is a domain? What are the three domains of life on Earth?
5. Create a taxonomy, modeled on the Linnaean classification system, for a set of common objects, such as motor vehicles, tools, or office supplies. Identify the groupings that correspond to the different taxa in the Linnaean system.

References

1. Christopher Auyeung (based on image by Peter Halasz). Levels in the Linnaean classification system . CC BY-NC 3.0 (original image in public domain)
2. . http://en.wikipedia.org/wiki/Image:Phylogenetic_tree.svg . Public Domain

CONCEPT 24 Five Kingdom Classification

In biology, what would classification refer to?

There are millions and millions of species, so classifying organisms into proper categories can be a difficult task. To make it easier for all scientists to do, a classification system had to be developed.

Linnaean Classification

The evolution of life on Earth over the past 4 billion years has resulted in a huge variety of species. For more than 2,000 years, humans have been trying to classify the great diversity of life. The science of classifying organisms is called **taxonomy.** Classification is an important step in understanding the present diversity and past evolutionary history of life on Earth.

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The Linnaean system of classification consists of a hierarchy of groupings, called **taxa** (singular, taxon). Taxa range from the kingdom to the species (see **Figure** 24.1). The **kingdom** is the largest and most inclusive grouping. It consists of organisms that share just a few basic similarities. Examples are the plant and animal kingdoms. The **species** is the smallest and most exclusive grouping. It consists of organisms that are similar enough to produce fertile offspring together. Closely related species are grouped together in a **genus.**

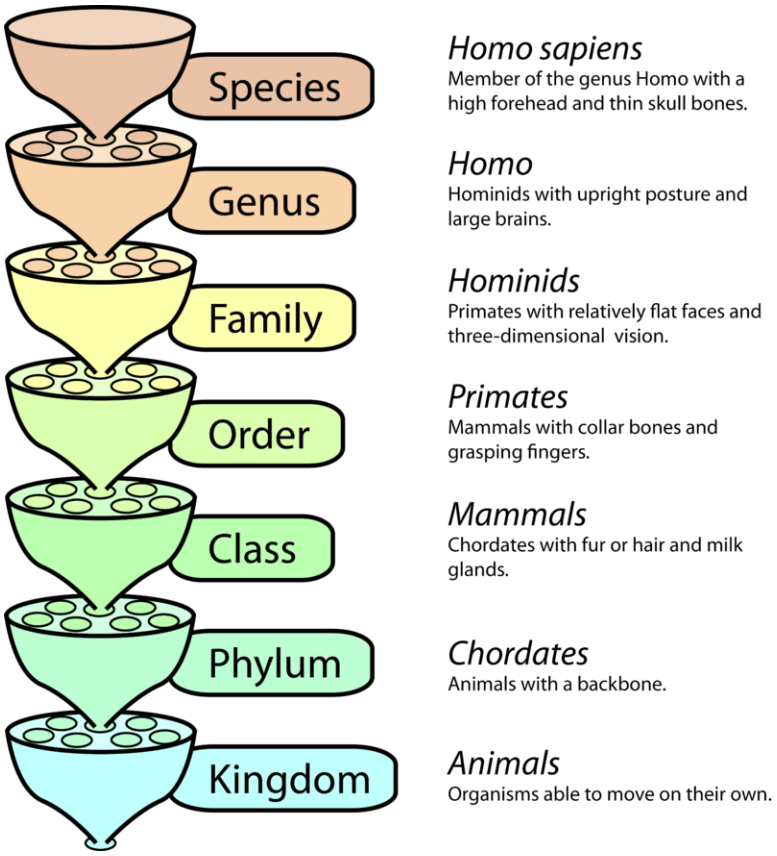

FIGURE 24.1

Linnaean Classification System: Classification of the Human Species. This chart shows the taxa of the Linnaean classification system. Each taxon is a subdivision of the taxon below it in the chart. For example, a species is a subdivision of a genus. The classification of humans is given in the chart as an example.

Binomial Nomenclature

Perhaps the single greatest contribution Linnaeus made to science was his method of naming species. This method, called **binomial nomenclature**, gives each species a unique, two-word Latin name consisting of the genus name and the species name. An example is *Homo sapiens*, the two-word Latin name for humans. It literally means "wise human." This is a reference to our big brains.

Why is having two names so important? It is similar to people having a first and a last name. You may know several people with the first name Michael, but adding Michael's last name usually pins down exactly whom you mean. In the same way, having two names uniquely identifies a species.

References

1. Christopher Auyeung (based on image by Peter Halasz). Levels in the Linnaean classification system .

CONCEPT 25

The Linnaean System - Advanced

Learning Objectives

- Describe Linnaean taxonomy and binomial nomenclature.

How are these insects identified?

Many insects may look similar, but they are distinct. They are separated and classified due to their uniqueness. The classification of species is an extremely important aspect of biology.

The Linnaean System of Classification

The most influential classification system was developed by Carolus Linnaeus. In fact, all modern classification systems have their roots in Linnaeus' system. **Linnaeus** was a Swedish botanist who lived during the 1700s. He is known as the "father of taxonomy." Linnaeus tried to describe and classify the entire known natural world. In 1735, he published his classification system in a work called *Systema Naturae* ("System of Nature").

MEDIA

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Linnaean taxonomy divides all of nature into three kingdoms: animal, vegetable (or plant), and mineral (The mineral kingdom does not include living organisms, so it is not discussed any further here.). Both plant and animal kingdoms

are subdivided into smaller and smaller categories of organisms. An updated version of Linnaean taxonomy is shown in **Figure** 25.1.

Linnaean Classification System

The classification in **Figure** 25.1 includes a few more taxa than Linnaeus identified. However, it follows the same general plan as Linnaeus' original taxonomy. The taxa are as follows below:

- **Kingdom**—This is the highest taxon in Linnaean taxonomy, representing major divisions of organisms. Kingdoms of organisms include the plant and animal kingdoms.
- **Phylum** (plural, **phyla**)—This taxon is a division of a kingdom. Phyla in the animal kingdom include chordates (animals with an internal skeleton) and arthropods (animals with an external skeleton).
- **Class**—This taxon is a division of a phylum. Classes in the chordate phylum include mammals and birds.
- **Order**—This taxon is a division of a class. Orders in the mammal class include rodents and primates.
- **Family**—This taxon is a division of an order. Families in the primate order include hominids (apes and humans) and hylobatids (gibbons).
- **Genus**—This taxon is a division of a family. Genera in the hominid family include *Homo* (humans) and *Pan* (chimpanzees).
- **Species**—This taxon is below the genus and the lowest taxon in Linnaeus' system. Species in the *Pan* genus include *Pan troglodytes* (common chimpanzees) and *Pan paniscus* (Bonobos).

To remember the order of the taxa in Linnaean taxonomy, it may help to learn a mnemonic: a sentence to help remember a list, in which the words begin with the same letters as the taxa: k, p, c, o, f, g, and s. One sentence you could use is **King Philip Came Over For Green Sugar** or **Kings Play Chess On Fine Grain Sand.**

Table 25.1 shows the classification of the human species. The table also lists some of the physical traits that are the basis of the classification. For example, humans are members of the animal kingdom. Animals are organisms capable of independent movement. Within the animal kingdom, humans belong to the mammal class. Mammals are animals that have milk glands and either fur or hair. At each lower taxon, additional physical traits further narrow the group to which humans belong. The final grouping, the species *sapiens* (as in *Homo sapiens*), includes only organisms that have all of the traits listed in the table.

TABLE 25.1: Classification of the Human Species

Taxon	Name	Example Traits*
Kingdom	Animal	Organisms capable of moving on their own.
Phylum	Chordate	Animals with a notochord (flexible rod that supports the body - the vertebral column in humans).
Class	Mammal	Chordates with milk glands and either fur or hair.
Order	Primate	Mammals with collar bones and grasping hands with fingers.
Family	Hominid	Primates with three-dimensional vision and relatively flat faces.
Genus	*Homo*	Hominids with upright posture and large brains.
Species	*sapiens*	Members of the genus *Homo* with a high forehead and thin skull bones.

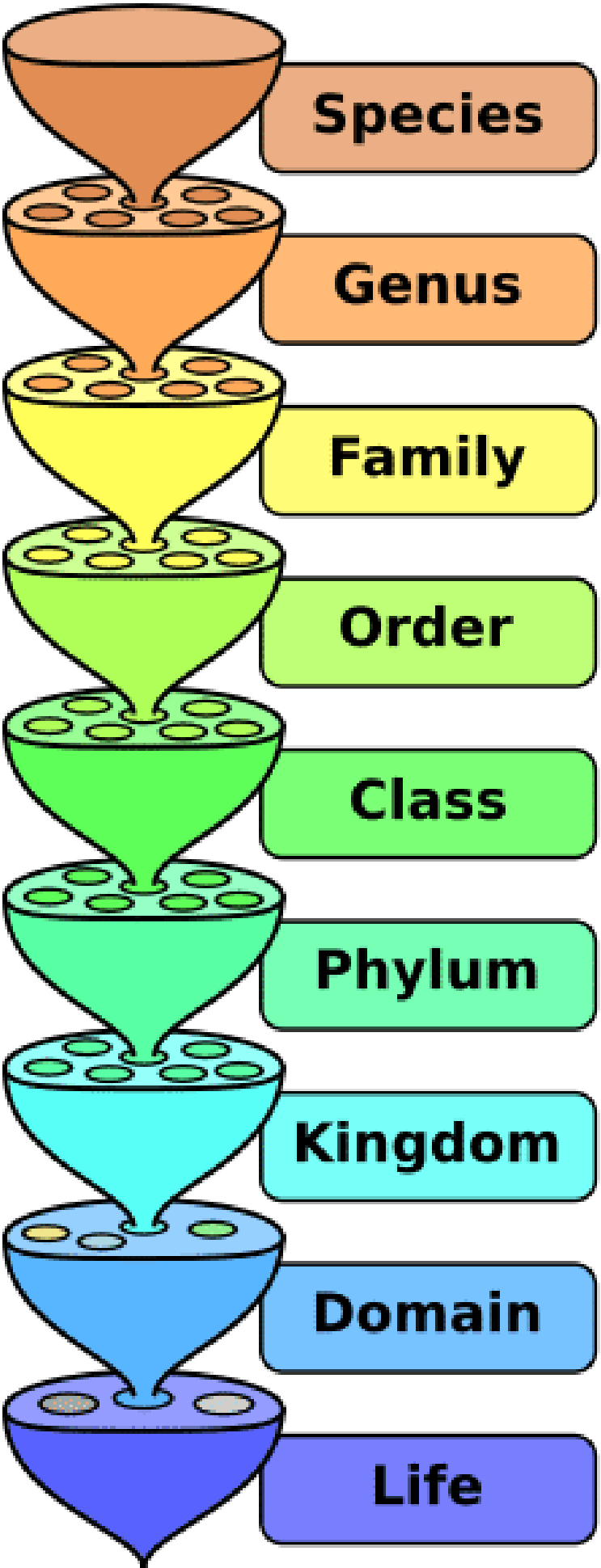

FIGURE 25.1

This is an updated version of Linnaeus' original classification system. In this classification system, organisms are classified into a hierarchy of taxa. First, all organisms are divided into kingdoms. Further subdivisions place organisms in smaller, more exclusive taxa, all the way down to the level of the species.

*Only one or two traits per taxon are listed in the table as examples. Additional traits may be needed to properly classify species.

Although Linnaeus grouped organisms according to their physical similarities, he made no claims about relationships between similar species. Linnaeus lived a century before Charles Darwin, so the theory of evolution had not yet been developed. Darwin explained how evolution, or changes in species over time, can explain the diversity of organisms (see the *Evolution* concepts). In contrast, Linnaeus (like Aristotle before him) thought each species was an unchanging "ideal type." Individual organisms that differed from the species' ideal type were considered deviant and imperfect.

Binomial Nomenclature

The single greatest contribution that Linnaeus made to science is his method of naming species. This method, called **binomial nomenclature**, gives each species a unique, two-word name (also called a scientific or Latin name). Just like we have a first and last name, organisms have a distinguishable two word name as well. The two words in the name are the genus name and the species name. For example, the human species is uniquely identified by both its genus and species names as *Homo sapiens.* No other species has this name.

Both words in a scientific name are Latin words or words that have been given Latin endings. The genus name is always written first and starts with an upper-case letter. The species name is always written second and starts with a lower-case letter. Both names are written in italics.

As another example, consider the group of organisms called *Panthera*. This is a genus in the cat family. It consists of all large cats that are able to roar. Within the genus *Panthera*, there are four different species that differ from one another in several ways. One obvious way they differ is in the markings on their fur. As shown in **Figure** 25.2, *Panthera leo* (lion species) has solid-colored fur, *Panthera tigris* (tiger species) has striped fur, and the other two *Panthera* species have fur with different types of spots. As this example shows, the genus name *Panthera* narrows a given cat's classification to big cats that roar. Adding the species name limits it to a single species of cat within this genus.

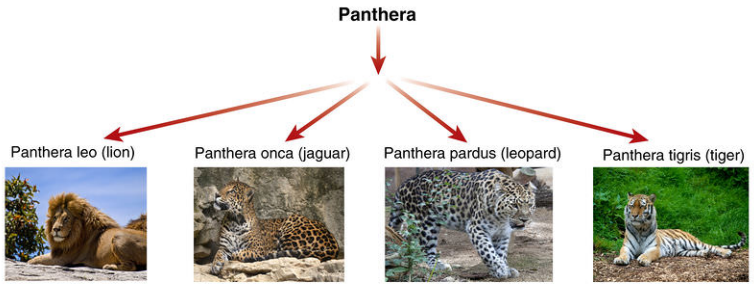

FIGURE 25.2

Species in the Genus Panthera. All four species in the Panthera genus are similar, but each is a unique type of organism, clearly identified by its combined genus and species name.

Why is Linnaeus' method of naming organisms so important? Before Linnaeus introduced his method, naming practices were not standardized. Some names were used to refer to more than one species. Conversely, the same species often had more than one name. In addition, a name could be very long, consisting of a string of descriptive words. For example, at one time, common wild roses were named *Rosa sylvestris alba cum rubore folio glabro.* Names such as this were obviously cumbersome to use and hard to remember.

For all these reasons, there was not a simple, universal name by which a species could always be identified. This led to a great deal of confusion and misunderstanding, especially as more and more species were discovered. Linnaeus changed all that by giving each species a unique and unchanging two-word name. Linnaeus's method of naming organisms was soon widely accepted and is still used today.

Changes in the Linnaean System

Linnaean taxonomy has been revised considerably since it was introduced in 1735. One reason revisions have been needed is that many new organisms have been discovered since Linnaeus' time. Another reason is that scientists started classifying organisms on the basis of evolutionary relationships rather than solely on the basis of similarities in physical traits.

Scientists have had to add several new taxa to the original Linnaean taxonomy in order to accommodate new knowledge of organisms and their evolutionary relationships. Examples of added taxa include the **subphylum**, **superfamily**, and **domain**.

- A subphylum is a division of a phylum that is higher than the class. An example of a subphylum is Vertebrates (animals with a backbone). It is a subphylum of the Chordate phylum (animals with a notochord).
- A superfamily is a taxon that groups together related families but is lower than the order. An example of a superfamily is Hominoids (apes). This superfamily consists of the Hominid family (gorillas, chimps, and humans) and the Hylobatid family (gibbons). **Figure** 25.3 shows species from both of these families of the Hominoid superfamily.
- A domain is a taxon higher than the kingdom. An example of a domain is Eukarya, which includes both plant and animal kingdoms. You can read more about domains in Lesson 14.3.

FIGURE 25.3

The Hominoid superfamily includes the Hominid and Hylobatid families. Members of the Hominid family are chimpanzees (*Pan troglodytes*, left), gorillas, orangutans, and humans. Members of the Hylobatid are all gibbons (*Nomaskus concolor*, right).

Multimedia

MEDIA

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Summary

- Linnaean taxonomy groups organisms in a hierarchy of taxa, based on similarities in physical traits.
- Linnaeus' binomial nomenclature gives each species a unique two-word name.

Review

1. What contributions did Carolus Linnaeus make to taxonomy?
2. List the order of taxa in Linnaean taxonomy from most to least inclusive.
3. What is binomial nomenclature?
4. Assume that a new organism has been discovered. It has a notochord, fur, forward-facing eyes, and grasping hands with fingers. In which taxa should the new organism be placed? Justify your answer.
5. Why was Linnaeus' naming system such an important contribution to biology?

References

1. Peter Halasz (User:Pengo/Wikipedia). http://commons.wikimedia.org/wiki/File:Biological_classification_-L_Pengo.svg . Public Domain
2. William Warby, Charles Barilleaux, Tony Hisgett, Daniel Dudek-Corrigan. Lion: https://www.flickr.com/photos/wwarby/2404546005/; Jaguar: https://www.flickr.com/photos/bontempscharly/6887508272/; Leopard: https://www.flickr.com/photos/hisgett/5017704631; Tiger: https://www.flickr.com/photos/dansapples/7131157917/ . CC BY 2.0
3. Chimpanzee: Johan Hansson; Gibbon: Blair Gannon. Chimpanzee: https://www.flickr.com/photos/plastanka/7296180988/; Gibbon: https://www.flickr.com/photos/blairgannon/7756671976/ . CC BY 2.0

CONCEPT 26 Nomenclature

Classification of Living Things

Linnaean System of Classification

People have been concerned with classifying organisms for thousands of years. Over 2,000 years ago, the Greek philosopher Aristotle developed a classification system that divided living things into several groups that we still use today, including mammals, insects, and reptiles.

Carolus (Carl) Linnaeus (1707-1778) (figure below) built on Aristotleâ[U+0080][U+0099]s work to create his own classification system. He invented the way we name organisms today, with each organism having a two word name. Linnaeus is considered the inventor of modern **taxonomy**, the science of naming and grouping organisms.

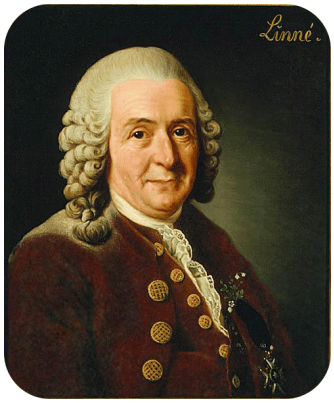


FIGURE 26.1

In the 18th century, Carl Linnaeus invented the two-name system of naming organisms (genus and species) and introduced the most complete classification system then known.

Linnaeus developed **binomial nomenclature**, a way to give a scientific name to every organism. In this system, each organism receives a two-part name in which the first word is the **genus** (a group of species), and the second word refers to one species in that genus. For example, a coyote's species name is *Canis latrans*. *Latrans* is the species and *Canis* is the genus, a larger group that includes dogs, wolves, and other dog-like animals. Here is another example: the red maple, *Acer rubra*, and the sugar maple, *Acer saccharum*, are both in the same genus and they look similar (figure below). Notice that the genus is capitalized and the species is not, and that the whole scientific name is in italics. The names may seem strange, but the names are written in a language called Latin.

FIGURE 26.2

These leaves are from two different species of trees in the *Acer*, or maple, genus. The green leaf (*far left*) is from the sugar maple, and the red leaf (*center*) are from the red maple. One of the characteristics of the maple genus is winged seeds (*far right*).

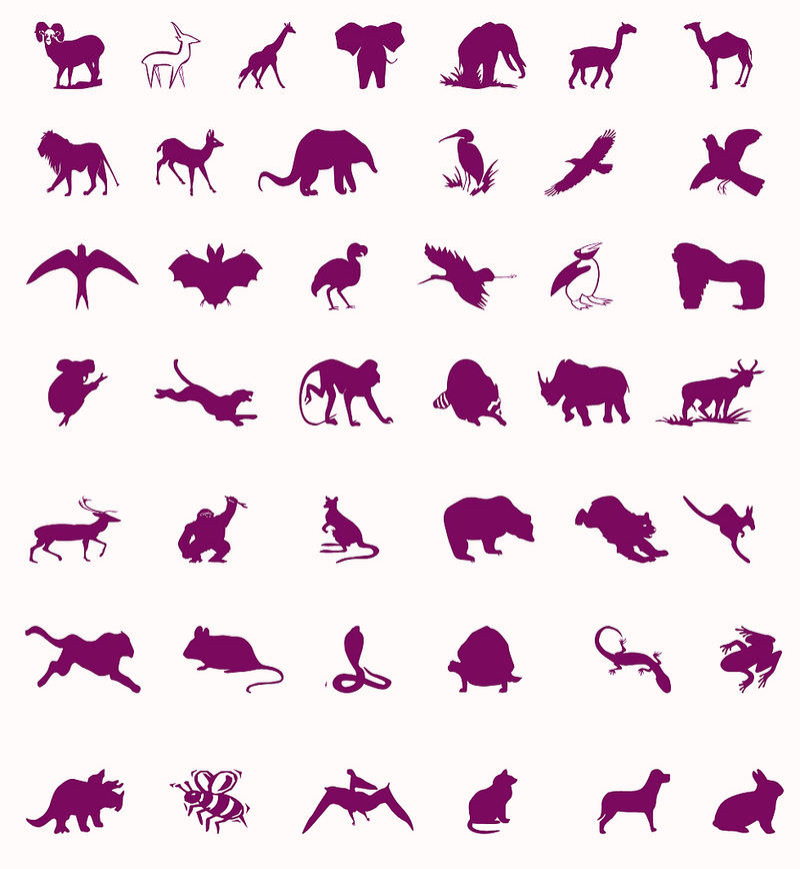
References

1. Alexander Roslin. Portrait of Carl Linnaeus, the inventor of modern taxonomy.
2. Left to right: Evelyn Fitzgerald; Liz West; Flickr:DaraKero_F. Leaves from the green and red maple tree, and a maple seed.

CONCEPT 27 Phylogeny and Cladistics

Learning Objectives

- Define clade.
- Describe phylogenetic classification.
- Interpret a phylogenetic tree and cladogram.
- Distinguish phylogenetic classification from Linnaean classification.



Can two different species be related?

Of course they can. For example, there are many different species of mammals, or of one type of mammal, such as mice. And they are all related. In other words, how close or how far apart did they separate from a common ancestor during evolution? Determining how different species are evolutionarily related can be a tremendous task.

Phylogenetic Classification

Linnaeus classified organisms based on obvious physical traits. Basically, organisms were grouped together if they looked alike. After Darwin published his theory of evolution in the 1800s, scientists looked for a way to classify organisms that showed phylogeny. **Phylogeny** is the evolutionary history of a group of related organisms. It is represented by a **phylogenetic tree**, like the one in **Figure** 27.1.

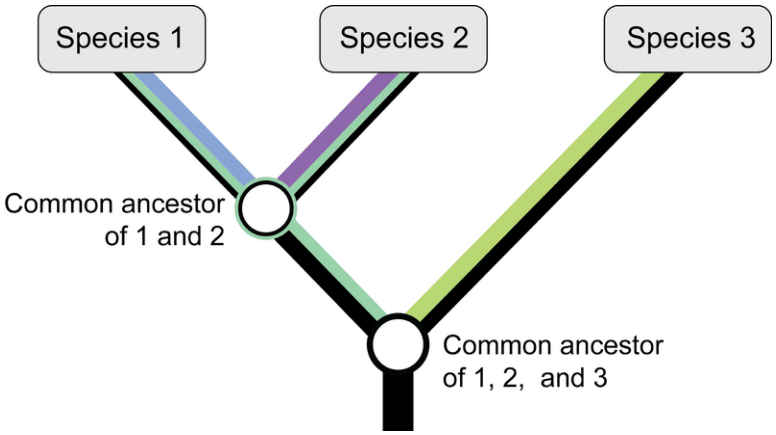


FIGURE 27.1

Phylogenetic Tree. This phylogenetic tree shows how three hypothetical species are related to each other through common ancestors. Do you see why Species 1 and 2 are more closely related to each other than either is to Species 3?

One way of classifying organisms that shows phylogeny is by using the clade. A **clade** is a group of organisms that includes an ancestor and all of its descendants. Clades are based on **cladistics**. This is a method of comparing traits in related species to determine ancestor-descendant relationships. Clades are represented by **cladograms**, like the one in **Figure** 27.2. This cladogram represents the mammal and reptile clades. The reptile clade includes birds. It shows that birds evolved from reptiles. Linnaeus classified mammals, reptiles, and birds in separate classes. This masks their evolutionary relationships.

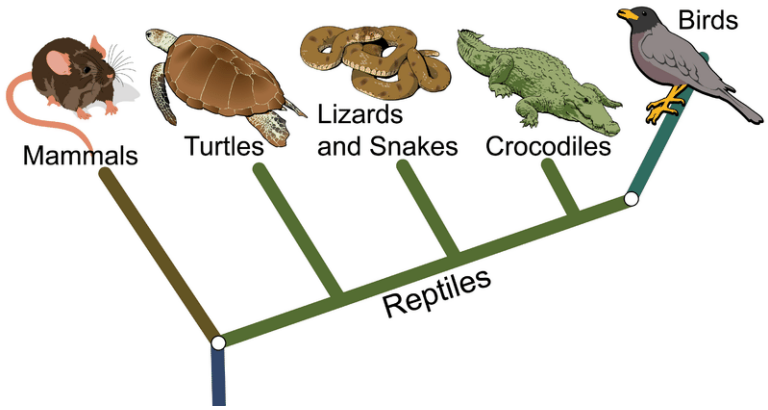


FIGURE 27.2

This cladogram classifies mammals, reptiles, and birds in clades based on their evolutionary relationships.

MEDIA

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Summary

- Phylogeny is the evolutionary history of group of related organisms. It is represented by a phylogenetic tree that shows how species are related to each other through common ancestors.
- A clade is a group of organisms that includes an ancestor and all of its descendants. It is a phylogenetic classification, based on evolutionary relationships.

Review

1. What is a clade?
2. What is cladistics, and what is it used for?
3. Explain why reptiles and birds are placed in the same clade.
4. Dogs and wolves are more closely related to each other than either is to cats. Draw a phylogenetic tree to show these relationships.

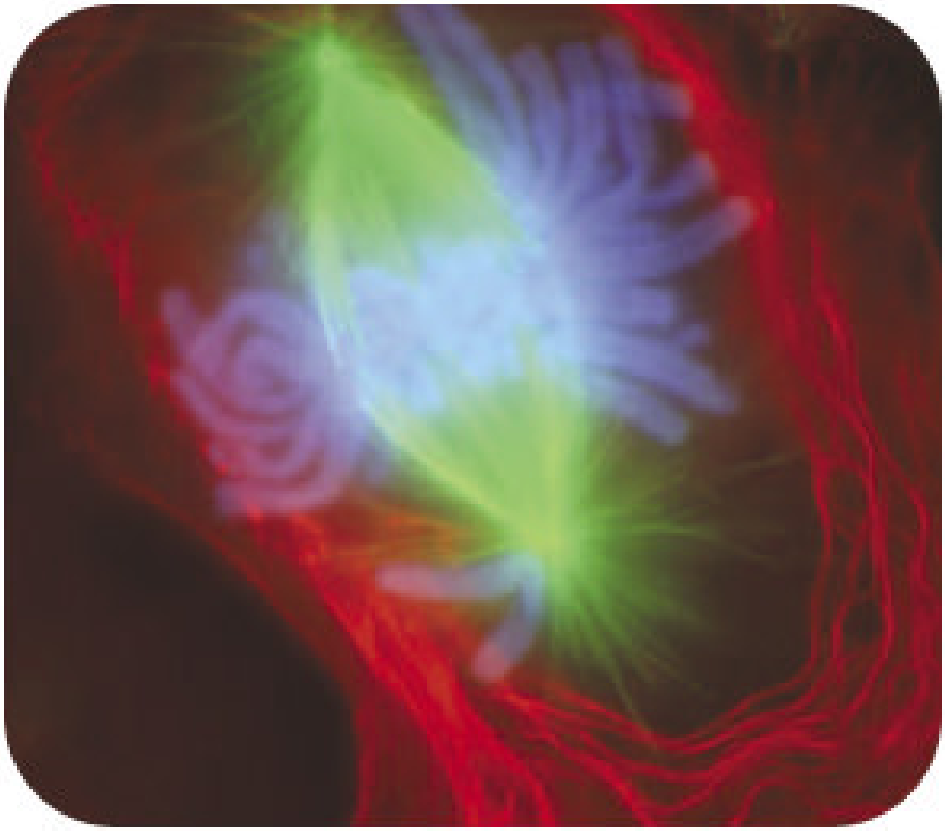
References

1. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0
2. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0

CONCEPT 28 Mitosis

Learning Objectives

- Summarize mitosis.
- Outline the phases of mitosis.
- Describe the function of the centrioles and the spindle.
- Explain the importance of the metaphase plate.
- Define cytokinesis.



What is meant by the "division of the nucleus"?

What do you think this colorful picture shows? If you guessed that it's a picture of a cell undergoing cell division, you are right. But more specifically, the image is a lung cell stained with fluorescent dyes undergoing mitosis, during early anaphase.

Mitosis and Cytokinesis

During **mitosis**, when the nucleus divides, the two chromatids that make up each chromosome separate from each other and move to opposite poles of the cell. This is shown in **Figure** 28.1.

Mitosis actually occurs in four phases. The phases are called prophase, metaphase, anaphase, and telophase. They are shown in **Figure** 28.2 and described in greater detail in the following sections.

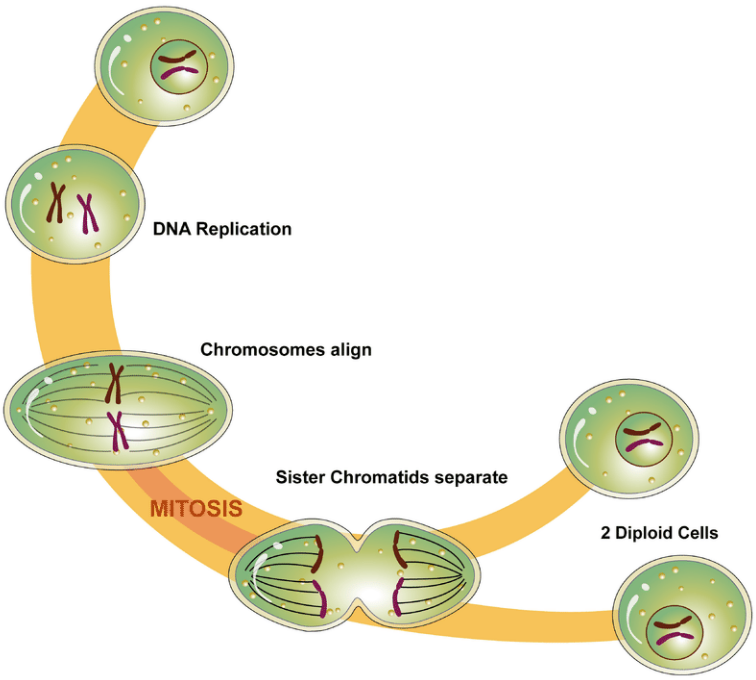


FIGURE 28.1

Mitosis is the phase of the eukaryotic cell cycle that occurs between DNA replication and the formation of two daughter cells. What happens during mitosis?

Prophase

The first and longest phase of mitosis is **prophase**. During prophase, chromatin condenses into chromosomes, and the nuclear envelope, or membrane, breaks down. In animal cells, the **centrioles** near the nucleus begin to separate and move to opposite poles (sides) of the cell. As the centrioles move, a **spindle** starts to form between them. The spindle, shown in **Figure** 28.3, consists of fibers made of microtubules.

Metaphase

During **metaphase**, spindle fibers attach to the centromere of each pair of sister chromatids (see **Figure** 28.4). The sister chromatids line up at the equator, or center, of the cell. This is also known as the metaphase plate. The spindle fibers ensure that sister chromatids will separate and go to different daughter cells when the cell divides.

Anaphase

During **anaphase**, sister chromatids separate and the centromeres divide. The sister chromatids are pulled apart by the shortening of the spindle fibers. This is like reeling in a fish by shortening the fishing line. One sister chromatid moves to one pole of the cell, and the other sister chromatid moves to the opposite pole. At the end of anaphase, each pole of the cell has a complete set of chromosomes.

Telophase

During **telophase**, the chromosomes begin to uncoil and form chromatin. This prepares the genetic material for directing the metabolic activities of the new cells. The spindle also breaks down, and new nuclear membranes (nuclear envelope) form.

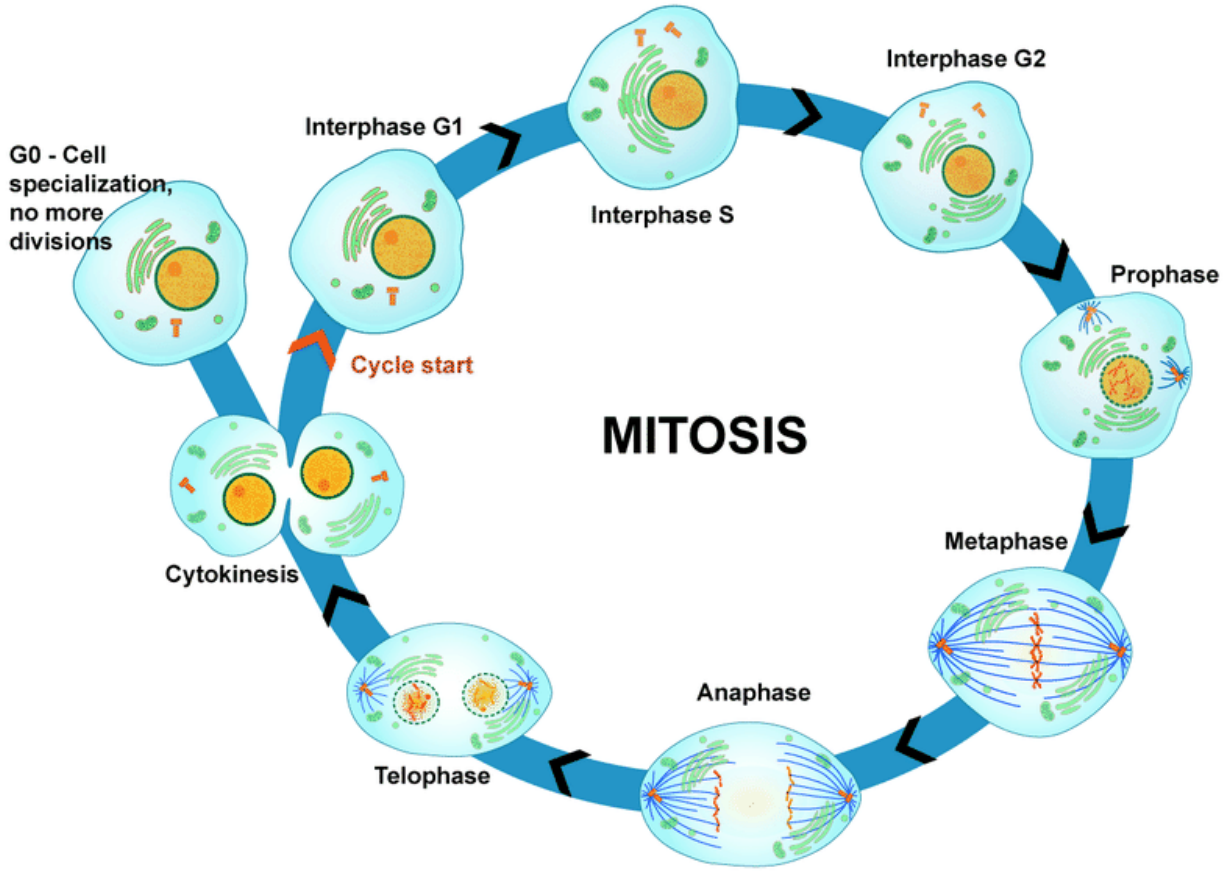


FIGURE 28.2

Mitosis in the Eukaryotic Cell Cycle. Mitosis is the multi-phase process in which the nucleus of a eukaryotic cell divides.

Cytokinesis

Cytokinesis is the final stage of cell division in eukaryotes as well as prokaryotes. During cytokinesis, the cytoplasm splits in two and the cell divides. Cytokinesis occurs somewhat differently in plant and animal cells, as shown in **Figure** 28.5. In animal cells, the plasma membrane of the parent cell pinches inward along the cell's equator until two daughter cells form. In plant cells, a cell plate forms along the equator of the parent cell. Then, a new plasma membrane and cell wall form along each side of the cell plate.

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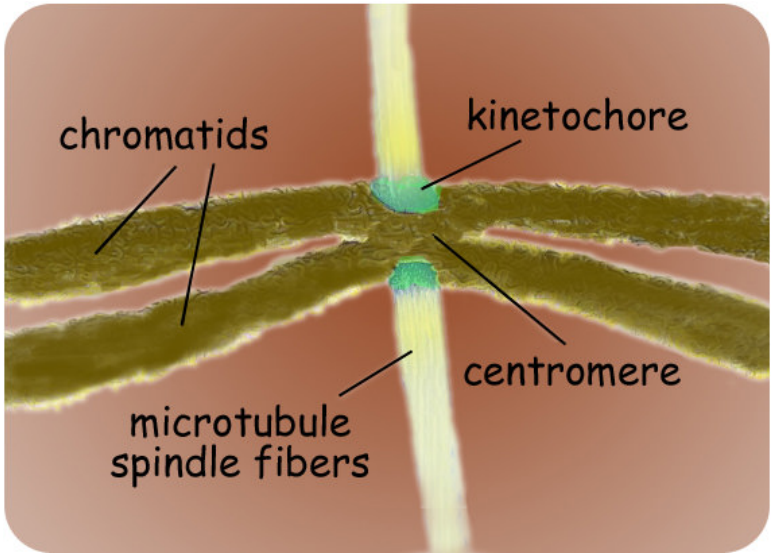


FIGURE 28.3

Spindle. The spindle starts to form during prophase of mitosis. Kinetochores on the spindle attach to the centromeres of sister chromatids.

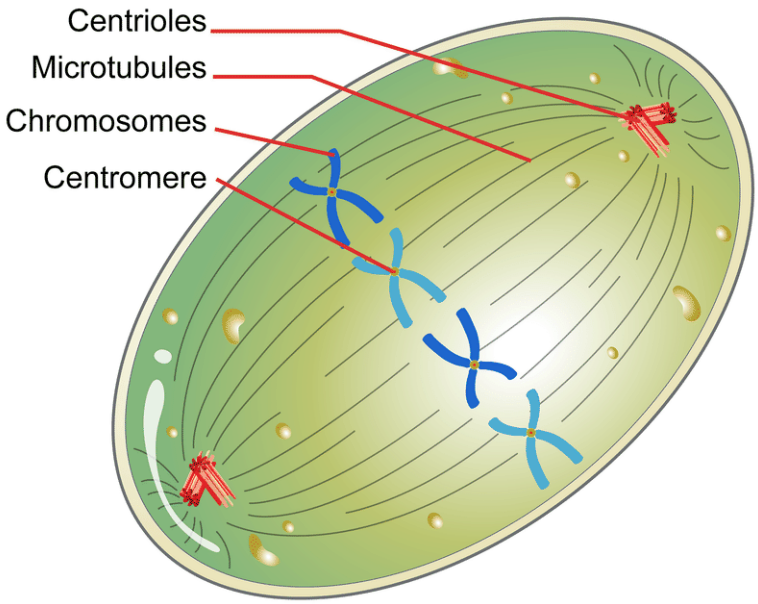


FIGURE 28.4

Chromosomes, consisting of sister chromatids, line up at the equator or middle of the cell during metaphase.

Summary

- Cell division in eukaryotic cells includes mitosis, in which the nucleus divides, and cytokinesis, in which the cytoplasm divides and daughter cells form.
- Mitosis occurs in four phases, called prophase, metaphase, anaphase, and telophase.

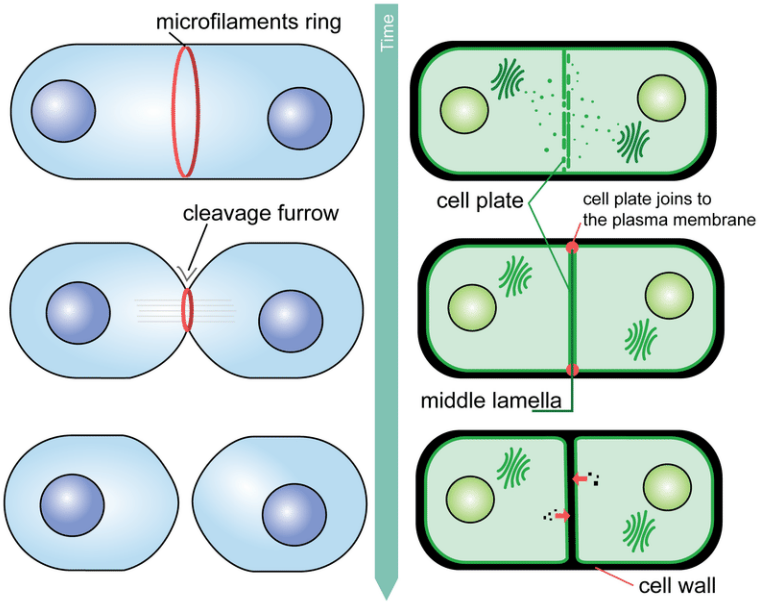


FIGURE 28.5

Cytokinesis is the final stage of eukaryotic cell division. It occurs differently in animal (left) and plant (right) cells.

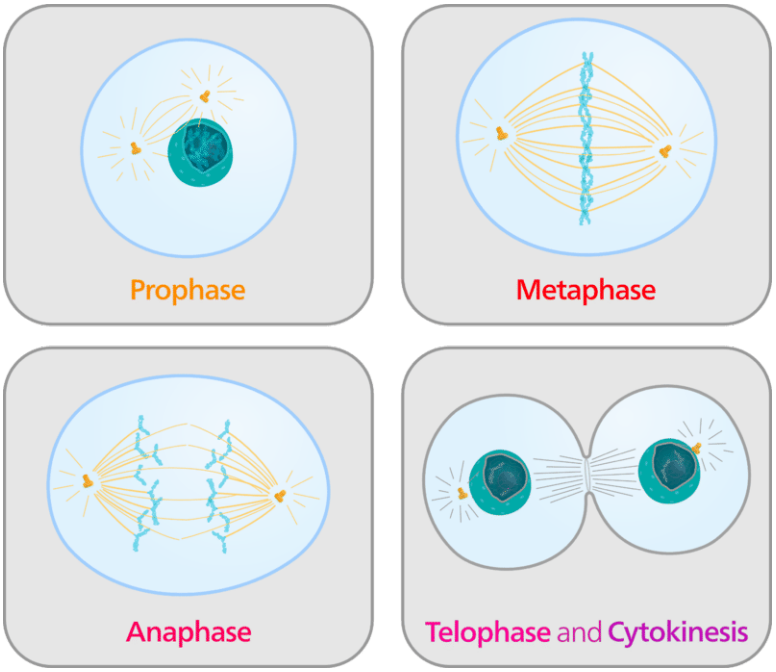


FIGURE 28.6

The four phases of mitosis. Can you describe what happens in each phase?

Review

1. List the phases of mitosis.
2. What happens during prophase of mitosis?
3. During which phase of mitosis do sister chromatids separate?
4. Describe what happens during cytokinesis in animal cells.
5. If a cell skipped metaphase during mitosis, how might this affect the two daughter cells?
6. Explain the significance of the spindle fibers in mitosis.

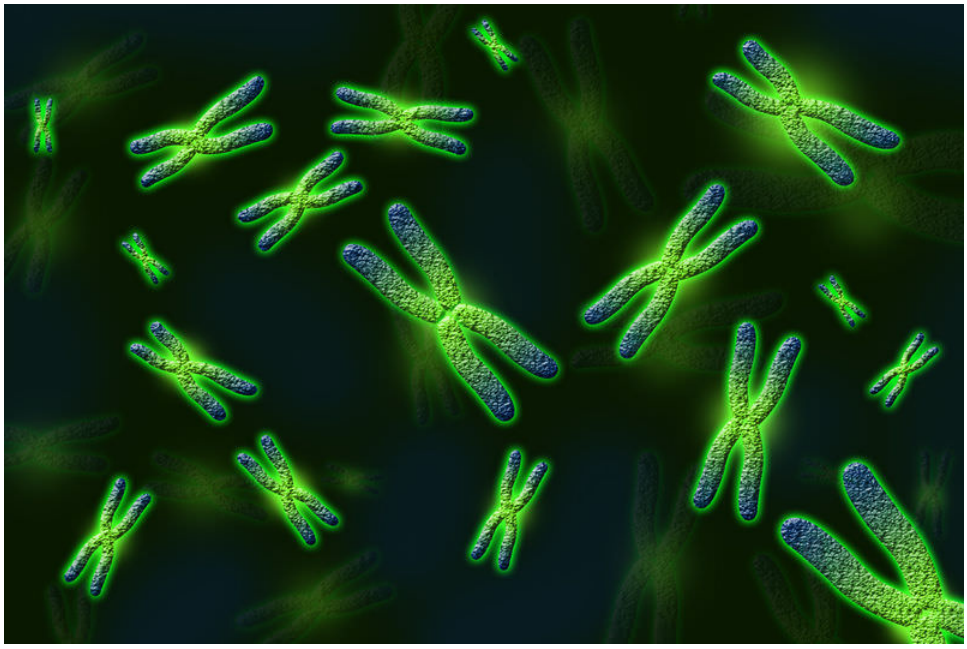
References

1. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Process of mitosis . CC BY-NC 3.0
2. Zachary Wilson and Mariana Ruiz Villarreal (LadyofHats) (cell images can be found at http://commons.wikimedia.org/wiki Mitosis in the eukaryotic cell cycle . CC BY-NC 3.0
3. Courtesy of Nogales group and Lawrence Berkeley National Laboratory. Spindle fiber and chromatids . Public Domain
4. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Sister chromatids line up during metaphase . CC BY-NC 3.0
5. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Cytokinesis is the final stage of mitosis . CC BY-NC 3.0
6. User:Kelvinsong/Wikimedia Commons. The four phases of mitosis . Public Domain

CONCEPT 29 Meiosis

Learning Objectives

- Explain the importance of meiosis.
- Distinguish between haploid and diploid.
- List the stages of meiosis.
- Summarize the steps of meiosis.
- Define crossing-over and explain its significance.



Do you have ALL your parents' chromosomes?

No, you only received half of your mother's chromosomes and half of your father's chromosomes. If you inherited them all, you would have twice the number of chromosomes that you're supposed to have. Humans typically have 23 pairs of chromosomes. If you received all your parents' chromosomes, you would have 46 pairs!

Introduction to Meiosis

Sexual reproduction combines gametes from two parents. **Gametes** are reproductive cells, such as sperm and egg. As gametes are produced, the number of chromosomes must be reduced by half. Why? The **zygote** must contain genetic information from the mother and from the father, so the gametes must contain half of the chromosomes found in normal body cells. When two gametes come together at fertilization, the normal amount of chromosomes results. Gametes are produced by a special type of cell division known as **meiosis**. Meiosis contains two rounds of cell division without DNA replication in between. This process reduces the number of chromosomes by half.

Human cells have 23 pairs of chromosomes, and each chromosome within a pair is called a **homologous chromosome**. For each of the 23 chromosome pairs, you received one chromosome from your father and one chromosome from your mother. **Alleles** are alternate forms of genes found on chromosomes. Homologous chromosomes have the same genes, though they may have different alleles. So, though homologous chromosomes are very similar, they are not identical. The homologous chromosomes are separated when gametes are formed. Therefore, gametes have only 23 chromosomes, not 23 pairs.

Haploid vs. Diploid

A cell with two sets of chromosomes is **diploid**, referred to as $2n$, where n is the number of sets of chromosomes. Most of the cells in a human body are diploid. A cell with one set of chromosomes, such as a gamete, is **haploid**, referred to as n. Sex cells are haploid. When a haploid sperm (n) and a haploid egg (n) combine, a diploid zygote will be formed ($2n$). In short, when a diploid zygote is formed, half of the DNA comes from each parent.

Overview of Meiosis

Before meiosis begins, DNA replication occurs, so each chromosome contains two sister chromatids that are identical to the original chromosome. Meiosis (**Figure** 29.1) is divided into two divisions: Meiosis I and Meiosis II. Each division can be divided into the same phases: prophase, metaphase, anaphase, and telophase. Cytokinesis follows telophase each time. Between the two cell divisions, DNA replication does not occur. Through this process, one diploid cell will divide into four haploid cells.

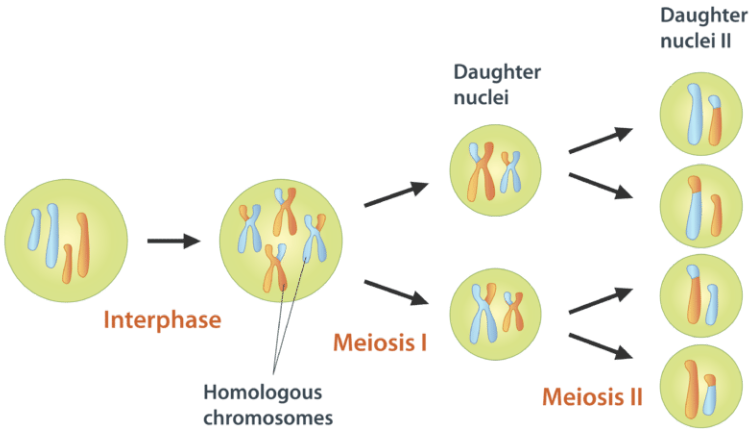


FIGURE 29.1

Overview of Meiosis. During meiosis, four haploid cells are created from one diploid parent cell.

Meiosis I

During meiosis I, the pairs of homologous chromosomes are separated from each other. This requires that they line up in their homologous paris during metaphase I. The steps are outlined below:

1. Prophase I: The homologous chromosomes line up together. During this time, a process that only happens in meiosis can occur. This process is called **crossing-over** (**Figure** 29.2), which is the exchange of DNA between homologous chromosomes. Crossing-over forms new combinations of alleles on the resulting chromosome. Without crossing-over, the offspring would always inherit all of the alleles on one of the homologous chromosomes. Also during prophase I, the **spindle** forms, the chromosomes condense as they coil up tightly, and the nuclear envelope disappears.
2. Metaphase I: The homologous chromosomes line up in their pairs in the middle of the cell. Chromosomes from the mother or from the father can each attach to either side of the spindle. Their attachment is random, so all of the chromosomes from the mother or father do not end up in the same gamete. The gamete will contain some chromosomes from the mother and some chromosomes from the father.
3. Anaphase I: The homologous chromosomes are separated as the spindle shortens, and begin to move to opposite sides (opposite poles) of the cell.
4. Telophase I: The spindle fibers dissolves, but a new nuclear envelope does not need to form. This is because, after cytokinesis, the nucleus will immediately begin to divide again. No DNA replication occurs between

meiosis I and meiosis II because the chromosomes are already duplicated. After cytokinesis, two haploid cells result, each with chromosomes made of sister chromatids.

Since the separation of chromosomes into gametes is random during meiosis I, this process results in different combinations of chromosomes (and alleles) in each gamete. With 23 pairs of chromosomes, there is a possibility of over 8 million different combinations of chromosomes (2^{23}) in a human gamete.

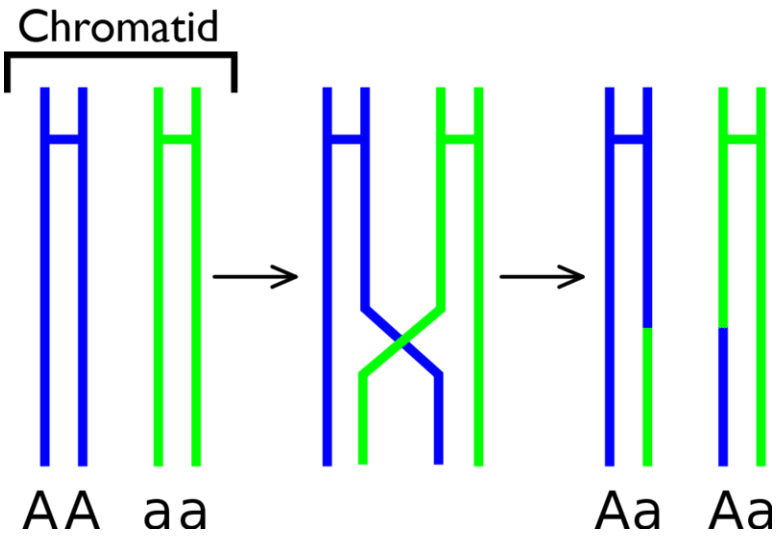


FIGURE 29.2

During crossing-over, segments of DNA are exchanged between non-sister chromatids of homologous chromosomes. Notice how this can result in an allele (A) on one chromatid being moved onto the other non-sister chromatid.

Meiosis II

During meiosis II, the sister chromatids are separated and the gametes are generated. This cell division is similar to that of **mitosis**, but results in four genetically unique haploid cells. The steps are outlined below:

1. Prophase II: The chromosomes condense.
2. Metaphase II: The chromosomes line up one on top of each other along the middle of the cell, similar to how they line up in mitosis. The spindle is attached to the centromere of each chromosome.
3. Anaphase II: The sister chromatids separate as the spindle shortens and move to opposite ends of the cell.
4. Telophase II: A nuclear envelope forms around the chromosomes in all four cells. This is followed by cytokinesis.

After cytokinesis, each cell has divided again. Therefore, meiosis results in four haploid genetically unique daughter cells, each with half the DNA of the parent cell (**Figure** 29.3). In human cells, the parent cell has 46 chromosomes (23 pairs), so the cells produced by meiosis have 23 chromosomes. These cells will become gametes.

Summary

- Meiosis is a process of cell division that reduces the chromosome number by half and produces sex cells, or gametes.
- Meiosis is divided into two parts: Meiosis I and Meiosis II. Each part is similar to mitosis and can be divided into the same phases: prophase, metaphase, anaphase, and telophase.
- Crossing-over occurs only during prophase I.
- Four genetically unique haploid cells result from meiosis.

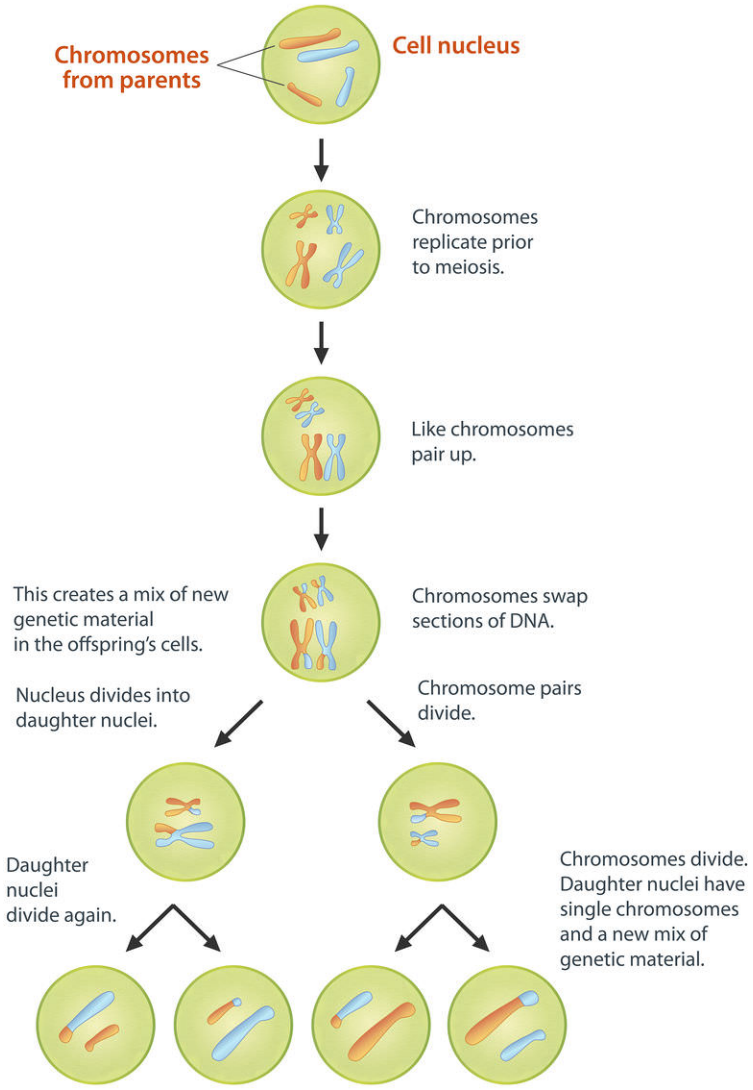
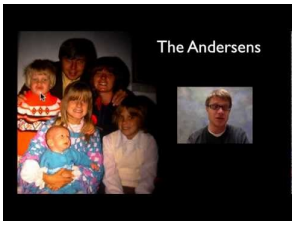


FIGURE 29.3
An overview of meiosis.

Explore More

Use the resource below to answer the questions that follow.

- **Meiosis** on YouTube at http://www.youtube.com/watch?v=rB_8dTuh73c (9:15)



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1. What is meiosis?
2. What is diploid? How many chromosomes are in a diploid human cell?
3. What is a zygote? How does the zygote form the organism?
4. What is the result of crossing-over?
5. How many cell divisions occur during meiosis?
6. Why are you genetically distinct?

Review

1. Define meiosis.
2. What is the difference between a haploid cell and a diploid cell?
3. Describe the steps of Meiosis I and Meiosis II.
4. Describe crossing-over. When does crossing-over occur?
5. What is the outcome of meiosis?

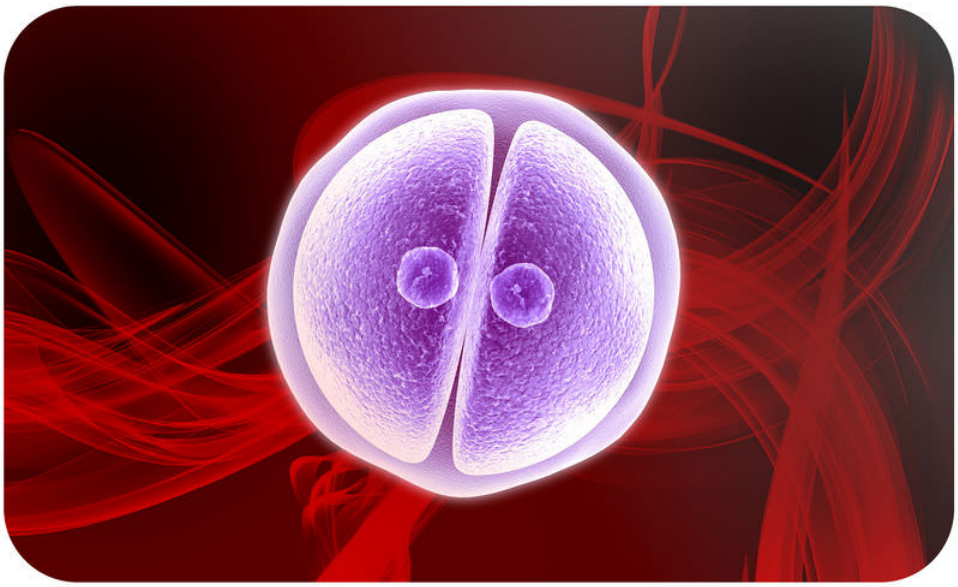
References

1. Hana Zavadska. Overview of Meiosis . CC BY-NC 3.0
2. Masur. Diagram of crossing-over . Public Domain
3. Hana Zavadska. An overview of meiosis . CC BY-NC 3.0

CONCEPT 30 Mitosis vs. Meiosis

Learning Objectives

- Distinguish between mitosis and meiosis.
- Summarize the necessity for mitosis and meiosis.

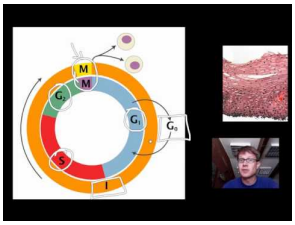


Mitosis or Meiosis?

This represents a tiny embryo just beginning to form. Once an egg is fertilized, the resulting single cell must divide many, many times to develop a fetus. Both mitosis and meiosis involve cell division; is this type of cell division an example of mitosis or meiosis? The answer is mitosis. With each division you are making a genetically exact copy of the parent cell, which only happens through mitosis.

Mitosis vs. Meiosis

Mitosis, meiosis, and sexual reproduction are discussed at https://www.youtube.com/watch?v=2aVnN4RePyI .



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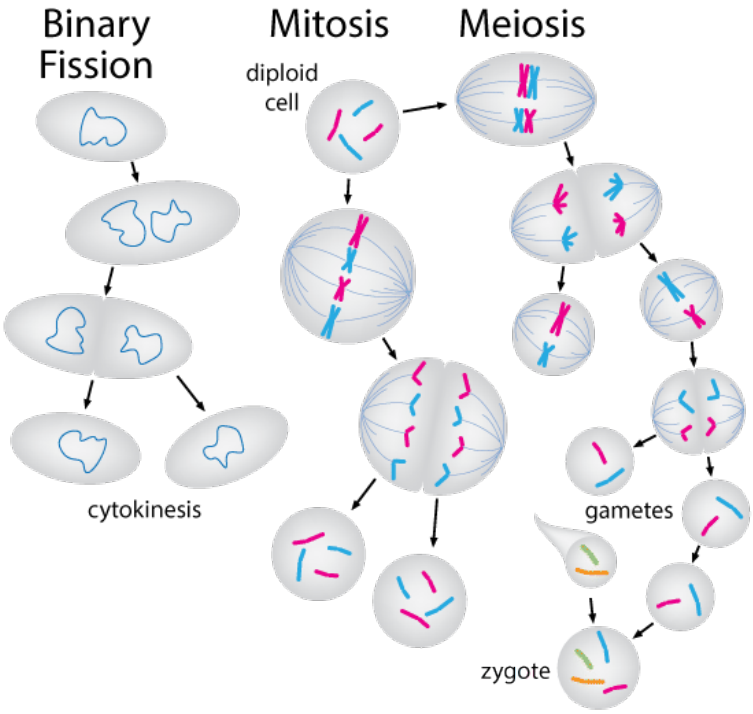

FIGURE 30.1
A comparison between binary fission, mitosis, and meiosis.

TABLE 30.1: Mitosis vs. Meiosis: A Comparison

	Mitosis	Meiosis
Purpose	To produce new cells	To produce gametes
Number of Cells Produced	2	4
Rounds of Cell Division	1	2
Haploid or Diploid	Diploid	Haploid
Daughter cells identical to parent cells?	Yes	No
Daughter cells identical to each other?	Yes	No

Summary

- The goal of mitosis is to produce a new cell that is identical to the parent cell.
- The goal of meiosis is to produce gametes that have half the DNA of the parent cell.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

- **Mitosis and Meiosis Simulation** at http://www.youtube.com/watch?v=zGVBAHAsjJM (11:53)

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Review

1. What is the goal of mitosis? Of meiosis?
2. How many cells are created from cytokinesis following mitosis? Following meiosis?
3. Which process, mitosis to meiosis, creates genetically identical cells?
4. "Gametes are haploid cells." What does this sentence mean?

References

1. Zachary Wilson. A comparison between binary fission, mitosis, and meiosis . CC BY-NC 3.0

CONCEPT 31

Gregor Mendel and Genetics

Why is heredity so important?

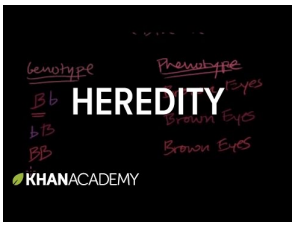
Genetics - the study of inheritance. Inheritance - the passing of traits from parents to offspring. How are these traits "passed"? Through DNA - the genetic material. And it all started with an Austrian Monk named Gregor Mendel and his vegetable garden.

Gregor Mendel: Teacher and Scientist

"My scientific studies have afforded me great gratification; and I am convinced that it will not be long before the whole world acknowledges the results of my work." Quote attributed to Gregor Mendel.

For thousands of years, humans have understood that characteristics such as eye color, hair color, or even flower color are passed from one generation to the next. The passing of characteristics from parent to offspring is called **heredity**. Humans have long been interested in understanding heredity. Many hereditary mechanisms were developed by scholars but were not properly tested or quantified. The scientific study of genetics did not begin until the late 19^{th} century. In experiments with garden peas, Austrian monk Gregor Mendel described the basic patterns of inheritance. Keep in mind that while we know about DNA and its role as the genetic material, Mendel did not know of the existence of DNA. Nor did he understand the concept of the chromosome or the process of meiosis, and yet, he was still able to correctly describe basic inheritance patterns.

An introduction to heredity can be seen at: http://www.youtube.com/watch?v=eEUvRrhmcxM (17:27)



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Gregor Johann Mendel was an Augustinian monk, a teacher, and a scientist (figure below). He is often called the "father of modern genetics" for his study of the inheritance of traits in pea plants. Mendel showed that the inheritance of traits follows particular laws, which were later named after him. The significance of Mendel's work was not recognized until the turn of the 20^{th} century. The rediscovery of his work led the foundation for the era of modern **genetics**, the branch of biology that focuses on heredity in organisms.

FIGURE 31.1

Gregor Johann Mendel "The Father of Modern Genetics." 1822-1884.

Johann Mendel was born in 1822 and grew up on his parents' farm in an area of Austria that is now in the Czech Republic. He overcame financial hardship and ill health to excel in school. In 1843 he entered the Augustinian Abbey in Brünn (now Brno, Czech Republic.) Upon entering monastic life, he took the name Gregor. While at the monastery, Mendel also attended lectures on the growing of fruit and agriculture at the Brünn Philosophical Institute. In 1849 he accepted a teaching job, but a year later he failed the state teaching examination. One of his examiners recommended that he be sent to university for further studies. In 1851 he was sent to the University of Vienna to study natural science and mathematics. Mendel's time at Vienna was very important in his development as a scientist. His professors encouraged him to learn science through experimentation and to use mathematics to help explain observations of natural events, which he did. In fact, it was the use of math in his analysis that made his conclusions much more convincing.

Mendel's Pea Plants

In 1853 and 1854, Mendel published two papers on crop damage by insects. However, he is best known for his later studies of the pea plant *Pisum sativum*. Mendel was inspired by both his professors at university and his colleagues at the monastery to study variation in plants. He had carried out artificial fertilization on plants many times in order to grow a plant with a new color or seed shape. **Artificial fertilization** is the process of transferring pollen from the male part of the flower to the female part of another flower. Artificial fertilization is done in order to have seeds that will grow into plants that have a desired trait, such as yellow flowers. Mendel returned to Brünn in 1854 as a natural

history and physics teacher. A brief biography of Mendel can be found at: http://www.accessexcellence.org/RC/AB/BC/Gregor_Mendel.php

Gregor Mendel - From the Garden to the Genome can be viewed at: http://www.youtube.com/watch?v=6OPJnO9W_rQ (30:24)

MEDIA

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Blending Theory of Inheritance

During Mendel's time, the **blending theory of inheritance** was popular. This is the theory that offspring have a blend, or mix, of the characteristics of their parents. Mendel noticed plants in his own garden that weren't a blend of the parents. For example, a tall plant and a short plant had offspring that were either tall or short but not medium in height. Observations such as these led Mendel to question the blending theory. He wondered if there was a different underlying principle that could explain how characteristics are inherited. He decided to experiment with pea plants to find out. In fact, Mendel experimented with almost 29,000 pea plants over the next several years! At the following link, you can watch an animation in which Mendel explains how he arrived at his decision to study inheritance in pea plants: http://www.dnalc.org/view/16170-Animation-3-Gene-s-don-t-blend-.html

Vocabulary

- **Artificial fertilization**: The process of transferring pollen from the male part of the flower to the female part of another flower; done in order to have seeds that will grow into plants that have a desired trait.
- **Blending theory of inheritance**: Hypothesis that stated that offspring were a "mix" of their parents.
- **Genetics**: The branch of biology that focuses on heredity in organisms; the study of heredity.
- **Heredity**: The passing of characteristics from parent to offspring.

Summary

- Genetics is the branch of biology that focuses on heredity in organisms.
- Modern genetics is based on Mendel's explanation of how traits are passed from generation to generation.
- Mendel's use of mathematics in his pea plant studies was important to the confidence he had in his results.

Explore More

Use this resource to answer the questions that follow.

- **Gregor Mendel biographbhy** at: http://www.biography.com/people/gregor-mendel-39282

1. For what is Gregor Mendel best known?
2. What subjects did Mendel excel in academically?
3. What was special about the St. Thomas Monastery?
4. Prior to Mendel's findings, what was thought about plant hybrids?
5. Why did Mendel choose to use pea plants?

Review

1. What is the blending theory of inheritance? Why did Mendel question this theory?
2. Why was Mendel's understanding of mathematics and science important for his research?
3. What did Gregor Mendel contribute to the science of genetics?
4. What is artificial fertilization? What plants did Mendel artificially fertilize?

Video on Mendelian Genetics - Overview

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URL: http://www.ck12.org/flx/render/embeddedobject/155417

Watch the video at: http://www.ck12.org/flx/render/embeddedobject/155417

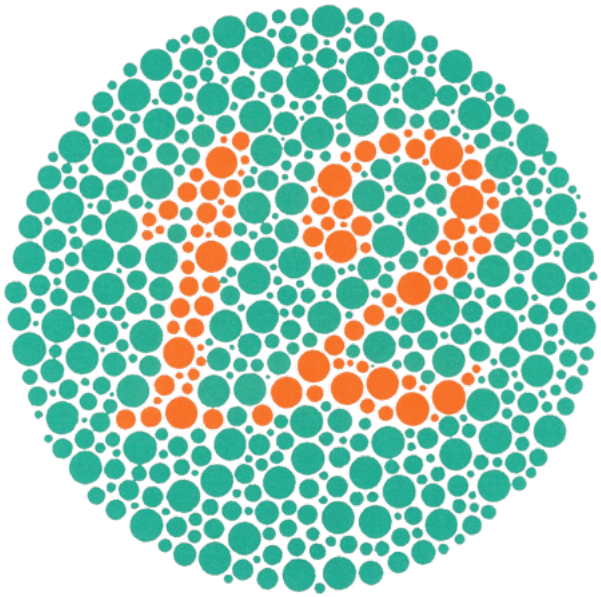
References

1. US National Library of Medicine. http://commons.wikimedia.org/wiki/Image:Mendel.png .

CONCEPT 32 Mendelian Inheritance

Learning Objectives

- Define genetic trait.
- Distinguish autosomal traits from X-linked traits.
- Use a pedigree to determine the mode of inheritance.
- Summarize the inheritance of red-green color blindness.



What number can you see?

Red-green colorblindness is a common inherited trait in humans. About 1 in 10 men have some form of color blindness, however, very few women are color blind. Why?

Mendelian Inheritance in Humans

Characteristics that are encoded in DNA are called **genetic traits**. Different types of human traits are inherited in different ways. Some human traits have simple inheritance patterns like the traits that Gregor Mendel studied in pea plants. Other human traits have more complex inheritance patterns.

Mendelian inheritance refers to the inheritance of traits controlled by a single gene with two alleles, one of which may be dominant to the other. Not many human traits are controlled by a single gene with two alleles, but they are a good starting point for understanding human heredity. How Mendelian traits are inherited depends on whether the traits are controlled by genes on autosomes or the X chromosome.

Autosomal Traits

Autosomal traits are controlled by genes on one of the 22 human autosomes. Consider earlobe attachment. A single autosomal gene with two alleles determines whether you have attached earlobes or free-hanging earlobes. The allele for free-hanging earlobes (F) is dominant to the allele for attached earlobes (f). Other single-gene autosomal traits include widow's peak and hitchhiker's thumb. The dominant and recessive forms of these traits are shown in **Figure** 32.1. Which form of these traits do you have? What are your possible genotypes for the traits?

The chart in **Figure** 32.1 is called a **pedigree**. It shows how the earlobe trait was passed from generation to generation within a family. Pedigrees are useful tools for studying inheritance patterns.

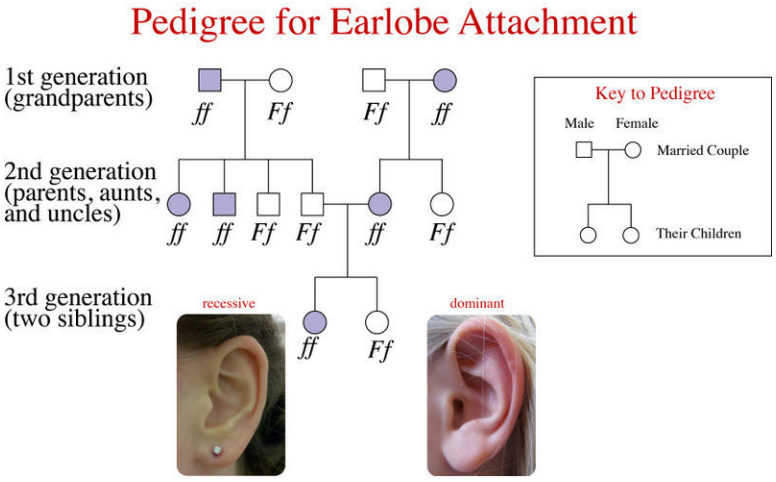


FIGURE 32.1

Having free-hanging earlobes is an autosomal dominant trait. This figure shows the trait and how it was inherited in a family over three generations. Shading indicates people who have the recessive form of the trait. Look at (or feel) your own earlobes. Which form of the trait do you have? Can you tell which genotype you have?

Other single-gene autosomal traits include widow's peak and hitchhiker's thumb. The dominant and recessive forms of these traits are shown in **Figure** 32.2. Which form of these traits do you have? What are your possible genotypes for the traits?

Sex-Linked Traits

Traits controlled by genes on the sex chromosomes are called **sex-linked traits**, or **X-linked traits** in the case of the X chromosome. Single-gene X-linked traits have a different pattern of inheritance than single-gene autosomal traits. Do you know why? It's because males have just one X chromosome. In addition, they always inherit their X chromosome from their mother, and they pass it on to all their daughters but none of their sons. This is illustrated in **Figure** 32.3.

Because males have just one X chromosome, they have only one allele for any X-linked trait. Therefore, a recessive X-linked allele is always expressed in males. Because females have two X chromosomes, they have two alleles for any X-linked trait. Therefore, they must inherit two copies of the recessive allele to express the recessive trait. This explains why X-linked recessive traits are less common in females than males. An example of a recessive X-linked trait is **red-green color blindness**. People with this trait cannot distinguish between the colors red and green. More than one recessive gene on the X chromosome codes for this trait, which is fairly common in males but relatively rare in females (**Figure** 32.4).

Summary

- A minority of human traits are controlled by single genes with two alleles.

FIGURE 32.2

Widow's peak and hitchhiker's thumb are dominant traits controlled by a single autosomal gene.

- They have different inheritance patterns depending on whether they are controlled by autosomal or X-linked genes.

Review

1. Describe the inheritance pattern for a single-gene autosomal dominant trait, such as free-hanging earlobes.
2. Draw a pedigree for hitchhiker's thumb. Your pedigree should cover at least two generations and include both dominant and recessive forms of the trait. Label the pedigree with genotypes, using the letter *H* to represent the dominant allele for the trait and the letter *h* to represent the recessive allele.
3. Why is a recessive X-linked allele always expressed in males?
4. What is necessary for a recessive X-linked allele to be expressed in females?
5. What is an example of a recessive X-linked trait?

Resources

MEDIA

Click image to the left or use the URL below.

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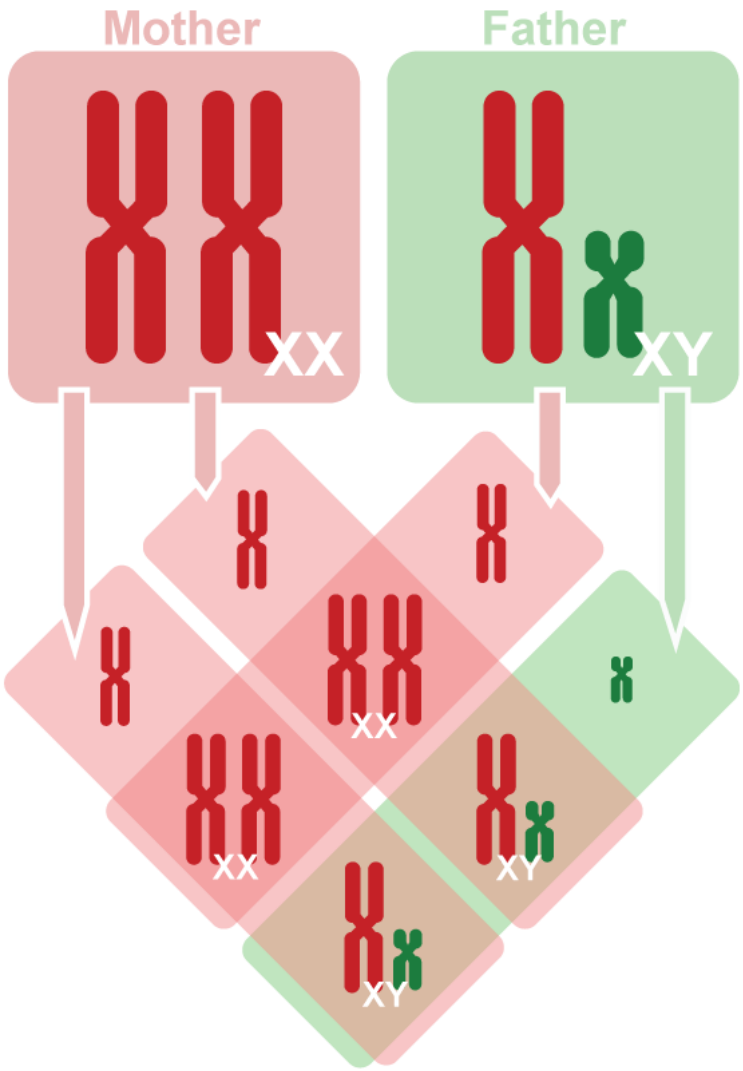


FIGURE 32.3

Inheritance of Sex Chromosomes. Mothers pass only X chromosomes to their children. Fathers always pass their X chromosome to their daughters and their Y chromosome to their sons. Can you explain why fathers always determine the sex of the offspring?

References

1. Dominant: User:Covalent/Wikipedia; Recessive: Claire P.; pedigree created by Sam McCabe (CK-12 Foundation). Pedigree for earlobe attachment . Dominant: Public Domain; Recessive: CC BY 2.0
2. Left to right: Image copyright Alberto Zornetta, 2014; Image copyright iko, 2014; Eva Blue; Sara Reid. Widow's peak and hitchhiker's thumb are dominant traits . Left to right: Used under license from Shutterstock.com, Used under license from Shutterstock.com; CC BY 2.0; CC BY 2.0
3. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Sex-linked traits and inheritance . CC BY-NC 3.0
4. Jodi So. Pedigree for color blindness . CC BY-NC 3.0

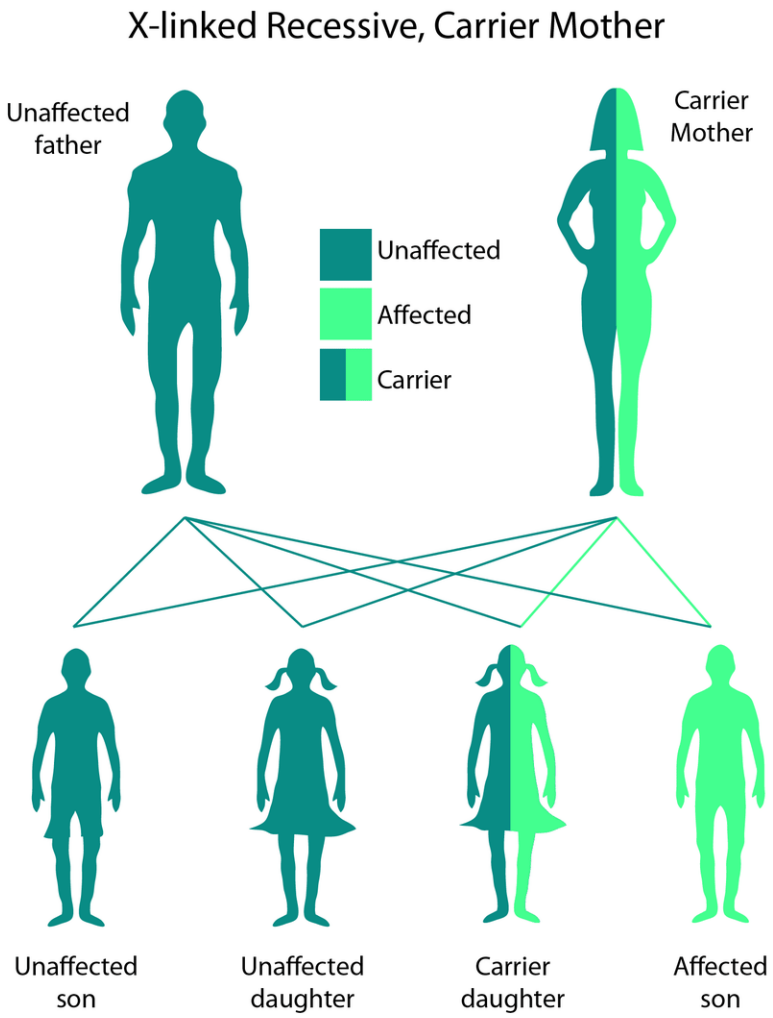


FIGURE 32.4

Pedigree for Color Blindness. Color blindness is an X-linked recessive trait. Mothers pass the recessive allele for the trait to their sons, who pass it to their daughters.

CONCEPT 33 Non-Mendelian Inheritance - Advanced

Learning Objectives

- Describe how codominance does not follow Mendelian Inheritance.
- Describe how incomplete dominance does not follow Mendelian Inheritance.
- Identify examples of polygenic traits in humans.

Green, blue, brown, black, hazel, violet, or grey. What color are your eyes?

Of course human eyes do not come in multi-color, but they do come in many colors. How do eyes come in so many colors? Are there more than two alleles? Is there more than one gene? That brings us to complex inheritance patterns, known as non-Mendelian inheritance. Many times inheritance is more complicated than the simple patterns observed by Mendel.

Non-Mendelian Modes of Inheritance

The relationship between genotype and phenotype is rarely as simple as the examples Mendel studied. Each characteristic he studied had two alleles, one of which was completely dominant and the other completely recessive, resulting in only two phenotypes. Geneticists now know that alleles can be codominant, or incompletely dominant, and that there are usually more than two alleles for a gene in a population. Complicating issues further, some phenotypes are controlled by more than one gene.

Codominance

What happens when there are two alleles in a heterozygote and neither allele is completely dominant nor completely recessive? Can both traits appear in the phenotype? Essentially, yes they can. Can there be two dominant alleles for the same gene? **Codominance** occurs when both traits appear in a heterozygous offspring. For example, roan shorthorn cattle have codominant genes for hair color. The coat has both red and white hairs; not pink hairs, but red AND white hairs. The letter *R* indicates red hair color, and *R'* white hair color. In cases of codominance, the genotype of the organism can be determined from its phenotype. The heifer in **Figure** 33.1 shows both coat colors

and therefore is *RR'* heterozygous for coat color. The flower in **Figure** 33.1 also has two codominant alleles; it has red and white petals, not pink petals. Both colors appear in the phenotype.

FIGURE 33.1

(left) The roan coat of this cow is made up of red and white hairs. Both the red and white hair alleles are codominant. Therefore cattle with a roan coat are heterozygous for coat color (*RR'*). (right) The flower has red and white petals because of codominance of red-petal and white-petal alleles.

Incomplete Dominance

But what if there were pink petals as opposed to red and white petals? Which allele would be dominant? Both? Neither?

Incomplete dominance occurs when the phenotype of the offspring is somewhere in between the phenotypes of both parents; a completely dominant allele does not occur. For example, when red snapdragons (C^RC^R) are crossed with white snapdragons (C^WC^W), the F_1 hybrids are all pink hetrozygotes for flower color (C^RC^W). The pink color is an intermediate between the two parent colors (**Figure** 33.2). When two F_1 (C^RC^W) hybrids are crossed they will produce red, pink, and white flowers. The genotype of an organism with incomplete dominance can be determined from its phenotype (**Table** 33.1).

FIGURE 33.2

Snapdragons show incomplete dominance in the traits for flower color. The pink snapdragon has pink petals because of incomplete dominance of a red-petal allele and a recessive white-petal allele.

TABLE 33.1: Red Flower × White Flower

allele (phenotype)	C^W (white)	C^W (white)
C^R (red)	C^RC^W (pink)	C^RC^W (pink)
C^R (red)	C^RC^W (pink)	C^RC^W (pink)

Complex Forms of Heredity

Traits that are affected by more than one gene are called **polygenic traits**. The genes that affect a polygenic trait may be closely linked on a chromosome, unlinked on a chromosome, or on different chromosomes. Polygenic traits are often difficult for geneticists to track because the polygenic trait may have many alleles. Also, independent assortment ensures the genes combine differently in gametes. Therefore, many different intermediate phenotypes exist in offspring. Eye color (**Figure** 33.3), and skin color are examples of polygenic traits in humans.

FIGURE 33.3

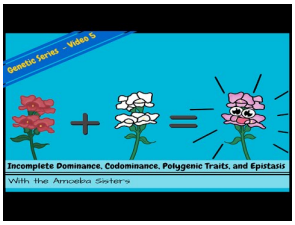
Eye color and skin color are examples of polygenic traits; they are influenced by more than one gene.

When three or more alleles determine a trait, the trait is said to have **multiple alleles**. The human **ABO blood group** is controlled by a single gene with three alleles: the dominant I^A and I^B, and the recessive i allele. The gene encodes an enzyme that affects carbohydrates that are found on the surface of the red blood cell. *A* and *B* refer to two carbohydrates found on the surface of red blood cells. There is not an O carbohydrate. Type O red blood cells do not have either type *A* or *B* carbohydrates on their surface.

As the alleles I^A and I^B are dominant over i, a person who is homozygous recessive (ii) will not have type A or type B blood, but will have type O blood. Homozygous dominant I^AI^A or heterozygous I^Ai have type A blood, and homozygous dominant I^BI^B or heterozygous I^Bi have type B blood. I^AI^B individuals have type AB blood, because the A and B alleles are codominant. Type A and type B parents can have a type AB child. Type A and a type B parent can also have a child with Type O blood, if they are both heterozygous (I^Bi, I^Ai). **Table** 33.2 shows how the different combinations of the blood group alleles can produce the four blood groups, A, AB, B, and O.

TABLE 33.2: Bloodtype as Determined by Multiple Alleles

	$\mathbf{I^A}$	$\mathbf{I^B}$	**i**
$\mathbf{I^A}$	I^AI^A Type A	I^AI^B Type AB	I^Ai Type A
$\mathbf{I^B}$	I^AI^B Type AB	I^BI^B Type B	I^Bi Type B
i	iI^A Type A	iI^B Type B	ii Type O



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Summary

- The Mendelian pattern of inheritance and expression does not apply to all traits.
- Codominant traits, incompletely dominant traits, and polygenic traits do not follow simple Mendelian patterns of inheritance. Their inheritance patterns are more complex.

Review

1. Mendelian inheritance does not apply to the inheritance of alleles that result in incomplete dominance and codominance. Explain why this is so.
2. Define codominance, incomplete dominance and polygenic trait.
3. A classmate tells you that a person can have type AO blood. Do you agree? Explain.
4. If you cross a red plant with a white plant and the offspring is pink, what is that called?

References

1. Cow: Jean; Flower: Darwin Cruz. Cow: http://www.flickr.com/photos/7326810@N08/1479490190; Flower: http://commons.wikimedia.org/wiki/File:Co-dominance_Rhododendron.jpg . CC BY 2.0
2. Pink snapdragon: Sandy Schultz (Flickr:chatblanc1); Red and white snapdragons: Flickr:Lana_aka_BAD-GRL. Pink snapdragon: http://www.flickr.com/photos/chatblanc1/4788366795/; Red and white snapdragons: http://www.flickr.com/photos/lanacar/834473349/ . CC BY 2.0
3. Left to right: Flickr:Look Into My Eyes; Oman Muscat; Flickr:Look Into My Eyes. Left to right: http://www.flickr.com/photos/weirdcolor/3878552964/; http://www.flickr.com/photos/marypaulose/292958125/; http://www.flickr.com/photos/weirdcolor/4088940371/ . CC BY 2.0

CONCEPT 34

Punnett Squares - Advanced

Learning Objectives

- Outline how a Punnett Square helps predict outcomes of genetic crosses.

What do you get when you cross an apple and an orange?

Though the above fruit may not result, it would be nice to scientifically predict what would result. The ability to predict the genotypes and phenotypes of offspring is important for many reasons. Predicting the possibility of a genetic cross is often aided by a Punnett square.

Predicting Genotypes with Punnett Squares

Mendel developed the law of segregation by following only a single characteristic, such as pod color, in his pea plants. Biologists use a diagram called a **Punnett square**, to help predict the probable inheritance of alleles in different crosses. The Punnett square is named after its developer, British geneticist Reginald C. Punnett.

In a **monohybrid cross**, such as the one in **Figure** 34.1, the Punnett square shows every possible combination when combining one maternal (mother) allele with one paternal (father) allele. In this example, both organisms are heterozygous for flower color *Bb* (purple). Both plants produce gametes that contain both the *B* and *b* alleles. The probability of any single offspring showing the dominant trait is 3:1, or 75%. To develop a Punnett square, possible combinations of alleles in a gamete are placed on the top and left side of a square. For a monohybrid cross (**Table** 34.1), individual alleles are used, whereas for a **dihybrid cross** (**Table** 34.2), pairs of alleles are used. A Punnett square for a monohybrid cross is divided into four squares, whereas a Punnett square for a dihybrid cross is divided into 16 squares. How many boxes would a Punnett square need if three traits were examined? The squares are filled in with the possible combinations of alleles formed when gametes combine, such as in a zygote.

TABLE 34.1: Monohybrid Cross

	A	a
A	AA	Aa
a	Aa	aa

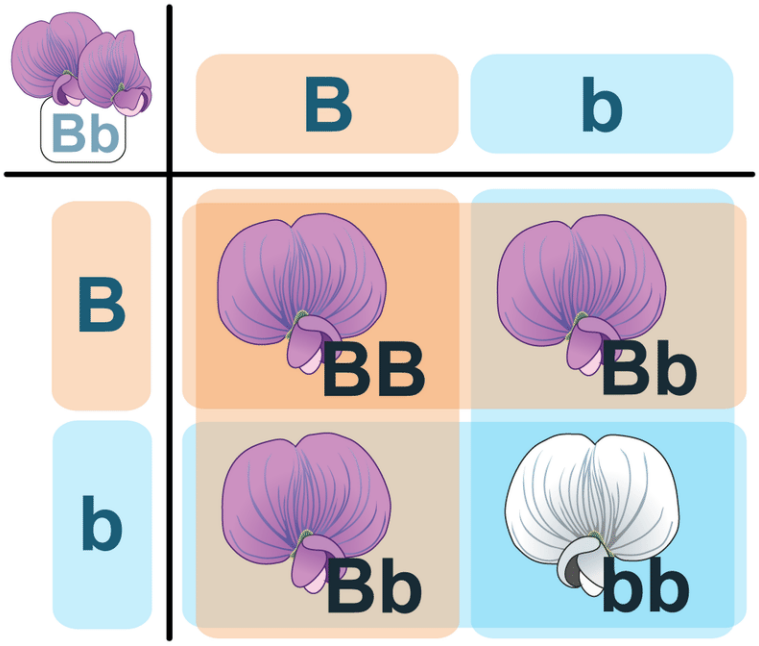

FIGURE 34.1

This Punnett square shows a cross between two heterozygotes, Bb. Do you know where each letter (allele) in all four cells comes from? Two pea plants, both heterozygous for flower color, are crossed. The offspring will show the dominant purple coloration in a 3:1 ratio. Or, about 75% of the offspring will be purple.

TABLE 34.2: Dihybrid Cross

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

Predicting Offspring Genotypes

In the cross shown in **Figure** 34.1, you can see that one out of four offspring (25 percent) has the genotype *BB*, one out of four (25 percent) has the genotype *bb*, and two out of four (50 percent) have the genotype *Bb*. These percents of genotypes are what you would expect in any cross between two heterozygous parents. Of course, when just four offspring are produced, the actual percents of genotypes may vary by chance from the expected percents. However, if you considered hundreds of such crosses and thousands of offspring, you would get very close to the expected results—just like tossing a coin.

Predicting Offspring Phenotypes

You can predict the percents of phenotypes in the offspring of this cross from their genotypes. *B* is dominant to *b*, so offspring with either the *BB* or *Bb* genotype will have the purple-flower phenotype. Only offspring with the *bb* genotype will have the white-flower phenotype. Therefore, in this cross, you would expect three out of four (75 percent) of the offspring to have purple flowers and one out of four (25 percent) to have white flowers. These are the same percents that Mendel obtained in his first experiment. The Punnett square is visual representation of Mendelian inheritance.

Video

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/155749

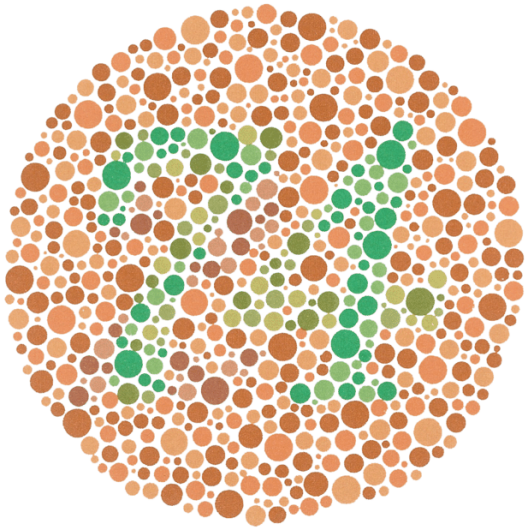
	A	A
?	A?	Aa
?	Aa	A?

4. How do the Punnett squares for a monohybrid cross and a dihybrid cross differ?

References

1. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0

CONCEPT 35 Sex-Linked Traits



What number can you see?

Red-green colorblindness is a common inherited trait in humans. About 1 in 10 men have some form of color blindness, however, very few women are color blind. Why?

Sex-Linked Genes

Sex-linked genes are located on either the X or Y chromosome, though it more commonly refers to genes located on the X-chromosome. For that reason, the genetics of **sex-linked** (or **X-linked**) diseases, disorders due to mutations in genes on the X-chromosome, results in a phenotype usually only seen in males.

Sex-linked traits are discussed at: http://www.youtube.com/watch?v=-ROhfKyxgCo

MEDIA

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Hemophilia

Hemophilia is a group of diseases in which blood does not clot normally. Factors in blood are involved in clotting. When you bleed, your body begins a coagulation cascade of reactions, involving special proteins known as coagulation factors, to stop that bleeding. When one or more of these clotting factors are missing, there is a higher chance of having dificulties stoping the bleeding. Hemophiliacs lacking the normal Factor VIII are said to have Hemophilia A (or Factor VIII deficiency), the most common form. Hemophilia is a genetic disease, passed down through family. It is linked to the X-chromosome, so it mostly affects males. F8 is the gene for the Factor VIII protein. Mutations in the F8 gene lead to the production of an abnormal version of coagulation factor VIII, or reduce the amount of the protein. The altered or missing protein cannot participate effectively in the blood clotting process.

England's Queen Victoria was a carrier for this disease. The allele was passed to two of her daughters and one son. Since royal families in Europe commonly intermarried, the allele spread, and may have contributed to the downfall of the Russian monarchy. See *Mendelian laws apply to human beings* at: http://www.dnaftb.org/13/animation.html for more on hemophilia and the royal family.

Hemophilia B is another type of hemophilia, caused by a mutation in the F9 gene, resulting in an abnormal Factor IX protein. This protein is normally also involved in the coagulation cascade. Hemophilia B is also caused by an inherited X-linked recessive trait, with the defective gene located on the X chromosome.

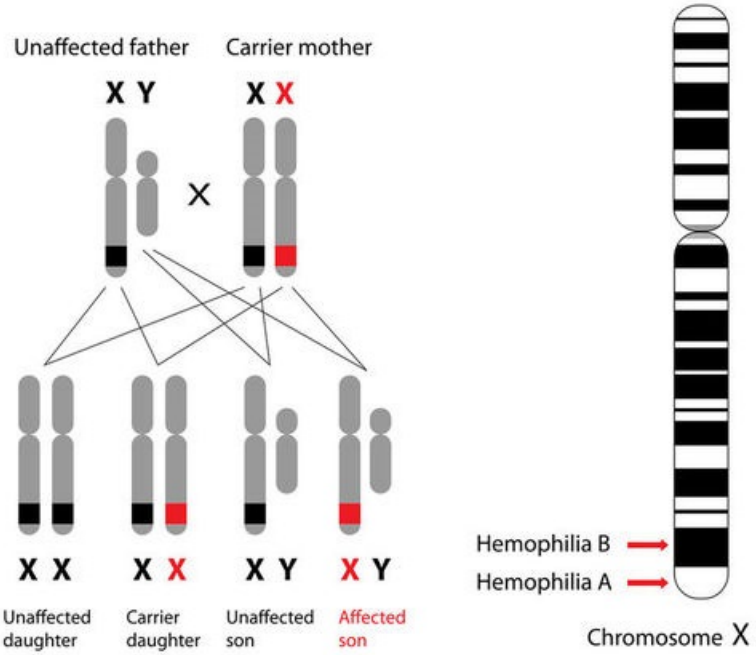


FIGURE 35.1

Hemophilia is a sex-linked trait. Carrier mothers can pass along the affected allele to 50% of their sons. Females with hemophilia would have to receive an affected allele from each parent, making females with hemophilia rare.

Color Blindness

Genetic red-green color blindness affects men much more often than women, because the genes for the red and green color receptors are located on the X chromosome. Females are red-green color blind only if both of their X chromosomes carry the defective gene, whereas males are color blind if their single X chromosome carries the defective gene. As males have only the one X-chromosome, the gene for red-green color blindness is transmitted from a color blind male to all his daughters, who are usually heterozygous **carriers** and therefore unaffected. Subsequently, this carrier woman has a fifty percent chance of passing on a X chromosome with a defective gene to each of her male offspring. The sons of an affected male will not inherit the trait from him, since they receive his Y chromosome and not his X chromosome. Should an affected male have children with a carrier or colorblind woman, their daughters may be colorblind by inheriting a X chromosome with the mutant gene from each parent.

See: http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0001997/ for additional information.

Sickle Cell Anaemia

A mutant recessive allele, such as the allele that causes sickle cell anemia (see figure below and the link that follows), is not expressed in people who inherit just one copy of it. These people are called **carriers**. They do not have the disorder themselves, but they carry the mutant allele and can pass it to their offspring. Thus, the allele is likely to pass on to the next generation rather than die out. http://www.dnalc.org/resources/3d/17-sickle-cell.html

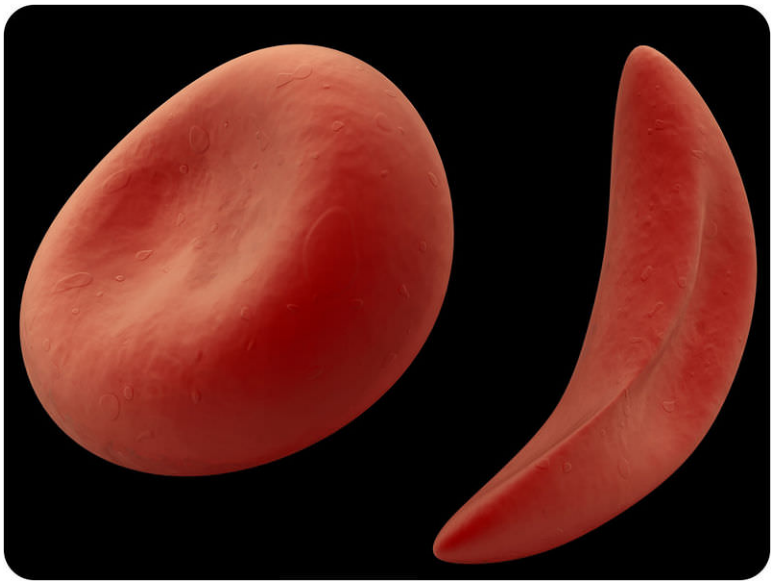


FIGURE 35.2

Sickle-Shaped and Normal Red Blood Cells. Sickle cell anemia is an autosomal recessive disorder. The mutation that causes the disorder affects just one amino acid in a single protein, but it has serious consequences for the affected person. This photo shows the sickle shape of red blood cells in people with sickle cell anemia.

Muscular Dystrophy

Muscular dystrophy is a term encompassing a variety of muscle wasting diseases. The most common type, **Duchenne Muscular Dystrophy (DMD)**, affects cardiac and skeletal muscle, as well as some mental functions. DMD is caused by a defective gene for dystrophin, a protein prevalent in skeletal and cardiac muscles. DMD is an X-linked recessive disorder occurring in 1 in 3,500 male newborns. Because DMD is X-linked, no females are affected. Most affected individuals die before their 20th birthday. Daughters of female carriers of the mutant allele have a 50% chance of also being carriers.

Vocabulary

- **Carrier:** A person who is heterozygous for a recessive allele of a trait.
- **Duchenne Muscular Dystrophy (DMD):** Most sever form of muscular dystrophy; quickly worsens over time.
- **Hemophilia:** The name of a group of hereditary genetic diseases that affect the body's ability to control blood clotting; characterized by a lack of clotting factors in the blood.
- **Muscular Dystrophy:** A group of inherited disorders that involve muscle weakness and loss of muscle tissue; progressively worsens over time.
- **Sex-Linked:** Located on a sex chromosome; usually refers to the X-chromosome.
- **X-linked:** Located on the X-chromosome.

Summary

- Sex chromosomes specify an organism's genetic sex. Humans have two different sex chromosomes, one called X and the other Y.
- Sex-linked genes are located on either the X or Y chromosome, though it more commonly refers to genes located on the X-chromosome.
- Color blindness, hemophilia and muscular dystrophy are three x-linked phenotypes.

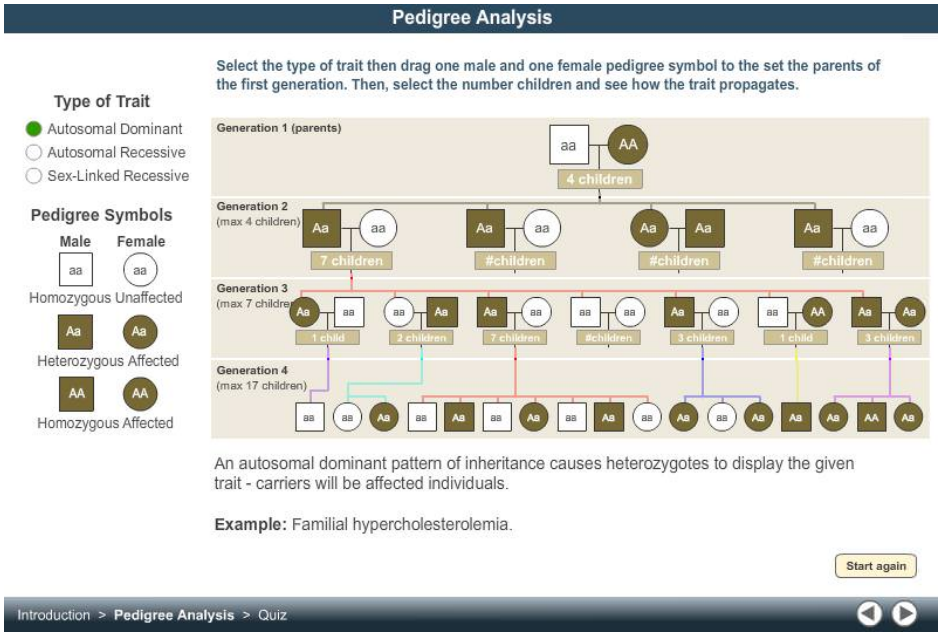
Explore More

Use this resource to answer the questions that follow.

- **Sex chromosomes and sex-linked inheritance** at: http://www.ncbi.nlm.nih.gov/books/NBK22079/

1. What is meant by the terms "homogametic sex" and "heterogametic sex?"
2. Compare the role of the Y chromosome in *Drosophila* and in mammals?
3. What is meant by "X-linkage?"
4. How was linkage to the X-chromosome determined?

- **Pedigree Analysis Activity:** The following link is to a pedigree analysis activity. Autosomal dominant, autosomal recessive and sex-linked recessive inheritance is explored through an interactive activity. CK-12 Pedigree Analysis Animation



Review

1. Why is it more common for males to have X-linked disorders?
2. Describe two X-linked phenotypes.

References

1. Image copyright Alila Medical Media, 2014. Genetics of hemophilia, A and B .
2. Image copyright Sebastian Kaulitzk, 2013. Sickle cell anemia and normal red blood cells .

CONCEPT 36 Pedigree

Learning Objectives

- Define pedigree.
- Interpret a pedigree to determine the mode of inheritance.

What's a pedigree?

When you are talking about a pedigree dog, it means the dog is purebred. Through selective breeding, the dog has all the traits of that particular breed. When talking about genetics, however, a pedigree is a chart that helps show family relationships.

Pedigree Analysis

A **pedigree** is a chart that shows the inheritance of a trait over several generations. A pedigree is commonly created for families, and it outlines the inheritance patterns of genetic disorders and traits. A pedigree can help predict the probability that offspring will inherit a genetic disorder.

Pictured below is a pedigree displaying recessive inheritance of a disorder through three generations (**Figure** 36.1). From studying a pedigree, scientists can determine the following:

- If the trait is **sex-linked** (on the X or Y chromosome) or **autosomal** (on a chromosome that does not determine sex).
- If the trait is inherited in a dominant or recessive fashion.

Sometimes pedigrees can also help determine whether individuals with the trait are heterozygous (two different alleles) or homozygous (two of the same allele). Some points to keep in mind when analyzing a pedigree are:

1. With autosomal recessive inheritance, all affected individuals will be homozygous recessive.
2. With dominant inheritance, all affected individuals will have at least one dominant allele. They will be either homozygous dominant or heterozygous.
3. With sex-linked inheritance, more males (XY) than females (XX) usually have the trait. Sex-linked inheritance is usually recessive.

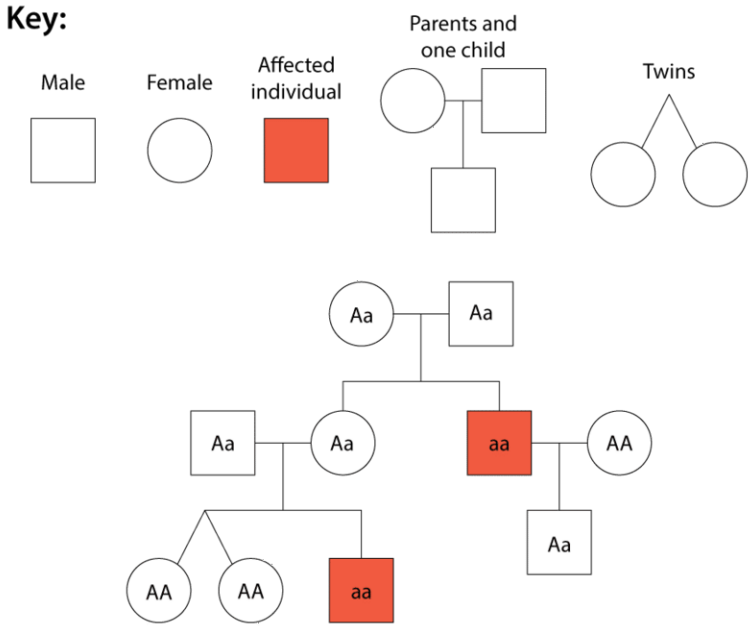


FIGURE 36.1

In a pedigree, squares symbolize males, and circles represent females. A horizontal line joining a male and female indicates that the couple had offspring. Vertical lines indicate offspring which are listed left to right, in order of birth. Shading of the circle or square indicates an individual who has the trait being traced. In this pedigree, the inheritance of the recessive trait is being traced. *A* is the dominant allele, and *a* is the recessive allele.

Summary

- A pedigree is a chart which shows the inheritance of a trait over several generations.
- From studying a pedigree, scientists can determine if a trait is sex-linked or autosomal.

Explore More

1. What is Whirling Disorder?

2. Is Whirling Dosorder inherited in a dominant or recessive mannor? Why?
3. Individual 5 does not have Whirling disorder, but what colored pieces does it have that potentially could have carried the gene for Whirling Disorder? From whom did he inherit these pieces.
4. Which puzzle piece (gene) is responsible for Whirling Disorder?

Review

1. What is a pedigree?
2. How might a pedigree aid a scientist?

References

1. Zachary Wilson. Symbols of a pedigree, and an example pedigree . CC BY-NC 3.0

CONCEPT 37

Genetics Glossary

alleles
different forms of genes. A gene pair is made up of a pair of alleles.

amino acids
the building blocks of proteins.

cells
the building blocks of living organisms that perform the functions of the body needed to keep it functioning.

characteristics
the distinctive qualities of living things.

chromosomes
the cell parts that carry the genes.

cloning
making copies of a gene by using bacteria.

continuity
the phenomenon of living organisms producing offspring with similar characteristics.

deoxyribonucleic acid (DNA)
the molecule responsible for the inheritance of traits.

diversity
the variation (or difference) among living organisms.

dominant allele
an allele that is always expressed regardless of whether the other allele of its pair is the same or different.

fertilization
the event of an egg cell, ovum, combining with a sperm cell.

gamete cells
the cells used to reproduce.

gene
a segment or a piece of DNA that codes for a specific trait.

gene mapping
the process of determining the location of a gene on a chromosome.

genetic counseling
a profession that is concerned with helping people who may have genetic-related conditions.

genetic engineering
the process of getting genes to produce their proteins their proteins in the laboratory.

genetics
the study of the biological causes of continuity and diversity among living things.

genome
all the DNA genes of a species.

genotype
the genetic makeup for a given individual.

heredity
the process of passing on traits and variations from one generation to the next.

heterozygous
members of a gene pair are different (e.g., Tt).

homozygous
members of a gene pair are the same (e.g., TT or tt).

karyotype
a portrait of the chromosomes of a cell.

linked genes
genes close together on the same chromosome and inherited together.

meiosis
the process that produces gamete cells.

mitosis
cell division in which the nucleus divides, producing two cells each with the same number and exact type of chromosomes as the parent cell.

mRNA
messenger RNA that moves from the nucleus to the cytoplasm carrying the coded message from the

DNA in the nucleus to the cytoplasm.

nucleotides
four different complex chemical molecules that make up a DNA molecule. The four complex chemical molecules are adenine, guanine, cytosine, and thymine.

nucleus
the part of a cell that contains the genetic information.

ova
female gamete cells.

pedigree
a family tree that shows relationships among members of a family.

population geneticists
geneticists who are concerned about how and why some alleles are found in people in certain parts of the world and not others.

protein synthesis
the process of making proteins.

recessive allele
an allele that will only be expressed if the other allele of its pair is the same, also recessive.

replication
the duplication of DNA that occurs just before a cell divides.

ribosomes
structures where amino acids are joined together to make a protein.

RNA
a molecule very much like DNA, composed of nucleotides in a Single-strand molecule rather than a

double-stranded helix.

species
a group of living organisms that has similar characteristics and can interbreed (reproduce among

themselves).

sperm
male gamete cells.

trait
a characteristic that can be passed from generation to generation.

tRNA
transfer RNA that carries amino acids to the ribosomes where protein is assembled.

variation
the characteristics that make members of the same species different from one another. Variations are the different forms of a trait.

X-linked
genes for these traits are part of the X chromosome, but are not on the Y chromosome. This is

because the X chromosome is larger and possesses more genes.

zygote
a fertilized egg.

CONCEPT 38 Types of Animal Tissues

Animal Tissues

A **tissue** is a group of connected cells that have a similar function within an organism.

There are four basic types of tissue in the body of all animals, including the human body. These make up all the organs, structures and other contents of the body. figure below shows an example of each tissue type.

The four basic types of animal tissue are:

- **Epithelial tissue** is made up of layers of tightly packed cells that line the surfaces of the body for protection, secretion, and absorption. Examples of epithelial tissue include the skin, the lining of the mouth and nose, and the lining of the digestive system.
- **Muscle tissue** is made up of cells contain contractile filaments that move past each other and change the size of the cell. There are three types of muscle tissue: smooth muscle which is found in the inner linings of organs; skeletal muscle, which is attached to bone and moves the body; and cardiac muscle which is found only in the heart.
- **Nervous tissue** is made up of the nerve cells (neurons) that together form the nervous system, including the brain and spinal cord.
- **Connective tissue** is made up of many different types of cells that are all involved in structure and support of the body. Bone, blood, fat, and cartilage are all connective tissues. Connective tissue can be densely packed together, as bone cells are, or loosely packed, as adipose tissue (fat cells) are.

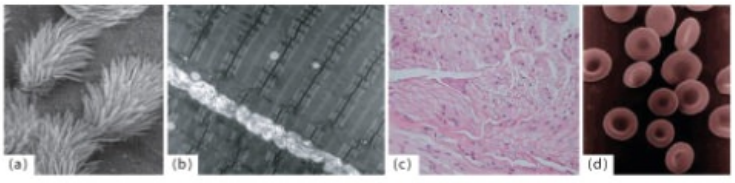
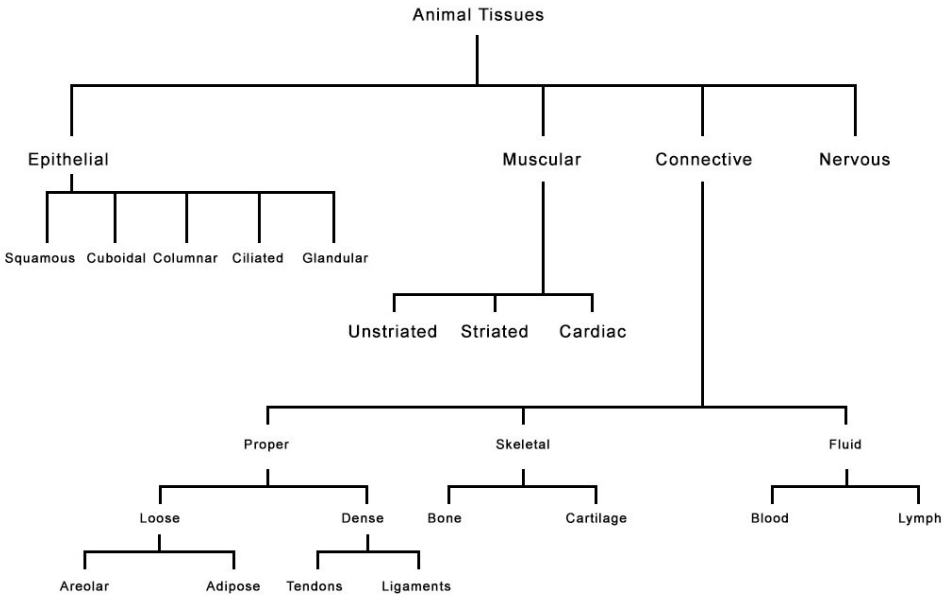
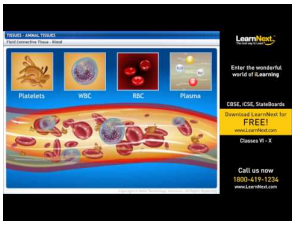


FIGURE 38.1

(a) Scanning electron micrograph (SEM) image of lung trachea epithelial tissue, (b) Transmission electron micrograph (TEM) image of skeletal muscle tissue, (c) Light microscope image of neurons of nervous tissue, (d) red blood cells, a connective tissue.



Check out the following video which beautifully gives a complete overview of all animal tissues.



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Watch the video at: https://www.youtube.com/watch?v=otoiSr7lb88

3.1 Epithelial Tissue

1. They cover the body, organs, blood vessels and all body cavities.
2. The cells are thin and lower most layer rest in a basement membrane.
3. Basically protective. Could be secretory and absorptive in function.

Types: They are of two types.

1. Simple (made up of one layer of cells) and
2. Stratified (made up of number of layers of cells)

1. **Simple:**

i) **Simple epithelium:** Made up of one layer of cells. Depending on the shape of cells, it could be of following types.

ii) **Simple suamous epithelium:** Made up of thin, flattened cells. Form lining of mouth, lungs and capillaries. Allow exchange of gases and materials.

iii) **Simple cuboidal epithelium:** Made up of cube like cells. Present in kidney tubules. Secretory and absorptive in function.

iv) **Simple columnar epithelium:** Made up of long column-like cells with generally nuclei at the base. Present in the lining of stomach, intestine, salivary glands. Secretory and absorptive in function.

2. **Stratified epithelium:** Made up of number of layers of cells. Covers the body. Protective in function.

3.2 Muscular Tissue

Smooth, Skeletal, and Cardiac Muscles

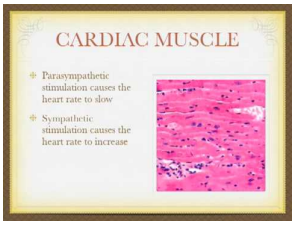
What exactly are muscles?

Does the word "muscle" make you think of the biceps of a weightlifter, like the man in pictured above? Muscles such as biceps that move the body are easy to feel and see, but they aren't the only muscles in the human body. Many muscles are deep within the body. They form the walls of internal organs such as the heart and stomach. You can flex your biceps like a body builder, but you cannot control the muscles inside you. It's a good thing that they work on their own without any conscious effort on your part, because movement of these muscles is essential for survival.

What Are Muscles?

The **muscular system** consists of all the muscles of the body. Muscles are organs composed mainly of muscle cells, which are also called **muscle fibers**. Each muscle fiber is a very long, thin cell that can do something no other cell can do. It can contract, or shorten. Muscle contractions are responsible for virtually all the movements of the body, both inside and out. There are three types of muscle tissues in the human body: cardiac, smooth, and skeletal muscle tissues. They are shown in figure below and described below.

You can also watch an overview of the three types at this link: http://www.youtube.com/watch?v=TermIXEkavY



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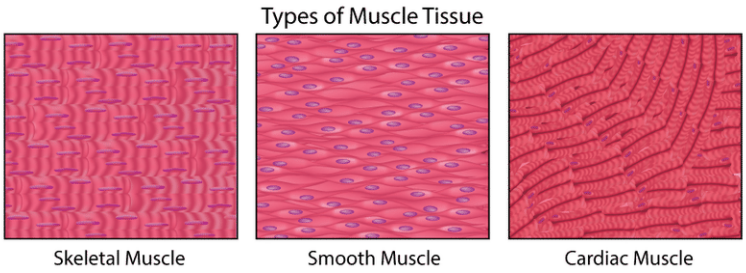

FIGURE 38.2

Types of Muscle Tissue. Both skeletal and cardiac muscles appear striated, or striped, because their cells are arranged in bundles. Smooth muscles are not striated because their cells are arranged in sheets instead of bundles.

Smooth Muscle

Muscle tissue in the walls of internal organs such as the stomach and intestines is **smooth muscle**. When smooth muscle contracts, it helps the organs carry out their functions. For example, when smooth muscle in the stomach contracts, it squeezes the food inside the stomach, which helps break the food into smaller pieces. Contractions of smooth muscle are involuntary. This means they are not under conscious control.

Skeletal Muscle

Muscle tissue that is attached to bone is **skeletal muscle**. Whether you are blinking your eyes or running a marathon, you are using skeletal muscle. Contractions of skeletal muscle are voluntary, or under conscious control. Skeletal muscle is the most common type of muscle in the human body.

Cardiac Muscle

Cardiac muscle is found only in the walls of the heart. When cardiac muscle contracts, the heart beats and pumps blood. Cardiac muscle contains a great many mitochondria, which produce ATP for energy. This helps the heart resist fatigue. Contractions of cardiac muscle are involuntary, like those of smooth muscle. Cardiac muscle, like skeletal muscle, is arranged in bundles, so it appears **striated**, or striped.

Summary

- There are three types of human muscle tissue: smooth muscle (in internal organs), skeletal muscle, and cardiac muscle (only in the heart).

Practice

- **Muscles Game** at http://www.bbc.co.uk/science/humanbody/body/index_interactivebody.shtml .

Review

1. Compare and contrast the three types of muscle tissue.
2. What can muscle cells do that other cells cannot?
3. Why are skeletal and cardiac muscles striated?
4. Where is smooth muscle tissue found?
5. What is the function of skeletal muscle?

Muscular System Structure and Function - Example 1

Three Types of Muscle Tissue

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URL: http://www.ck12.org/flx/render/embeddedobject/131766

Watch the video at: http://www.ck12.org/flx/render/embeddedobject/131766

3.3 Connective Tissue

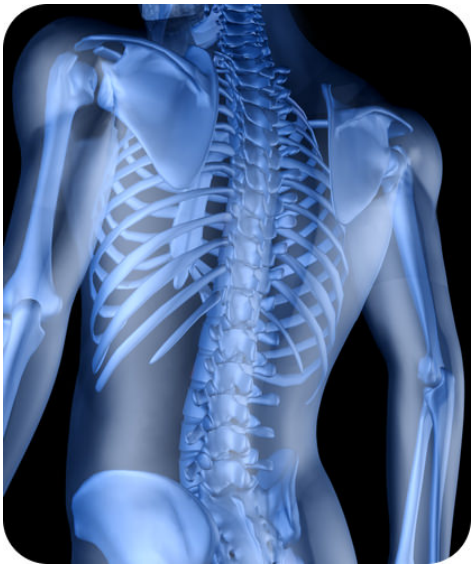
Connective tissues are made up of fibrous cells. Blood and Bone are good examples of specialized connective tissues. The cells of the connective tissue are separated by non-living material called extracellular matrix. These tissues help to hold other tissues together like during the formation of organs and have the ability to stretch and contract positively.

Bone Tissues

Bones consist of different types of tissue, including compact bone, spongy bone, bone marrow, and periosteum. All of these tissue types are shown in figure below.

- **Compact bone** makes up the dense outer layer of bone. Its functional unit is the **osteon**. Compact bone is very hard and strong.
- **Spongy bone** is found inside bones and is lighter and less dense than compact bone. This is because spongy bone is porous.
- **Bone marrow** is a soft connective tissue that produces blood cells. It is found inside the pores of spongy bone.
- **Periosteum** is a tough, fibrous membrane that covers and protects the outer surfaces of bone.

Human Skeletal System



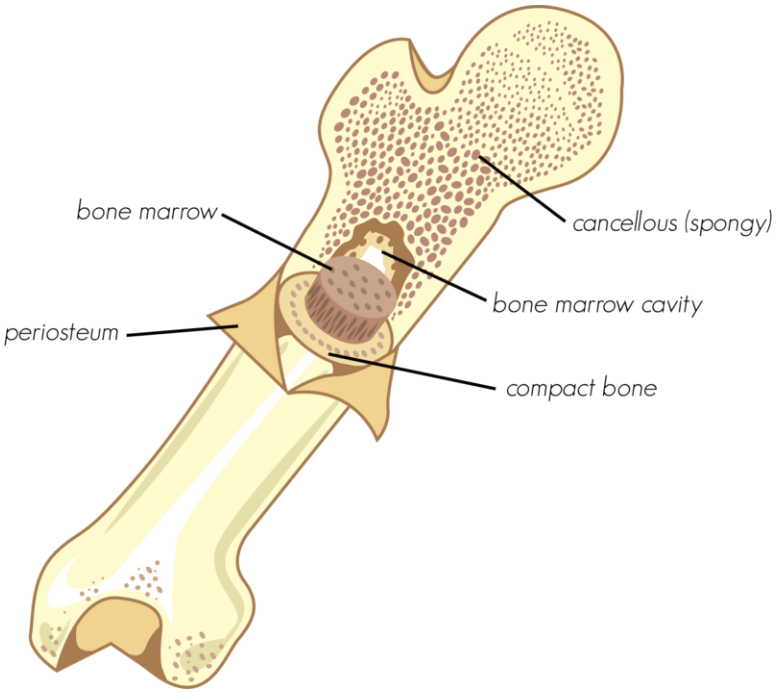


FIGURE 38.3

This bone contains different types of bone tissue. How does each type of tissue contribute to the functions of bone?

The skeletal system consists of all the bones of the body. How important are your bones?

Try to imagine what you would look like without them. You would be a soft, wobbly pile of skin, muscles, and internal organs, so you might look something like a very large slug. Not that you would be able to see yourself—folds of skin would droop down over your eyes and block your vision because of your lack of skull bones. You could push the skin out of the way, if you could only move your arms, but you need bones for that as well!

The Skeleton

The human skeleton is an internal framework that, in adults, consists of 206 **bones**, most of which are shown in figure below. Learn more about bones in the animation "Bones Narrated": http://medtropolis.com/virtual-body/

In addition to bones, the skeleton also consists of cartilage and ligaments:

- **Cartilage** is a type of dense connective tissue, made of tough protein fibers, that provides a smooth surface for the movement of bones at joints.
- A **ligament** is a band of fibrous connective tissue that holds bones together and keeps them in place.

The skeleton supports the body and gives it shape. It has several other functions as well, including:

1. Protecting internal organs
2. Providing attachment surfaces for muscles
3. Producing blood cells
4. Storing minerals
5. Maintaining mineral homeostasis.

Maintaining **mineral homeostasis** is a very important function of the skeleton, because just the right levels of calcium and other minerals are needed in the blood for normal functioning of the body. When mineral levels in the blood are too high, bones absorb some of the minerals and store them as mineral salts, which is why bones are

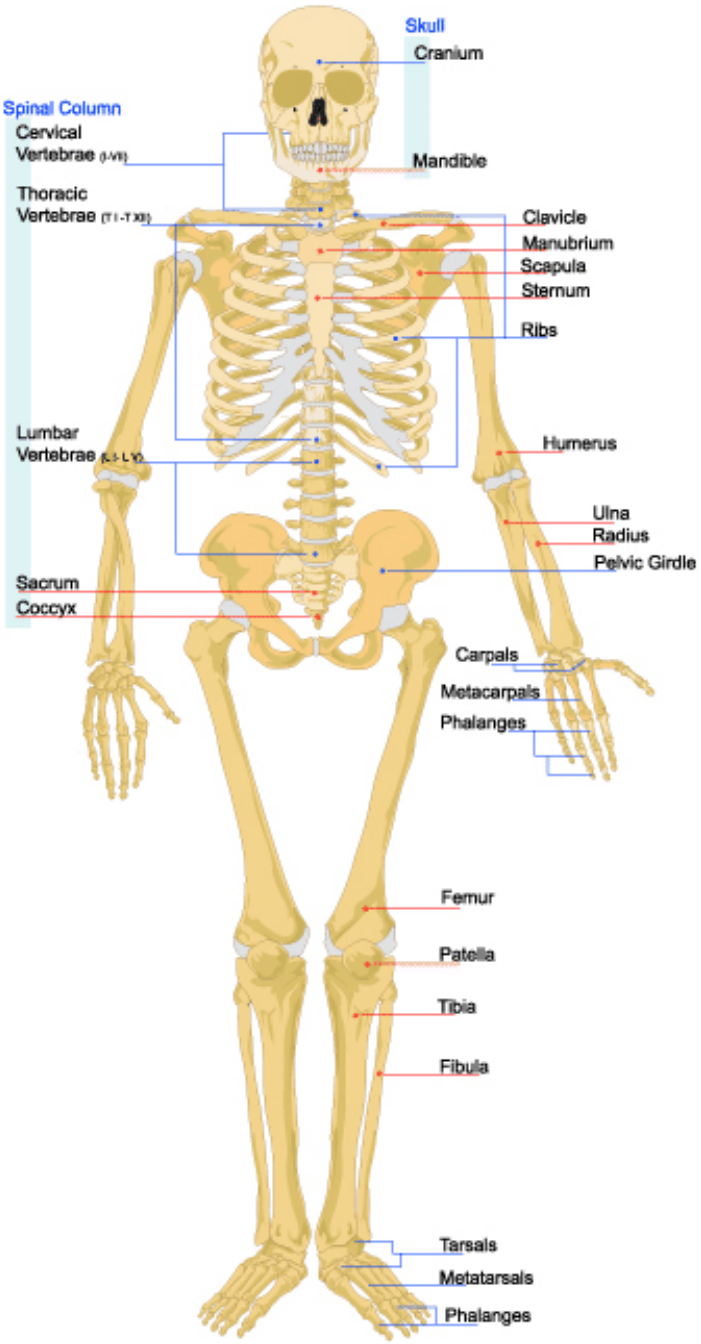


FIGURE 38.4

The human skeleton consists of bones, cartilage, and ligaments.

so hard. When blood levels of minerals are too low, bones release some of the minerals back into the blood, thus restoring homeostasis.

Summary

- The adult human skeleton includes 206 bones and other tissues.
- The skeleton supports the body, protects internal organs, produces blood cells, and maintains mineral homeostasis.

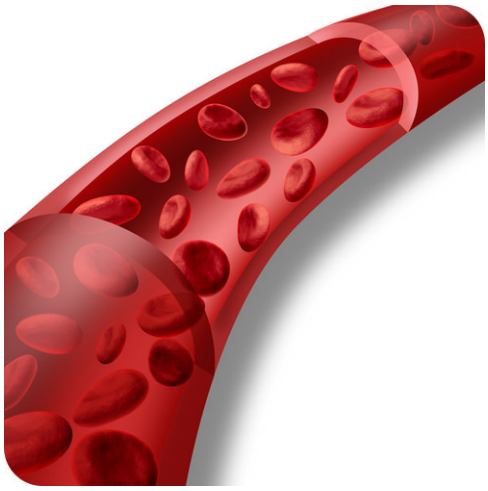
Practice

- **Skeleton Game** at: http://www.bbc.co.uk/science/humanbody/body/index_interactivebody.shtml

Review

1. What is cartilage? What is its role in the skeletal system?
2. List three functions of the human skeleton.
3. Explain how bones maintain mineral homeostasis in the body.

Blood



What exactly is blood?

All your cells need oxygen, as oxygen is the final electron acceptor during cellular respiration. How do they get this oxygen? From blood. Blood cells flow through the vessels of the human circulatory system. But what exactly is blood? It does transport oxygen, but also has other functions.

Blood

Blood is a fluid connective tissue. It circulates throughout the body through blood vessels by the pumping action of the heart. Blood in arteries carries oxygen and nutrients to all the body's cells. Blood in veins carries carbon dioxide and other wastes away from the cells to be excreted. Blood also defends the body against infection, repairs body tissues, transports hormones, and controls the body's pH.

Composition of Blood

The fluid part of blood is called **plasma**. It is a watery golden-yellow liquid that contains many dissolved substances and blood cells. Types of blood cells in plasma include red blood cells, white blood cells, and platelets (see figure below). You can learn more about blood and its components by watching the animation "What Is Blood?" at this link: http://www.apan.net/meetings/busan03/materials/ws/education/demo-los/blood-rlo/whatisblood.swf .

- The trillions of **red blood cells** in blood plasma carry oxygen. Red blood cells contain **hemoglobin**, a protein with iron that binds with oxygen.

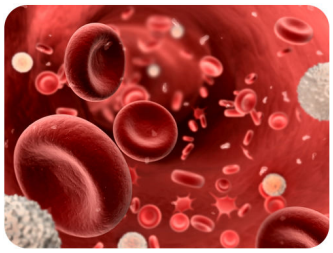
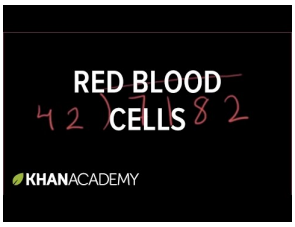


FIGURE 38.5

Cells in blood include red blood cells, white blood cells, and platelets.

- **White blood cells** are generally larger than red blood cells but far fewer in number. They defend the body in various ways. For example, white blood cells called **phagocytes** swallow and destroy microorganisms and debris in the blood.
- **Platelets** are cell fragments involved in blood clotting. They stick to tears in blood vessels and to each other, forming a plug at the site of injury. They also release chemicals that are needed for clotting to occur.

An overview of red blood cells can be viewed at http://www.youtube.com/watch?v=fLKOBQ6cZHA (16:30).



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Hemoglobin is discussed in detail at http://www.youtube.com/watch?v=LWtXthfG9_M (14:34).

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3.4 Nervous Tissue

Neuron Structure

As shown in figure below, a neuron consists of three basic parts: the cell body, dendrites, and axon. You can watch an animation of the parts of a neuron at this link: http://www.garyfisk.com/anim/neuronparts.swf .

- The **cell body** contains the nucleus and other cell organelles.
- **Dendrites** extend from the cell body and receive nerve impulses from other neurons.
- The **axon** is a long extension of the cell body that transmits nerve impulses to other cells. The axon branches at the end, forming **axon terminals**. These are the points where the neuron communicates with other cells.

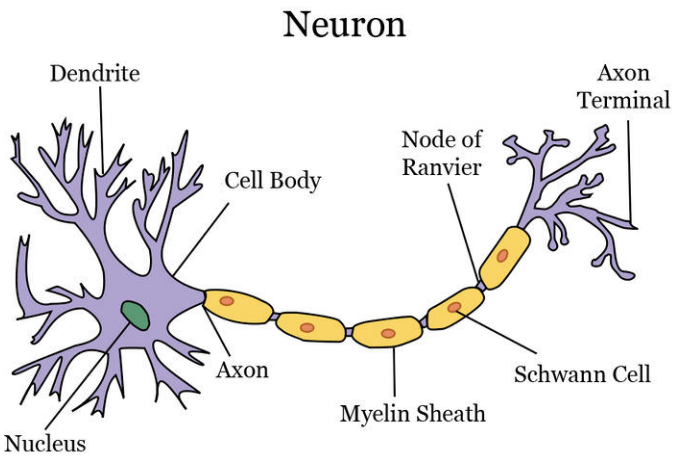
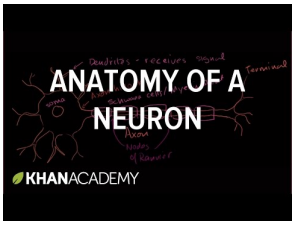


FIGURE 38.6

The structure of a neuron allows it to rapidly transmit nerve impulses to other cells.

The neuron is discussed at: http://www.youtube.com/watch?v=ob5U8zPbAX4 (6:13).



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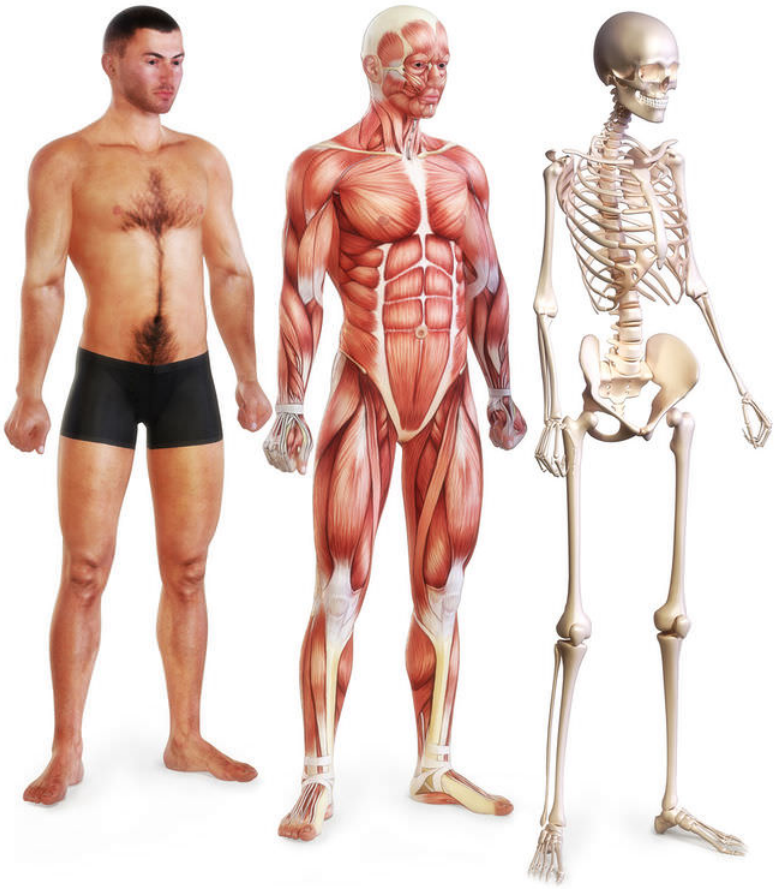
References

1. . Bio35a-1-n1.
2. Zachary Wilson. Types of muscle tissue.
3. Christopher Auyeung. Types of tissue in bone.
4. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons). Components of the skeletal system.
5. Image copyright Sebastian Kaulitzki, 2014. Components cells of blood.
6. Dhp1080. .

CONCEPT 39 Tissues of the Human Body - Advanced

Learning Objectives

- Identify the four tissue types found in the human body.



Muscle, connective, skeletal, and epithelial. What do these have in common?

Tissues

A **tissue** is a group of connected cells that have a similar function within an organism. The simplest living, multicellular organisms, sponges, are made of many specialized types of cells that work together for a common goal. Such cell types include digestive cells, tubular pore cells, and epidermal cells. Though the different cell types create a large organized, multicellular structure—the visible sponge—they are not organized into true tissues. If a sponge is broken up by passing it through a sieve, the sponge will reform on the other side.

More complex organisms, such as jellyfish, coral, and sea anemones, have a tissue level of organization. For example, jellyfish have tissues that have separate protective, digestive, and sensory functions. There are four basic

types of tissues in the bodies of all animals including the human body. These make up all the organs, structures, and other contents of the body. **Figure** 39.2 shows an example of each tissue type. The four basic types of tissues are epithelial, muscle, nervous, and connective.

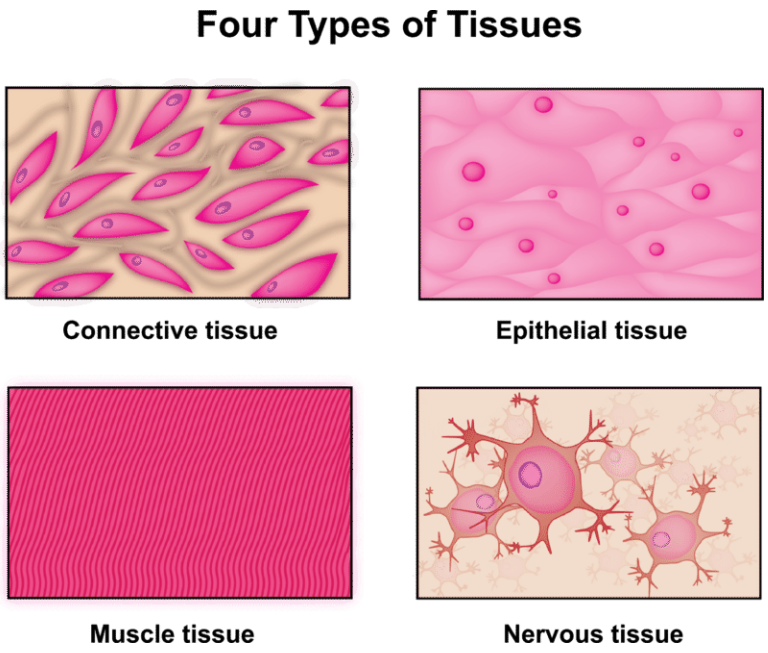


FIGURE 39.1

The human body consists of these four tissue types.

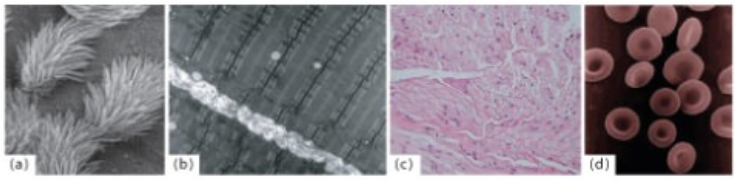


FIGURE 39.2

(a) A scanning electron micrograph (SEM) image of lung trachea epithelial tissue. (b) A transmission electron micrograph (TEM) image of skeletal muscle tissue. (c) A light microscope image of neurons of nervous tissue. (d) Red blood cells, a connective tissue.

Epithelial tissue is made up of a layer or layers of tightly packed cells that line the surfaces of the body. The largest example of epithelial tissue (also the largest organ in the human body) is the skin. Mammalian skin consists of stratified epithelium, which has several layers of cells. The outermost layers of cells, called squamous cells, are flat plate-like cells, while the deeper layers are roughly cube shaped and called cuboidal cells. Epithelial tissue has multiple functions, but it serves primarily to protect, absorb, and secrete. As you probably already know, our skin organ covers our entire body and protects underlying tissues from bacteria, chemicals, and other injury. Epithelial cells also line the small intestine where they absorb nutrients, and similar cells in the glands secrete enzymes and hormones.

Muscle tissue encompasses not only the muscles, such as those in our legs or fingers, that we actively control, but also the tissue that forms most of our internal organs. There are three types of muscle tissue: skeletal, cardiac, and smooth. Skeletal muscle tissue forms what we think of as our muscles; it is attached to our bones by our tendons and can be relaxed or contracted voluntarily. Similar in structure to skeletal muscle, cardiac muscle is found exclusively in the walls of the heart. The major difference, however, is that cardiac muscle is involuntary and cannot be actively controlled. Similarly, smooth muscle, which forms the muscle layers in internal organs such as the digestive tract

and bladder, is an involuntary tissue. Smooth muscle tissue controls slow involuntary movements such as stomach wall contractions and the contractions of arteries to regulate blood flow.

Nervous tissue is made up of the nerve cells (neurons) that form the nervous system, including the brain and spinal cord. These cells are especially responsive to stimuli, allowing nervous tissue to transmit stimuli from the brain to the body extremely rapidly.

Connective tissue connects, supports, or separates other tissues and organs. Connective tissue proper, a form of connective tissue, can be either loose or dense. Adipose tissue, or fat, is loose connective tissue, while tendons and ligaments, composed of collagen, are examples of dense connective tissue. Other forms of connective tissue include blood (fluid connective tissue) and cartilage and bone (both forms of supporting connective tissue).

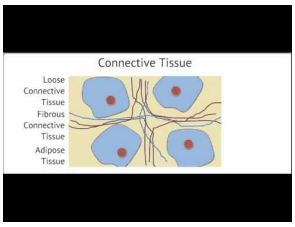
Summary

- Tissues are composed of cells, and multiple tissues together constitute an organ.
- The human body has four types of tissues: nervous, muscle, connective, and epithelial

Review

1. What are the four types of tissues? Give an example of each.
2. What is the difference between tissue and cellular level organization?
3. Are there any organisms that do not have tissue structures? If yes, what organism(s)?

Explore More



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Use the video above to answer the following questions:

1. What are some different types of connective tissue?
2. What is the extracellular matrix?
3. What are the differences between skeletal, cardiac, and smooth muscle tissue?

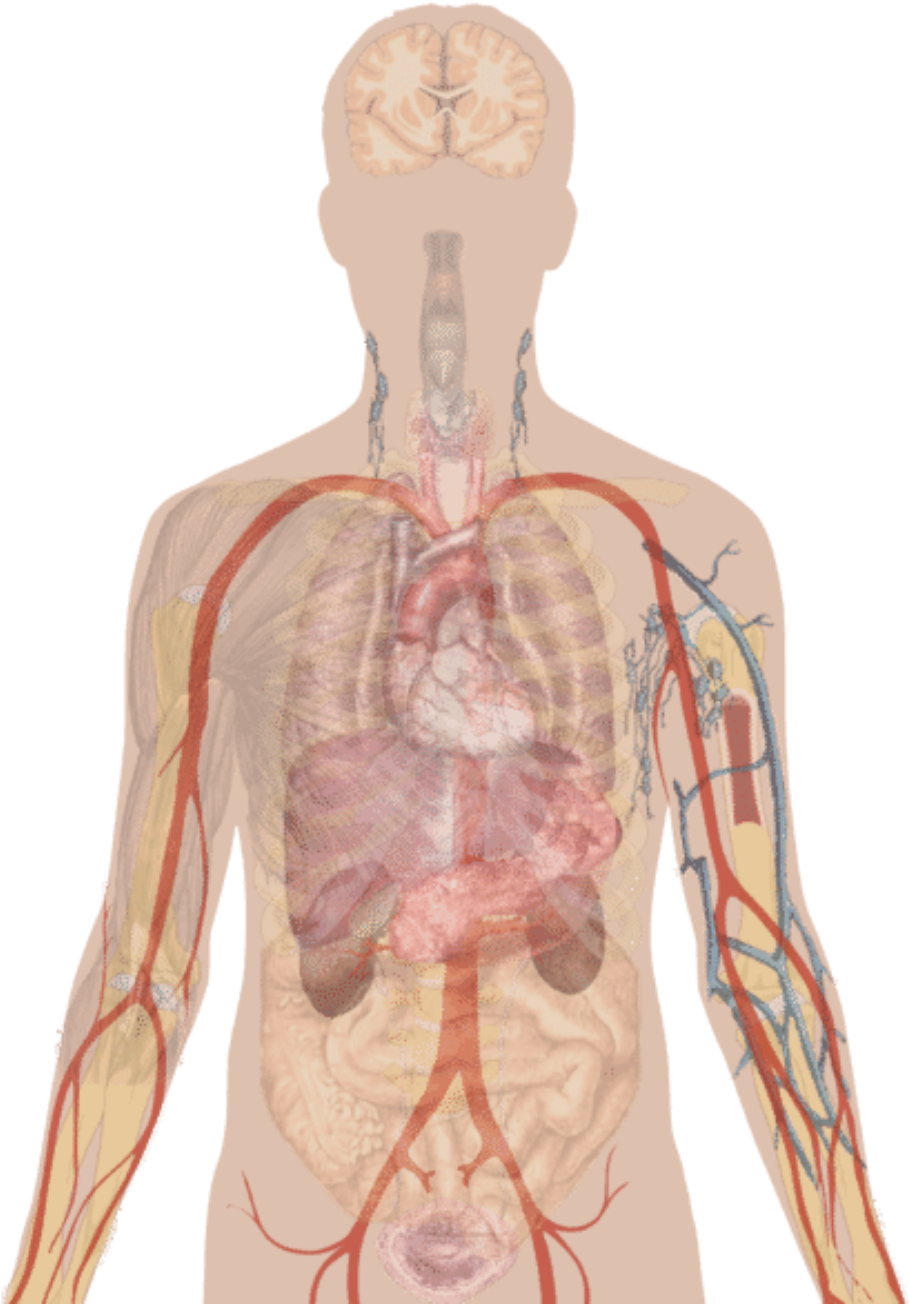
References

1. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0
2. Drs. Noguchi, Rodgers, and Schechter of NIDDK. http://remf.dartmouth.edu/images/mammalianLungSEM/source/9.html http://remf.dartmouth.edu/images/humanMuscleTEM/source/2.html http://commons.wikimedia.org/wiki/Image:Redbloodcells.jpg . (a) Public Domain (b) Public Domain (d) Public Domain

CONCEPT 40 Human Organs and Organ Systems - Advanced

Learning Objectives

- Summarize how tissues and organs relate to each other.
- Identify the defining features of organs and organ systems.
- Understand the relationship between organs and organ systems.



Organs and Organ Systems

Organs are the next level of organization in the body. An **organ** is a structure made of two or more tissues that work together for a common purpose. Skin, the largest organ in the body, is shown in **Figure** 40.1. Organs can be as primitive as the brain of a flatworm (a group of nerve cells), as large as the stem of a sequoia (up to 90 meters (300 feet) in height), or as complex as a human liver. The human body has many different organs including the heart, the kidneys, the pancreas, and the skin. Two or all of the tissue types can be found in each organ. Organs inside the body are called internal organs. The internal organs collectively are often called **viscera.**

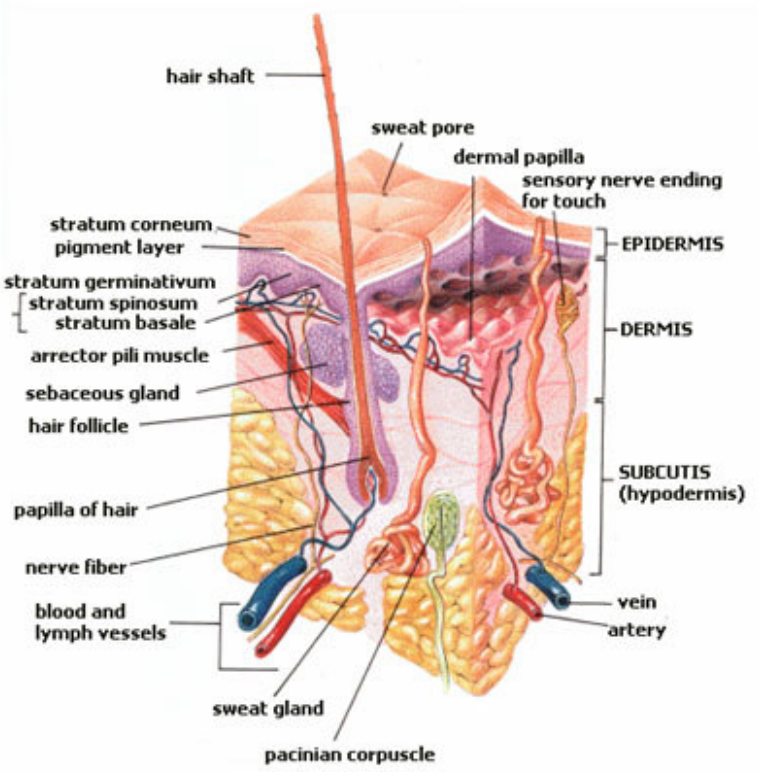


FIGURE 40.1

Your skin is the largest organ in your body. In this cross section image of skin, the four different tissue types (epithelial, connective, nervous, and muscle tissues) can be seen working together.

The most complex organisms have organ systems. An **organ system** is a group of organs that act together to carry out complex, interrelated functions, with each organ focusing on a subset of the task. For example, the human digestive system is an organ system in which the mouth and esophagus ingest food, the stomach crushes and liquefies it, the pancreas and gall bladder make and release digestive enzymes, and the intestines absorb nutrients into the blood. An organ can be part of more than one organ system. For example, the ovaries produce hormones, which makes them a part of the endocrine system; the ovaries also make eggs, which makes them a part of the reproductive system as well. One of the most important functions of organ systems is to provide cells with oxygen and nutrients and to remove toxic waste products such as carbon dioxide. A number of organ systems, including the cardiovascular and respiratory systems, work together to do this.

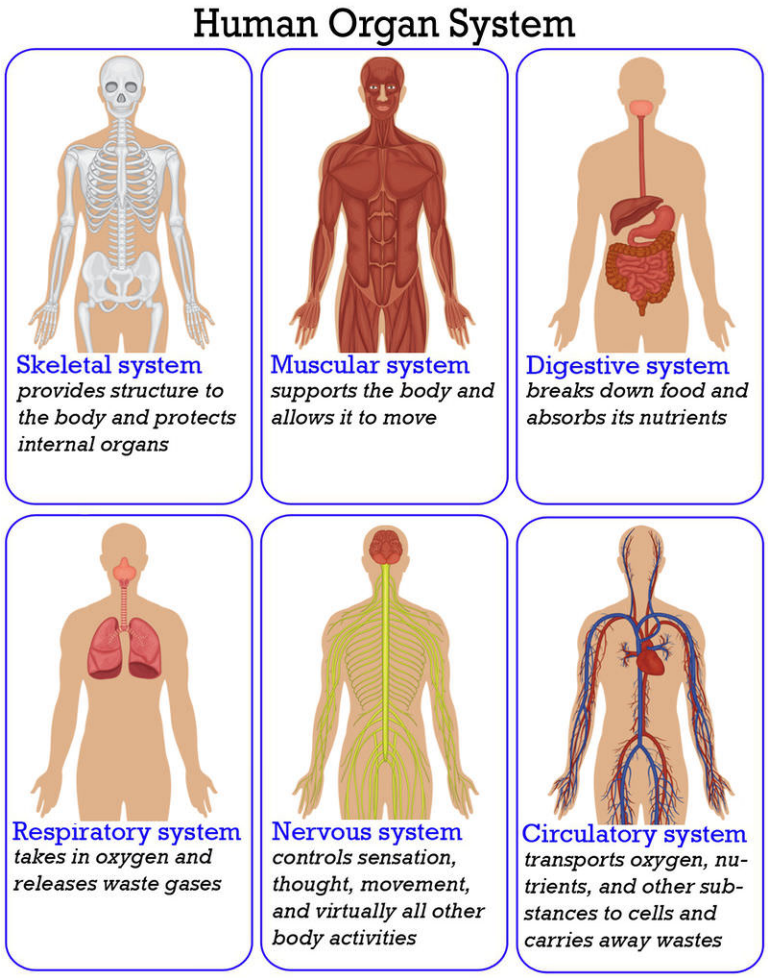


FIGURE 40.2

Many of the organ systems that make up the human body are represented here. What is the overall function of each organ system?

The different organ systems of the body are shown in **Table** 40.1. Sometimes the cardiovascular system and the lymphatic system are grouped together into one single system called the circulatory system.

TABLE 40.1: Major Organ Systems of the Human Body

Organ System	Function	Organs, Tissues, and Structures Involved
Cardiovascular	Transports oxygen, nutrients, and other substances to the cells, and transports wastes, carbon dioxide, and other substances away from the cells; it can also help stabilize body temperature and pH.	Heart, blood, and blood vessels.
Lymphatic	Defends against infection and disease. Transfers lymph between tissues and the blood stream.	Lymph, lymph nodes, and lymph vessels.
Digestive	Processes foods and absorbs nutrients, minerals, vitamins, and water.	Salivary glands, esophagus, stomach, liver, gallbladder, pancreas, small intestine, and large intestine.

TABLE 40.1: (continued)

Organ System	Function	Organs, Tissues, and Structures Involved
Endocrine	Provides communication within the body via hormones. Directs long-term change over other organ systems to maintain homeostasis.	Pituitary gland, pineal gland, thyroid, parathyroid gland, adrenal glands, testes, and ovaries.
Integumentary	Provides protection from both injury and fluid loss and provides physical defense against infection by microorganisms. Controls temperature.	Skin, hair, and nails.
Muscular	Provides movement, support, and heat production.	Tendons, skeletal, cardiac, and smooth muscles.
Nervous	Collects, transfers, and processes information. Directs short-term change over other organ systems in order to maintain homeostasis.	Brain, spinal cord, nerves, and sensory organs (eyes, ears, tongue, skin, and nose).
Reproductive	Produces gametes (sex cells) and sex hormones; ultimately produces offspring.	Fallopian tubes, uterus, vagina, ovaries, mammary glands, testes, vas deferens, seminal vesicles, prostate, and penis.
Respiratory	Delivers air to sites where gas exchange can occur between the blood and cells (around body) or blood and air (lungs).	Mouth, nose, pharynx, larynx, trachea, bronchi, lungs, and diaphragm.
Skeletal	Supports and protects soft tissues of the body. Provides movement at joints, produces blood cells, and stores minerals.	Bones, cartilage, and ligaments.
Urinary	Removes excess water, salts, and waste products from the blood and body. Controls pH.	Kidneys, ureters, urinary bladder, and urethra.
Immune	Defends against microbial pathogens (disease-causing agents) and other diseases.	Leukocytes, tonsils, adenoids, thymus, and spleen.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/139383

Summary

- Organs are structures composed of two or more tissues; organ systems are systems composed of two or more organs.
- Organ systems carry out complex tasks, with each organ completing one aspect of the task.

Review

1. What is the difference between an organ and an organ system?
2. How many major organ systems are there? What are they?

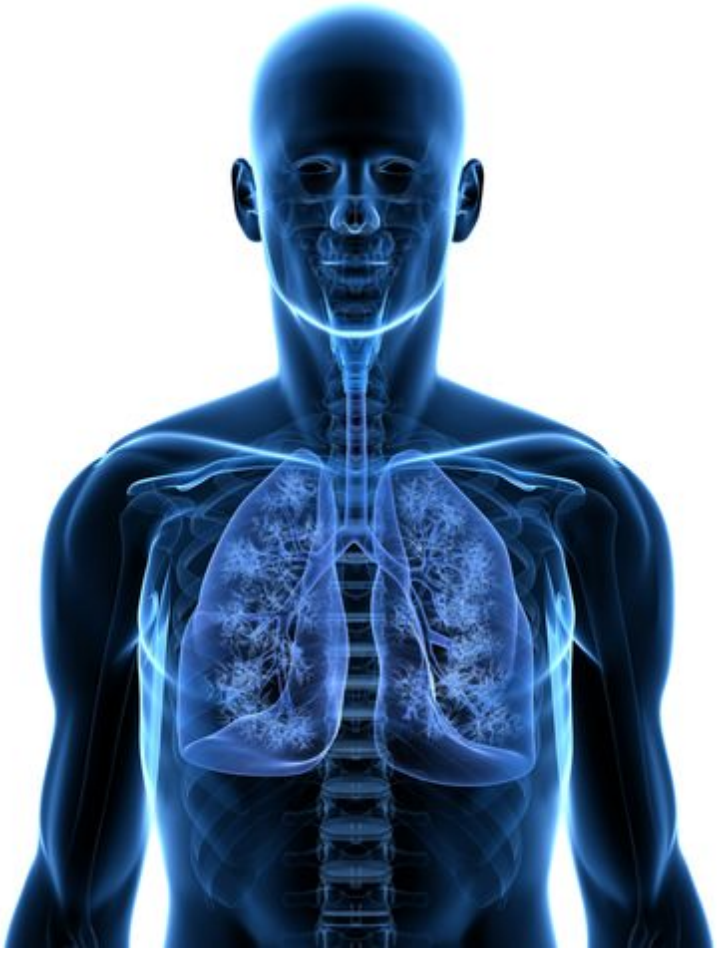
References

1. . http://upload.wikimedia.org/wikipedia/commons/3/34/Skin.jpg . Public Domain
2. Image copyright Matthew Cole, 2014. http://www.shutterstock.com . Used under licenses from Shutterstock.com

CONCEPT 41 The Respiratory System - Advanced

Learning Objectives

- Understand a broad overview pertaining to the function of the respiratory system.



Where does oxygen get into blood?

Red blood cells are like trucks that transport cargo on a highway system. Their cargo is oxygen, and the highways are blood vessels. Where do red blood cells pick up their cargo of oxygen? The answer is the lungs. The lungs are organs of the respiratory system. The respiratory system is the body system that brings air containing oxygen into the body and releases carbon dioxide into the atmosphere.

The Respiratory System

Each day, you breathe about 20,000 times, and, by the time you're 70 years old, you'll have taken at least 600 million breaths.

Have you ever wondered what it would be like to have gills? You would breathe and look very different from the rest of us, but they would be great for swimming and diving! Despite such differences, the main functions of **lungs** and gills are the same: to obtain oxygen and to release carbon dioxide.

The primary functions of the human respiratory system are to obtain the oxygen for the cells of the body and to eliminate the carbon dioxide that cells produce. The respiratory system brings oxygen, O_2, into the body and releases carbon dioxide, CO_2, into the atmosphere. The respiratory system includes the respiratory airways leading into and out of the lungs and the lungs themselves. Oxygen is drawn in through the respiratory tract, which is shown in **Figure** 41.1, and is then delivered to the blood. The exchange of gases (O_2 and CO_2) between the alveoli in the lungs and the blood occurs by simple diffusion. The process of bringing oxygen into the respiratory tract is called **external respiration,** and it is an active process, requiring the contraction of skeletal muscles. The exchange of gases between the blood and the cells of the body is called **internal respiration.**

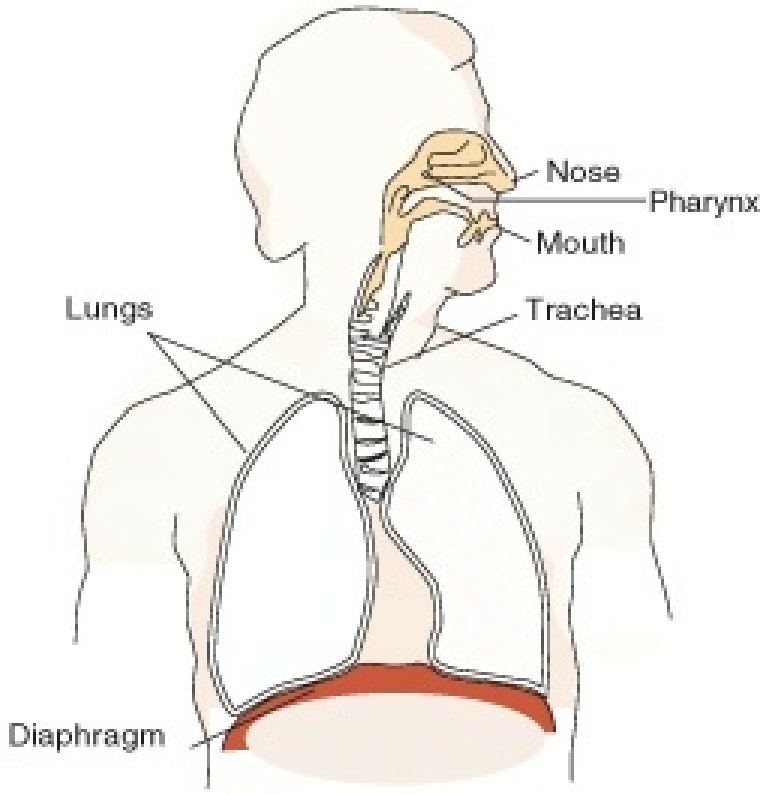


FIGURE 41.1

The respiratory system. Air moves down the trachea, a long straight tube in the chest. The diaphragm pulls air in and pushes it out. Respiratory systems of various types are found in a wide variety of organisms.

Multimedia

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/187010

Comparing Cellular Respiration and Respiration

Respiration is both the transportation of oxygen from the outside air to the cells of the body and the transportation of carbon dioxide in the opposite direction. This is in contrast to the biochemical definition of respiration, which refers to cellular respiration. **Cellular respiration** is the metabolic process by which an organism obtains energy by reacting oxygen with glucose to give water, carbon dioxide, and ATP (energy). Although respiration is necessary to sustain cellular respiration and thus life in animals, the processes are very different. Cellular respiration takes place in individual cells of the animal, while respiration involves the transport of metabolites between the organism and the external environment.

Summary

- The human respiratory system brings oxygen, O_2, into the body and releases carbon dioxide, CO_2, into the atmosphere.

Review

1. What is the difference between external and internal respiration?
2. What is the difference between respiration and cellular respiration?

References

1. Theresa Knott. http://commons.wikimedia.org/wiki/Image:Respiratory_system.svg . CC-BY-SA 2.5

CONCEPT 42 Circulatory Pathways (Open and Closed Circulatory System)

This section is not available in CK-12, little information needs to be added about this.

CONCEPT 43 Double Circulation - Pulmonary and Systemic Circulation

Circulatory System

How does oxygen get into the blood?

The main function of the circulatory system is to pump blood carrying oxygen around the body. But how does that oxygen get into the blood in the first place? You may already know that this occurs in the lungs. So the blood must also be pumped to the lungs, and this happens separately from the rest of the body.

Pulmonary and Systemic Circulations

The circulatory system actually consists of two separate systems: pulmonary circulation and systemic circulation. You can watch animations of both systems at the following link. http://www.pbs.org/wnet/redgold/journey/phase2_a1.html

Pulmonary Circulation

Pulmonary circulation is the part of the circulatory system that carries blood between the heart and lungs (the term "pulmonary" means "of the lungs"). It is illustrated in **Figure** 43.1. Deoxygenated blood leaves the right ventricle through pulmonary arteries, which transport it to the lungs. In the lungs, the blood gives up carbon dioxide and picks up oxygen. The oxygenated blood then returns to the left atrium of the heart through pulmonary veins.

Systemic Circulation

Systemic circulation is the part of the circulatory system that carries blood between the heart and body. It is illustrated in **Figure** 43.2. Oxygenated blood leaves the left ventricle through the aorta. The aorta and other arteries transport the blood throughout the body, where it gives up oxygen and picks up carbon dioxide. The deoxygenated blood then returns to the right atrium through veins.

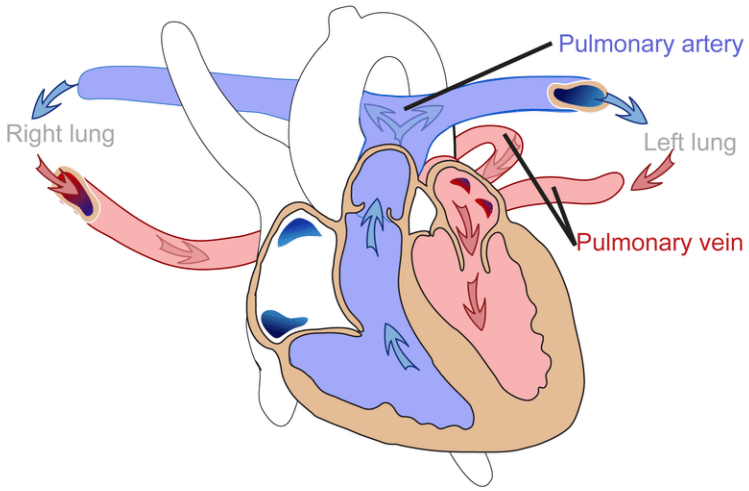


FIGURE 43.1

The pulmonary circulation carries blood between the heart and lungs.

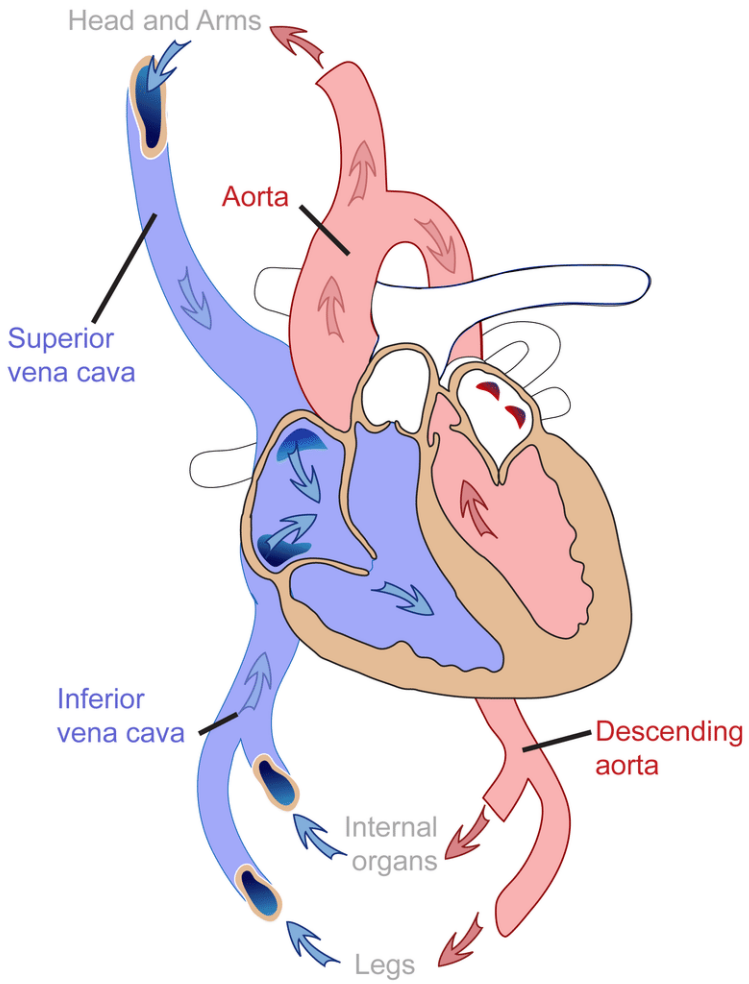


FIGURE 43.2

The systemic circulation carries blood between the heart and body.

Summary

- The pulmonary circulation carries blood between the heart and lungs.
- The systemic circulation carries blood between the heart and body.

Review

1. Compare and contrast the pulmonary and systemic circulations.

Circulatory System Structure and Function - Example 1

The Heart and the Path of Blood

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/144021

Watch the video at: http://www.ck12.org/flx/render/embeddedobject/144021

References

1. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Pulmonary circuit illustrated.
2. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Systematic circuit illustrated.

CONCEPT 44 The Cardiovascular System

Lesson Objectives

- Identify parts of the cardiovascular system.
- State functions of the cardiovascular system.

Lesson Vocabulary

- cardiovascular system

Introduction

What do you do for "cardio"?

"Cardio" has become slang for exercise. Cardio is the type of exercise that keeps your heart rate high. Cardio can include biking, running, or swimming. Cardio is short for cardiovascular system. Your heart is in this system. So are your blood and blood vessels. The cardiovascular system is the system of organs that delivers blood to all the cells of the body. It's like the body's lifeline. Without the cardiovascular system circulating your blood, you couldn't survive.

Parts of the Cardiovascular System

Of course, everyone has heard of the heart. It is the engine of your body. The heart and a network of blood vessels make up the cardiovascular system. The network of blood vessels runs throughout the body. The blood in the cardiovascular system is a liquid connective tissue. **Figure** 47.1 shows the heart and major vessels. You will notice it affects the entire body. The heart is basically a pump. It is what keeps the blood moving through the blood vessels.

Functions of the Cardiovascular System

Your cardiovascular system has many jobs. At times the cardiovascular system can work like a pump. This pump pushes your blood through your body. It helps you regulate temperature. It also supplies the cells with what they need to do their job. The cardiovascular system works with all the other organ systems in the body.

Every cell in your body depends on your cardiovascular system. If your cells don't receive what they need, they cannot survive. The main function of this system is to deliver oxygen to your cells. Blood receives oxygen in your lungs, which are a part of the respiratory system. Oxygen-rich blood is then pumped by your heart all around your body.

The cardiovascular system also plays a role in keeping your body temperature just right. It helps to keep you warm by moving warm blood around your body. Your blood vessels keep you from getting too hot or too cold. Your brain acts as the control center. If you are getting too hot, it sends a signal to the blood vessels in your skin. The skin receives these messages and the blood vessels expand. This action increases the amount of blood and heat to move near the skin's surface. The heat is then released from the skin. This helps you cool down. What do you think happens when you are cold? How would your blood vessels react?

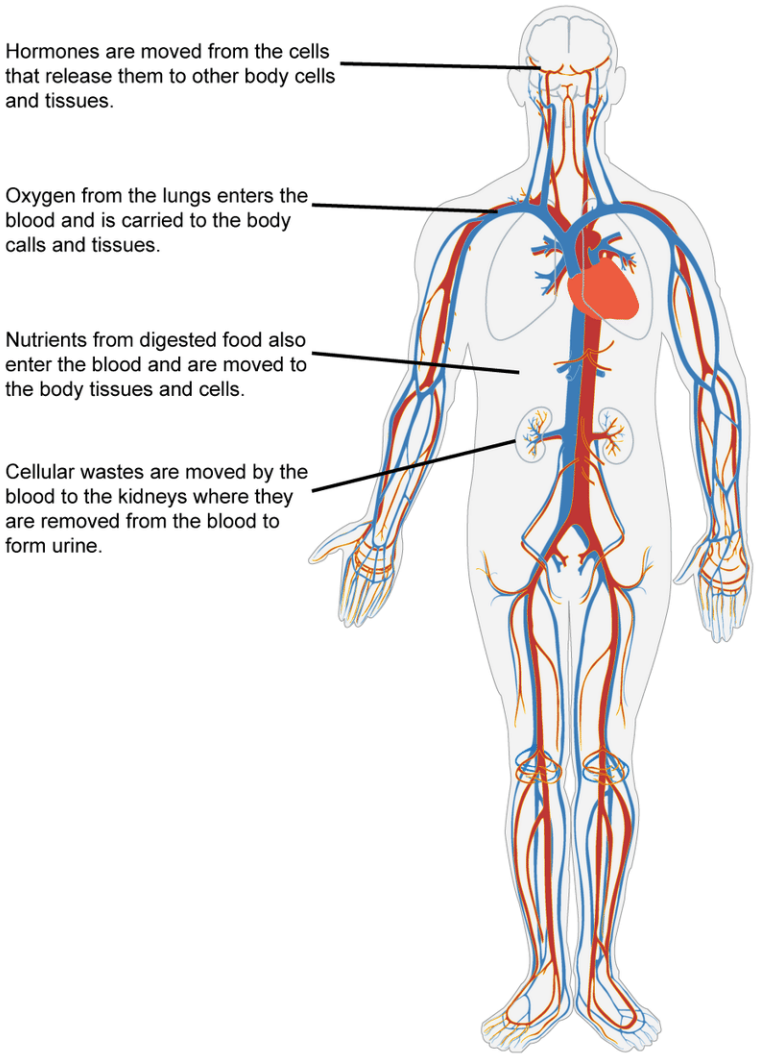


FIGURE 44.1

The cardiovascular system transports many substances to and from cells throughout the body.

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/137140

The blood also carries other special chemicals. These special chemicals are produced by organs of the endocrine system and carried through your body. These special chemicals are produced in one area of your body and have an effect on another. To get to that other area, they must travel through your blood. You may have heard of adrenaline. You may have heard the term, "My adrenaline is pumping." Adrenaline is produced by the adrenal glands on top of the kidneys . Adrenaline has multiple effects on the heart . We mostly feel its effects as a quicker heart rate.

Lesson Summary

- The cardiovascular system consists of the heart, a network of blood vessels, and blood. Blood is a liquid tissue. The heart is a pump that keeps blood flowing through the vessels of the system.
- The main function of the cardiovascular system is transport. It carries special chemicals, oxygen, nutrients, and cellular wastes around the body. The cardiovascular system also helps regulate body temperature by controlling blood flow.

Lesson Review Questions

Recall

1. List the parts of the cardiovascular system.
2. State two general functions of the cardiovascular system.

Apply Concepts

3. The cardiovascular system has been called the highway system of the body. Do you think this is a good analogy for the cardiovascular system? Why or why not?

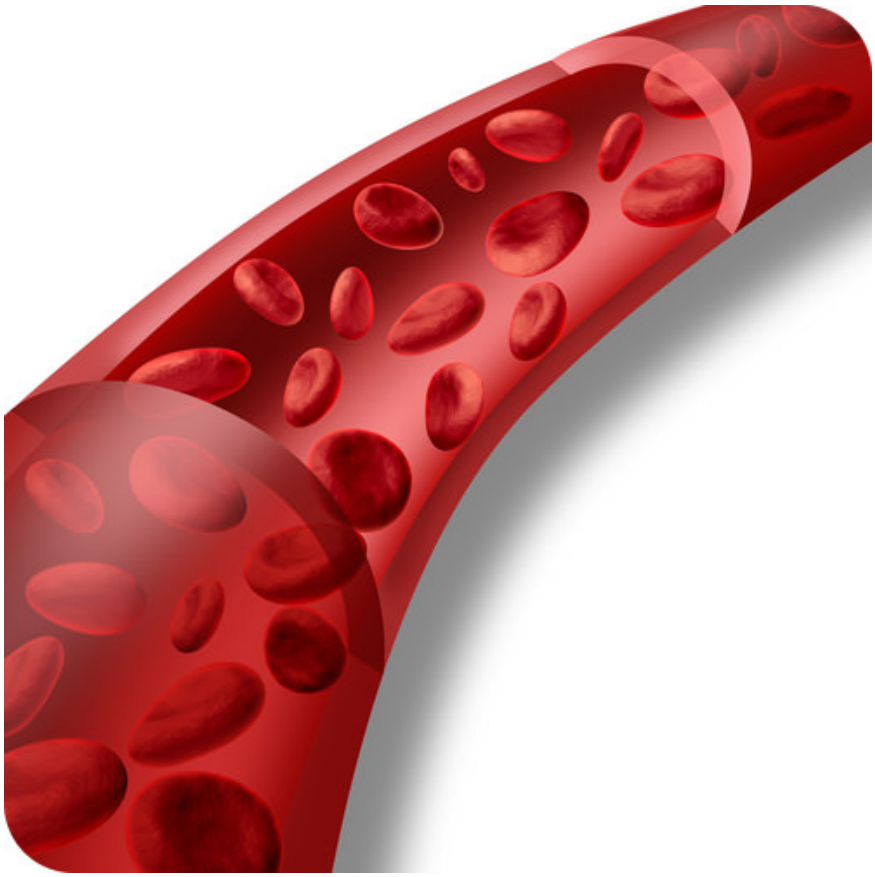
References

1. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons), modified by CK-12 Foundation. http://commons.wikimedia.org/wiki/File:Circulatory_System_no_tags.svg . Public Domain

CONCEPT 45 Composition of Blood - Advanced

Learning Objectives

- Understand the composition of blood and what plasma is.
- Differentiate between different blood cells.



What exactly is blood?

All your cells need oxygen, as oxygen is the final electron acceptor during cellular respiration. How do they get this oxygen? From blood. Blood cells flow through the vessels of the human circulatory system. But what exactly is blood? It does transport oxygen, but it also has other functions.

The Composition of Blood

Blood is a fluid connective tissue. It circulates around the body through the blood vessels due to the pumping action of the heart. Arterial blood carries oxygen and nutrients to all the body's cells, and venous blood carries carbon dioxide and other metabolic wastes away from the cells.

In addition to the transport of gases, nutrients, and wastes, blood has many other functions:

- The removal of waste, such as carbon dioxide, urea, and lactic acid, from the body tissues.

- Defending the body against infections by microorganisms or parasites.
- The repair of damaged body tissues.
- The transport of chemical messages such as hormones and hormone-like substances.
- The control of body pH (the normal pH of blood is in the range of 7.35 - 7.45).
- The control of body temperature.

Blood is a colloidal solution; it is made up of particles suspended in a fluid. It accounts for about 7% of the human body weight. The average adult has a blood volume of roughly 5 liters, which is composed of a fluid called plasma and several kinds of cells. Within the blood plasma are erythrocytes (red blood cells), leukocytes (white blood cells), thrombocytes (platelets), and other substances. The cells that make up the blood can be seen in **Figure** 45.1.

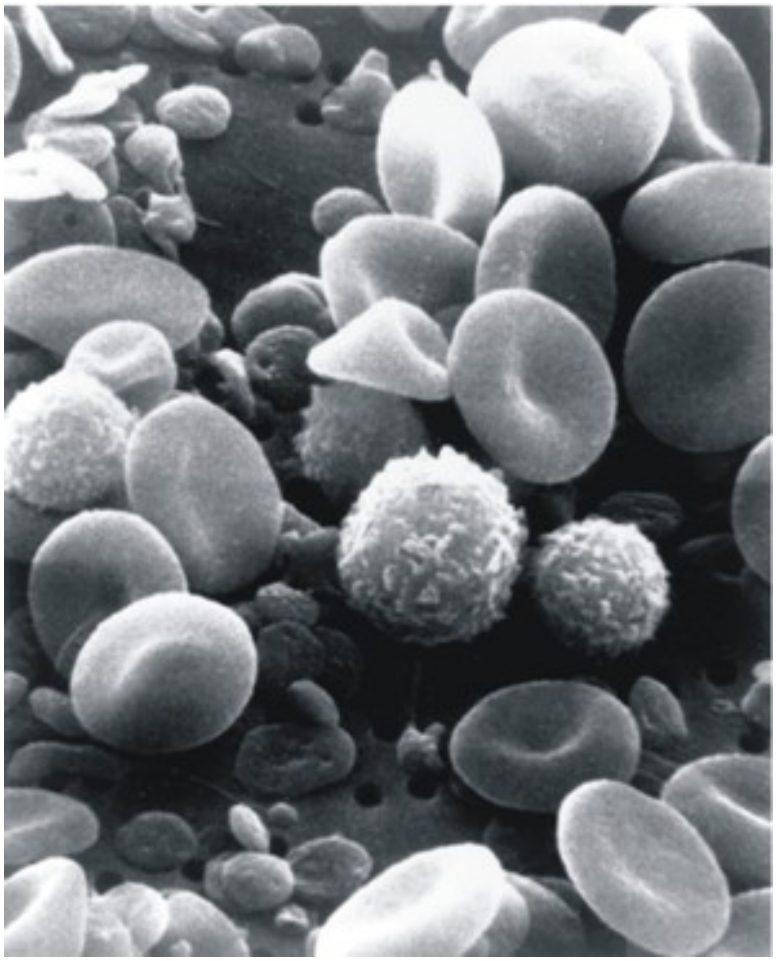


FIGURE 45.1

A scanning electron microscope (SEM) image of normal circulating human blood. One can see red blood cells, several white blood cells, including knobby lymphocytes, a monocyte, a neutrophil, and many small disc-shaped platelets.

Plasma

Plasma is the golden-yellow liquid part of the blood. Plasma is 90% water and 10% dissolved materials including proteins, glucose, ions, hormones, and gases. It acts as a buffer, maintaining pH near 7.4. Plasma is about 54% the volume of blood; cells and fragments make up about 46% of the volume.

Red Blood Cells

Red blood cells, also known as **erythrocytes,** are flattened, doubly concave cells that carry oxygen. There are about

4 to 6 million cells per cubic millimeter of blood. Red blood cells make up about 45% of blood volume, as shown in **Figure** 45.2. Each red blood cell has 200 million hemoglobin molecules. Humans have a total of 25 trillion red blood cells (about 1/3 of all the cells in the body). Red blood cells are continuously made in the red marrow of long bones, ribs, the skull, and vertebrae. Each red blood cell lives for only 120 days, after which they are destroyed in the liver and spleen.

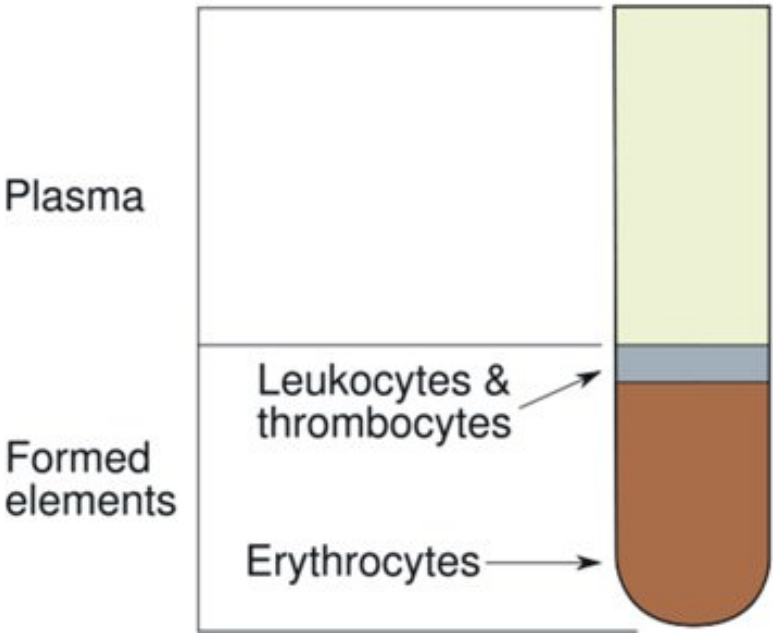


FIGURE 45.2

The components of blood. Red blood cells make up about 45% of the blood volume. White blood cells make up about one percent and platelets less than one percent. Plasma makes up the rest of the blood.

Mature red blood cells do not have nuclei or other organelles. They contain the protein hemoglobin, which gives blood its red color. The iron-containing heme portion of hemoglobin enables the protein to carry oxygen to cells. Heme binds to molecules of oxygen, which increases the ability of the blood to carry the gas.

Iron from hemoglobin is recovered and reused by red marrow. The liver degrades the heme units and secretes them as pigment in the bile, which is responsible for the color of feces. Each second, two million red blood cells are produced to replace those taken out of circulation.

White Blood Cells

White blood cells, also known as **leukocytes,** are generally larger than red blood cells, as shown in **Figure** 45.3. They have a nucleus but do not have hemoglobin. White blood cells make up less than one percent of the blood's volume. They are made from stem cells in bone marrow. They function in the cellular immune response system. There are five types of white blood cells. Neutrophils enter the tissue fluid by squeezing through capillary walls and phagocytize (swallow) foreign bodies. Macrophages also swallow and destroy cell debris and bacteria or viruses. In **Figure** 45.4, a white blood cell is shown phagocytizing two bacteria. Macrophages also release substances that cause the numbers of white blood cells to increase. Antigen-antibody complexes are swallowed by macrophages. Lymphocytes fight infection. T-cells attack cells containing viruses. B-cells produce antibodies. To learn more about the role of white blood cells in fighting infection, refer to the *Immune System* concepts.

Platelets

Platelets, also known as **thrombocytes,** are important in blood clotting. Platelets are cell fragments that bud off bone marrow cells called megakaryocytes. A platelet is shown in **Figure** 45.5. They make up less than one percent

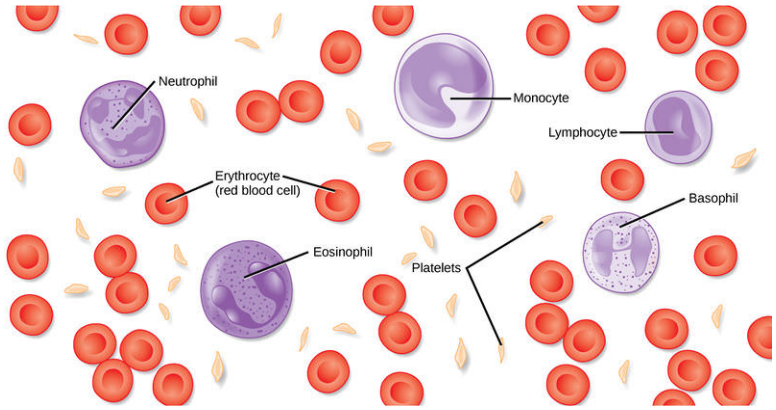


FIGURE 45.3

The relative sizes of red and white blood cells. Neutrophils, eosinophils, basophils, monocytes, and lymphocytes are white blood cells.

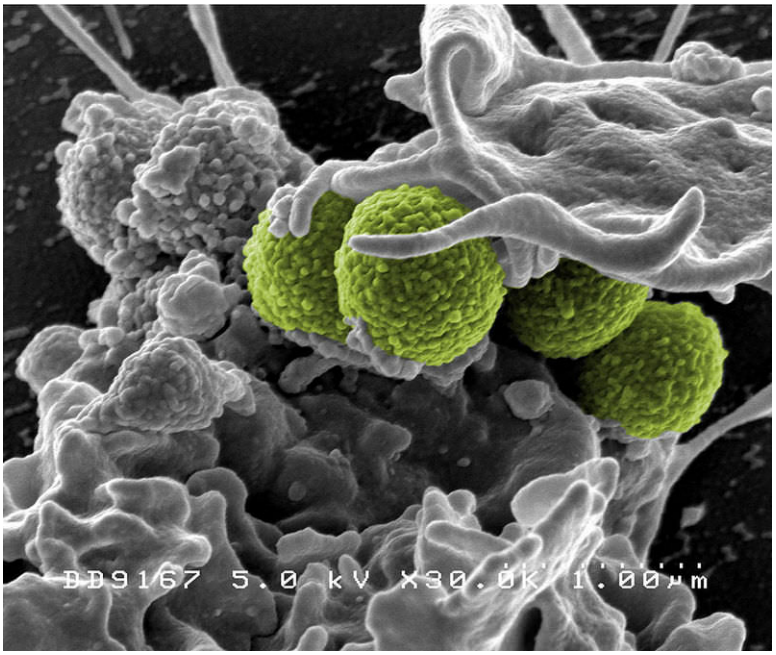


FIGURE 45.4

A white blood cell showing cytoplasmic extensions that allow it to "swallow" particles or pathogens.

of blood volume. Platelets carry chemicals essential to blood clotting. They change fibrinogen into fibrin, a protein that creates a mesh onto which red blood cells collect, forming a clot. This clot stops more blood from leaving the body and also helps prevent bacteria from entering the body. Platelets survive for 10 days before being removed by the liver and spleen. There are 150,000 to 300,000 platelets in each milliliter of blood. Platelets stick to tears in blood vessels, and they release clotting factors.

Other Blood Components

Blood plasma also contains substances other than water. Some important components of blood include the following:

- Serum albumin: a plasma protein that acts as a transporter of hormones and other molecules.
- Antibodies: proteins that are used by the immune system to identify and destroy foreign objects such as bacteria and viruses.
- Hormones: chemical messengers that are produced by one cell and carried to another.

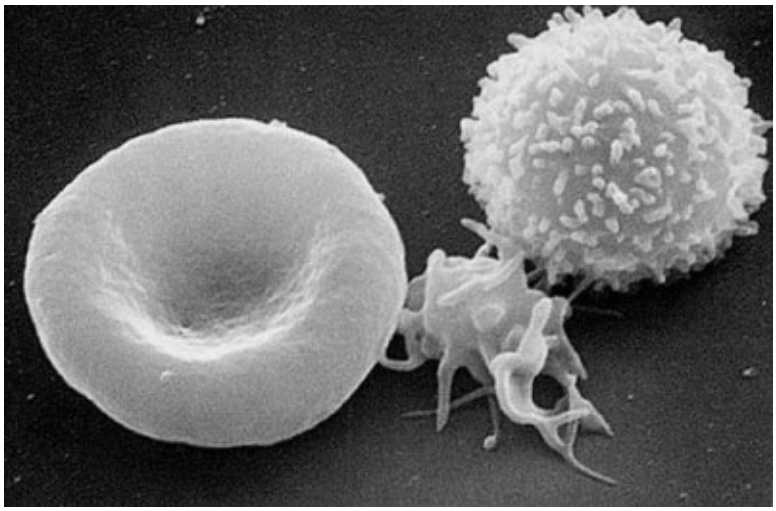


FIGURE 45.5

Cells of the blood. From left to right: red blood cell, platelet, white blood cell. The concave side of the red blood cell can be seen. Both sides of red blood cells are concave. The biconcave shape gives the red blood cells a smaller surface to volume ratio, which allows them to pick up large amounts of oxygen.

- Electrolytes such as sodium (Na^+) and chloride (Cl^-) ions.

Production and Breakdown of Blood Cells

Blood cells are produced in the red and yellow bone marrow in a process called **hematopoiesis.** The currently accepted theory of hematopoiesis is called the monophyletic theory. It simply postulates that a single type of stem cell gives rise to all the mature blood cells in the body. This stem cell is an example of a pluripotent stem cell.

Blood cells are broken down by the spleen and certain cells in the liver. The liver also clears some proteins, lipids, and amino acids from the blood. The kidney actively secretes waste products of the blood into the urine.

Summary

- Functions of blood include transport of nutrients, removal of waste, defense of the body, repair of damaged tissue, transport of chemical messages, control of pH, and control of temperature.
- Blood is composed of 54% plasma and 46% cells/fragments. Red blood cells make up about 45% of the volume.
- White blood cells are made from stem cells in bone marrow and function in the cellular immune response system.
- Platelets are cell fragments that bud off bone marrow cells called megakaryocytes; platelets carry chemicals essential to blood clotting.

Review

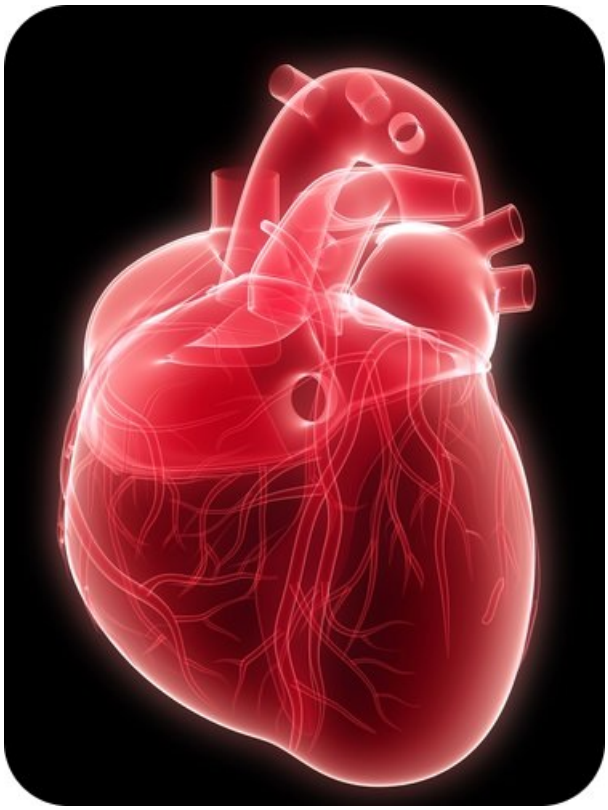
1. What type of solution is blood an example of?
2. How many liters of blood does an average adult have?
3. Where are red blood cells made?
4. What distinguishes mature red blood cells?
5. How do platelets begin the blood clotting process?

References

1. . http://visualsonline.cancer.gov/details.cfm?imageid=2129 . Public Domain
2. MesserWoland. http://commons.wikimedia.org/wiki/Image:Illu_blood_components.svg . CC-BY-SA 3.0
3. N/A Rice University. http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@9.45:210#fig-ch40_02_01 . CC-BY-3.0
4. NIAID. https://www.flickr.com/photos/niaid/5950870300/ . CC-BY-2.0
5. . fin . Public Domain

CONCEPT 46 Heart

4.1 Structure of heart



What's the most active muscle in the body?

The human heart. An absolutely remarkable organ. Obviously, its main function is to pump blood throughout the body. And it does this extremely well. On average, this muscular organ will beat about 100,000 times in one day and about 35 million times in a year. During an average lifetime, the human heart will beat more than 2.5 billion times.

The Circulatory System

The **circulatory system** can be compared to a system of interconnected, one-way roads that range from superhighways to back alleys. Like a network of roads, the job of the circulatory system is to allow the transport of materials from one place to another. As described in **Figure** 47.1, the materials carried by the circulatory system include hormones, oxygen, cellular wastes, and nutrients from digested food. Transport of all these materials is necessary to maintain homeostasis of the body. The main components of the circulatory system are the **heart, blood vessels,** and **blood.**

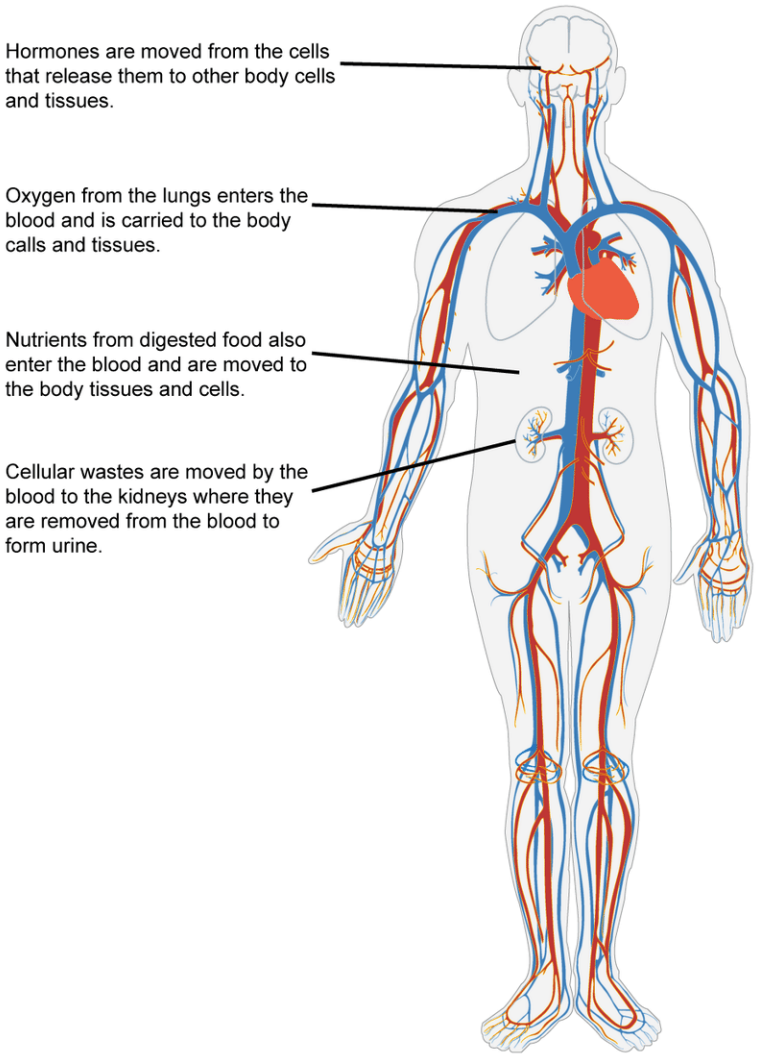


FIGURE 46.1

The function of the circulatory system is to move materials around the body.

The Heart

The heart is a muscular organ in the chest. It consists mainly of cardiac muscle tissue and pumps blood through blood vessels by repeated, rhythmic contractions. The heart has four chambers, as shown in **Figure** 46.2 two upper **atria** (singular, **atrium**) and two lower **ventricles**. Valves between chambers keep blood flowing through the heart in just one direction.

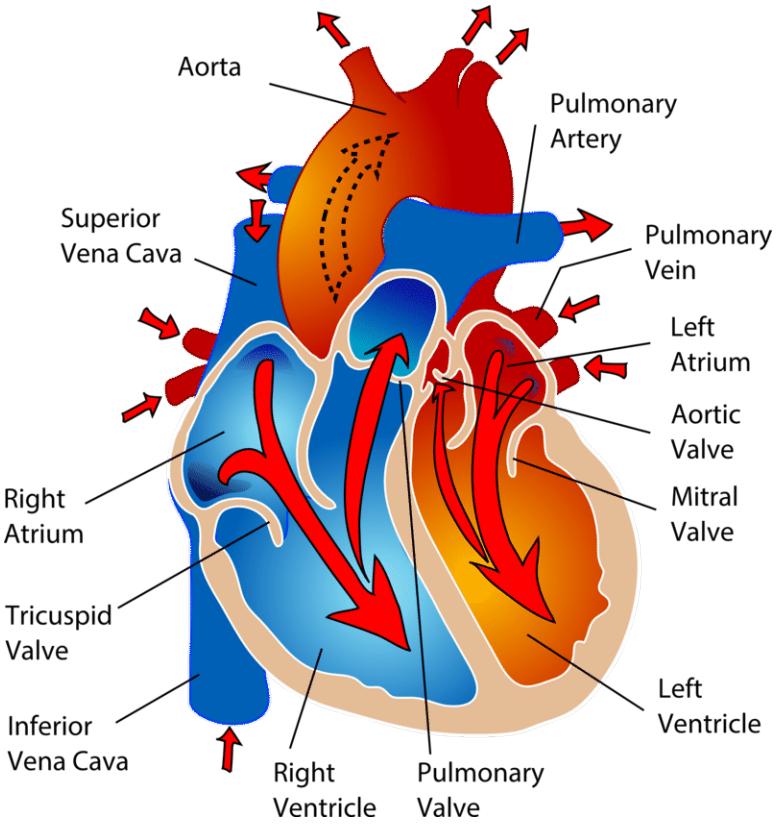


FIGURE 46.2

The chambers of the heart and the valves between them are shown here.

Blood Flow Through the Heart

Blood flows through the heart in two separate loops, which are indicated by the arrows in **Figure** 46.2. You can also watch an animation of the heart pumping blood at this link: http://www.nhlbi.nih.gov/health/dci/Diseases/hhw/hhw_pumping.html .

1. Blood from the body enters the right atrium of the heart. The right atrium pumps the blood to the right ventricle, which pumps it to the lungs. This loop is represented by the blue arrows in **Figure** 46.2.

2. Blood from the lungs enters the left atrium of the heart. The left atrium pumps the blood to the left ventricle, which pumps it to the body. This loop is represented by the red arrows in **Figure** 46.2.

Heartbeat

Unlike skeletal muscle, cardiac muscle contracts without stimulation by the nervous system. Instead, specialized cardiac muscle cells send out electrical impulses that stimulate the contractions. As a result, the atria and ventricles normally contract with just the right timing to keep blood pumping efficiently through the heart. You can watch an animation to see how this happens at this link: http://www.nhlbi.nih.gov/health/dci/Diseases/hhw/hhw_electrical.html .

Summary

- The heart contracts rhythmically to pump blood to the lungs and the rest of the body.
- Specialized cardiac muscle cells trigger the contractions.

Review

1. What are the main components of the circulatory system?
2. Describe how blood flows through the heart.
3. What controls heartbeat?

Anatomy of heart

Community Contributed

An interactive that allows you to choose the average bpm of a heart. It shows you a step by step process of what a heart looks like beating and how it functions (day and night), providing helpful facts along the way.

Open the resource in a new window.

http://www.pbs.org/wgbh/nova/assets/swf/1/map-human-heart/map-human-heart.swf

4.2 Regulation of Cardiac Activity (Heart's Electrical System)

This animation shows how your heart's electrical system works.

Open the resource in a new window.

http://www.nhlbi.nih.gov/health/health-topics/topics/hhw/electrical.html

4.3 Cardiac Cycle

Heart Contraction and Blood Flow

This animation shows how your heart pumps blood.

Open the resource in a new window.

http://www.nhlbi.nih.gov/health/health-topics/topics/hhw/contraction.html

4.4 Electrocardiograph

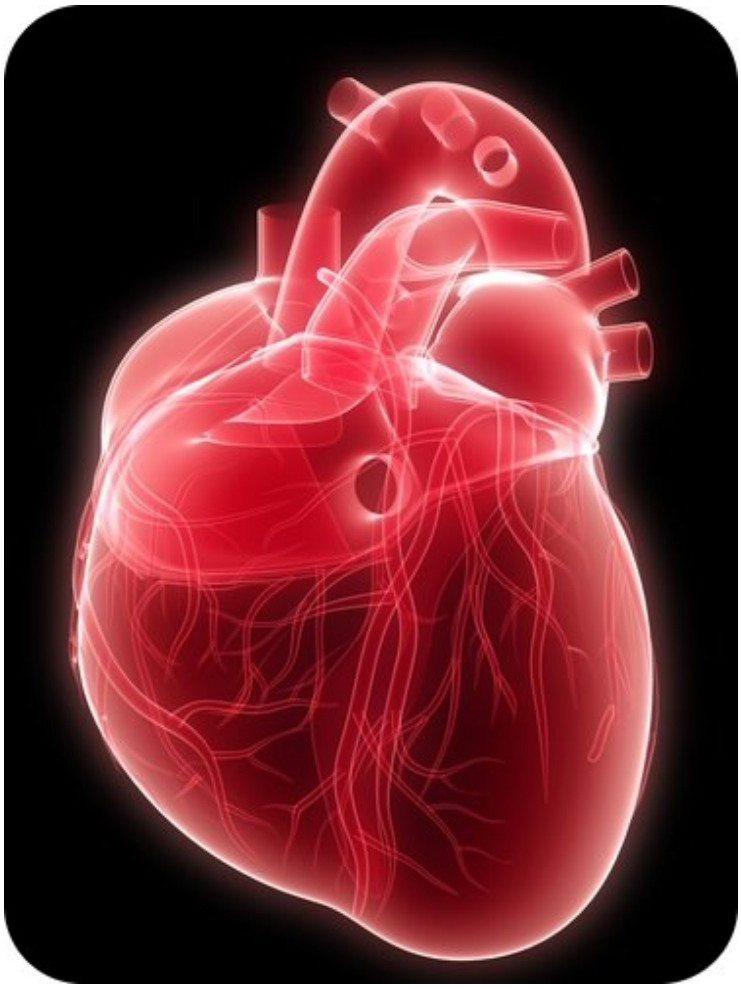
References

1. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation. Circulatory system relative to body.
2. Mariana Ruiz Villarreal (Wikimedia: LadyofHats), modified by CK-12 Foundation. .

CONCEPT 47 The Heart - Advanced

Learning Objectives

- Learn about the different sections of the heart.
- Understand how the different areas of the heart coordinate a heartbeat.



What's the most active muscle in the body?

The heart. An absolutely remarkable organ. Obviously, its main function is to pump blood throughout the body. And it does this extremely well. On average, this muscular organ will beat about 100,000 times in one day and about 35 million times in a year. During an average lifetime, the human heart will beat more than 2.5 billion times.

The Heart

The **cardiovascular system,** shown in **Figure** 47.1, is an organ system that moves nutrients, hormones, gases, and wastes to and from body cells and distributes heat to maintain homeostasis. The main components of the cardiovascular system are the heart, the blood vessels, and the blood.

The **heart** is the muscular organ that pumps blood through the blood vessels by repeated, rhythmic contractions. The term cardiac means "related to the heart" and comes from the Greek word *kardia,* meaning "heart." The heart is

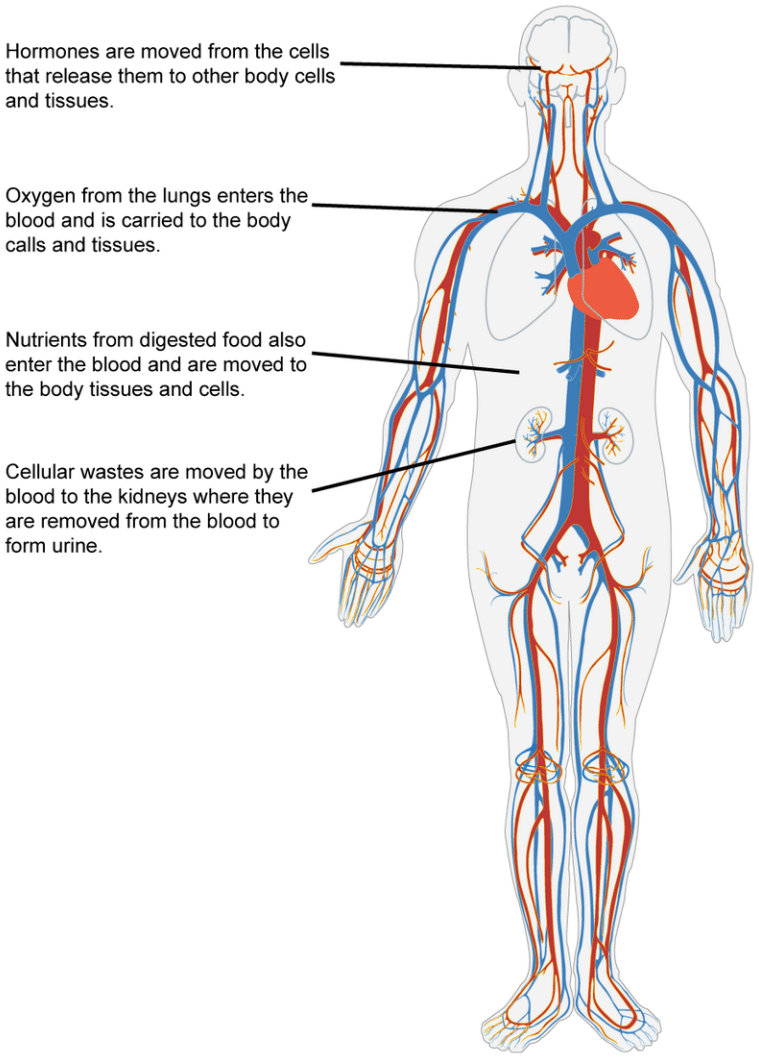


FIGURE 47.1

The function of the circulatory system is to move materials around the body. The main organs of the circulatory system are the heart, blood vessels, and blood. Blood acts as the transporter in the body, while blood vessels act like little (one way) roads.

made up mostly of cardiac muscle tissue (shown in **Figure** 47.2), which contracts to pump blood around the body. In adults, the normal mass of the heart is 250-350 grams (9-12 oz), or about three quarters the size of a clenched fist, but badly diseased hearts can be up to 1000 g (2 lb) in mass due to enlargement of the cardiac muscle.

The heart is usually found in the left to middle of the chest, with the largest part of the heart slightly to the left. The heart is usually felt to be on the left side because the left ventricle is stronger (it pumps to all the body parts). The heart is surrounded by the lungs. The left lung is smaller than the right lung because the heart takes up more room in the left side of the chest. The position of the heart within the chest is shown in **Figure** 47.3.

Blood Flow Through the Heart

Blood flows through the heart in two separate loops; you could think of them as a “left side loop” and a “right side loop.” The right side and left side of the heart refer to your heart as it sits within your chest. Its left side is your left side, and its right side is your right side.

The right side of the heart collects deoxygenated blood from the body and pumps it into the lungs, where it releases carbon dioxide and picks up oxygen. The left-side carries the oxygenated blood back from the lungs and into the

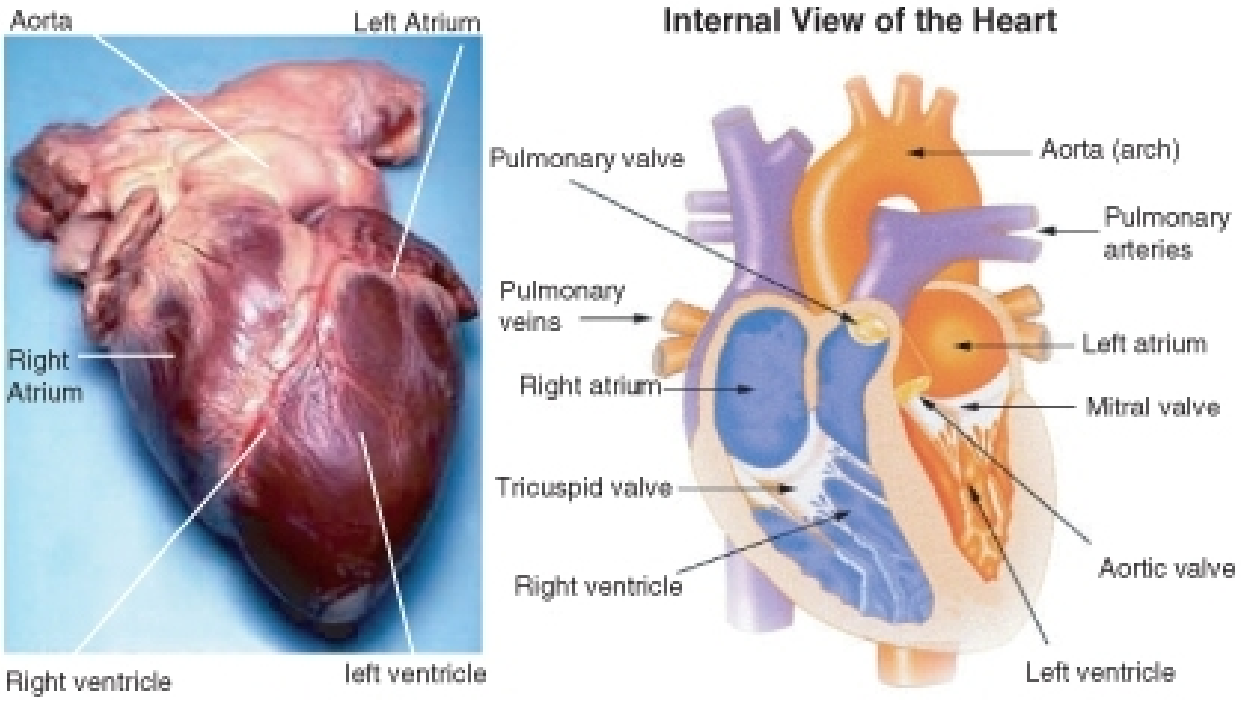


FIGURE 47.2

External and internal views of the human heart. The aorta in the photo cannot be seen clearly because it is covered by a layer of adipose tissue (fat).

FIGURE 47.3

The position of the heart in relation to the lungs. The heart can be seen in the lower middle area of the figure, behind the lungs.

left side of the heart, which then pumps the oxygenated blood throughout the rest of the body.

The heart has four chambers: the two upper atria and the two lower ventricles. **Atria** (singular atrium) are the thin-walled blood collection chambers of the heart. Atria pump the blood into the ventricles. **Ventricles** are the heart

chambers that collect blood from the atria and pump it out of the heart. On the right side of the heart, deoxygenated blood from the body enters the right atrium from the superior vena cava and the inferior vena cava, as shown in **Figure** 47.4. Blood enters the right ventricle, which then pumps the blood through the pulmonary arteries and into the lungs. In the lungs, carbon dioxide is released from the blood, and oxygen is picked up.

Pulmonary veins bring the oxygenated blood back toward the heart and into the left atrium. From the left atrium, the blood moves to the left ventricle, which pumps it out to the body through the aorta. On both sides, the lower ventricles are thicker and stronger than the upper atria. The muscle wall surrounding the left ventricle is thicker and stronger than the wall surrounding the right ventricle because the left ventricle needs to exert enough force to pump the blood through the body. The right ventricle only needs to pump the blood as far as the lungs, which does not require as much contractile force.

Valves in the heart maintain the flow of blood by opening and closing in one direction only. Blood can move only forward through the heart and is prevented from flowing backward by the valves. Such movement of the blood is called unidirectional flow. There are four valves of the heart:

- The two **atrioventricular (AV) valves** ensure blood flows from the atria to the ventricles and not the other way. The AV valve on the right side of the heart is called the tricuspid valve, and the one on the left side of the heart is called the mitral, or bicuspid, valve.

- The two **semilunar (SL) valves** are present in the arteries leaving the heart, and they prevent blood from flowing back from the arteries into the ventricles. The SL valve on the right side of the heart is called the pulmonary valve because it leads to the pulmonary arteries, and the SL valve on the left side of the heart is called the aortic valve because it leads to the aorta. The valves of the heart are shown in **Figure** 47.4.

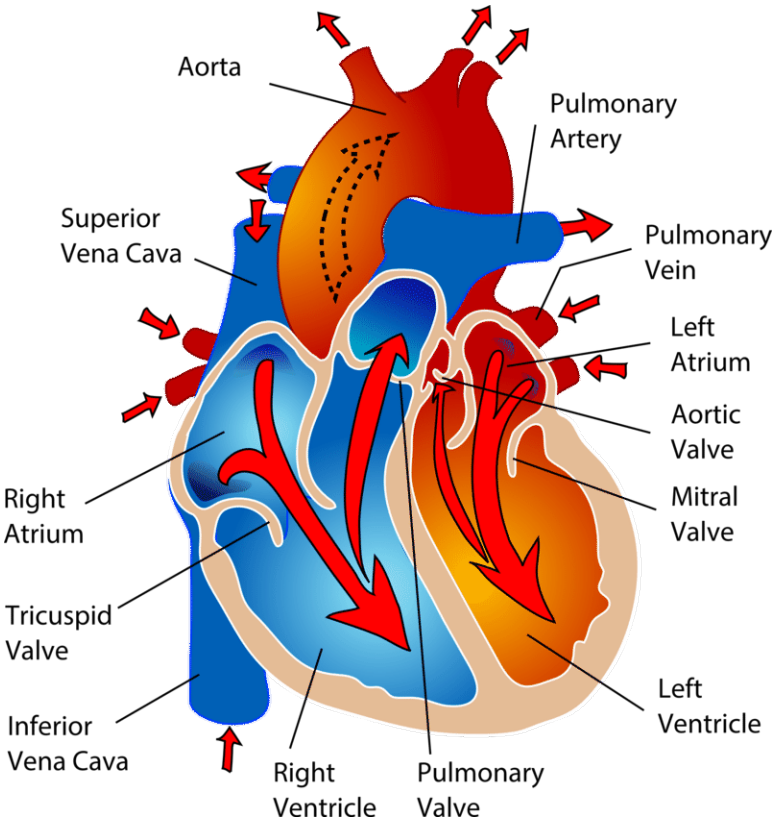


FIGURE 47.4

The direction of blood flow through the heart.

The Heartbeat

The heart is a meshwork of cardiac muscle cells that are interconnected by little channels called gap junctions. This interconnection allows the electrical stimulation of one cell to spread quickly to its neighboring cells. Cardiac muscle is self-exciting. This contrasts skeletal muscle, which needs nervous stimulation to contract. The heart's rhythmic contractions occur spontaneously, although the frequency of the contractions, called the **heart rate,** can be changed by nervous or hormonal signals, such as during exercise or when perceiving danger.

Control of the Heartbeat

The rhythmic sequence of contractions of the heart is coordinated by two small groups of cardiac muscle cells called the sinoatrial (SA) and atrioventricular (AV) nodes. The **sinoatrial node (SA node),** often known as the "cardiac pacemaker," is found in the upper wall of the right atrium and is responsible for creating an action potential to start the wave of electrical stimulation that starts atrial contraction. The action potential causes the cardiac cells to contract. This wave of contraction then spreads across the cells of the atrium, reaching the **atrioventricular node (AV node),** which is found in the lower right atrium, as shown in **Figure** 47.5. The AV node conducts the electrical impulses that come from the SA node through the atria to the ventricles. The impulse is delayed there before being conducted through special bundles of heart muscle cells called the bundle of His and the Purkinje fibers, which leads to a contraction of the ventricles. This delay allows for the ventricles to fill with blood before the ventricles contract. Heartbeat is also controlled by nerve messages originating from the autonomic nervous system.

There are important physiological differences between cardiac cells found in the nodes and cardiac cells found in the ventricles. Differences in ion channels and mechanisms of polarization give rise to unique properties of SA node cells—the most important being the spontaneous depolarizations necessary for the SA node's pacemaker activity.

The **Bundle of His** is a collection of heart muscle cells (fibers) specialized for electrical conduction that transmits the electrical impulses from the AV node. The bundle of His branches into the Purkinje fibers. **Purkinje fibers,** shown in **Figure** 47.6, are specialized cardiac muscle cells that conduct action potentials into the ventricles, causing the cardiac muscle of the ventricles to contract in a controlled way.

The heartbeat is made up of two parts: muscle contraction and relaxation. **Systole** is the contraction of the heart chambers, which drives blood out of the chambers. **Diastole** is the period of time when the heart relaxes after contraction. All four chambers of the heart undergo systole and diastole in a timed fashion so that blood is moved forward through the cardiovascular system. For example, ventricular systole is the point at which the ventricles are contracting, and atrial systole is the point at which the atria are contracting. Likewise, ventricular diastole is the period during which the ventricles are relaxing, while atrial diastole is the period during which the atria are relaxing. In general, when referring to systole and diastole, the chambers being referred to are the ventricles, which are shown in **Figure** 47.7.

Heart Sounds

In healthy adults, there are two normal heart sounds, often described as a "lub" and a "dub," that occur with each heart beat (lub-dub, lub-dub). In addition to these normal sounds, a variety of other sounds may be heard including heart murmurs or clicks. A medical practitioner uses a stethoscope to listen for these sounds, which gives him or her important information about the condition of the heart.

The sound of the heart valves shutting causes the heart sounds, or a heartbeat. The closing of the mitral and tricuspid valves (known together as the atrioventricular valves) at the beginning of ventricular systole causes the first part of the "lub-dub" sound made by the heart as it beats. The second part of the "lub-dub" sound is caused by the closure of the aortic and pulmonic valves at the end of ventricular systole. As the left ventricle empties, its pressure falls below the pressure in the aorta, and the aortic valve closes. Similarly, as the pressure in the right ventricle falls below the pressure in the pulmonary artery, the pulmonic valve closes.

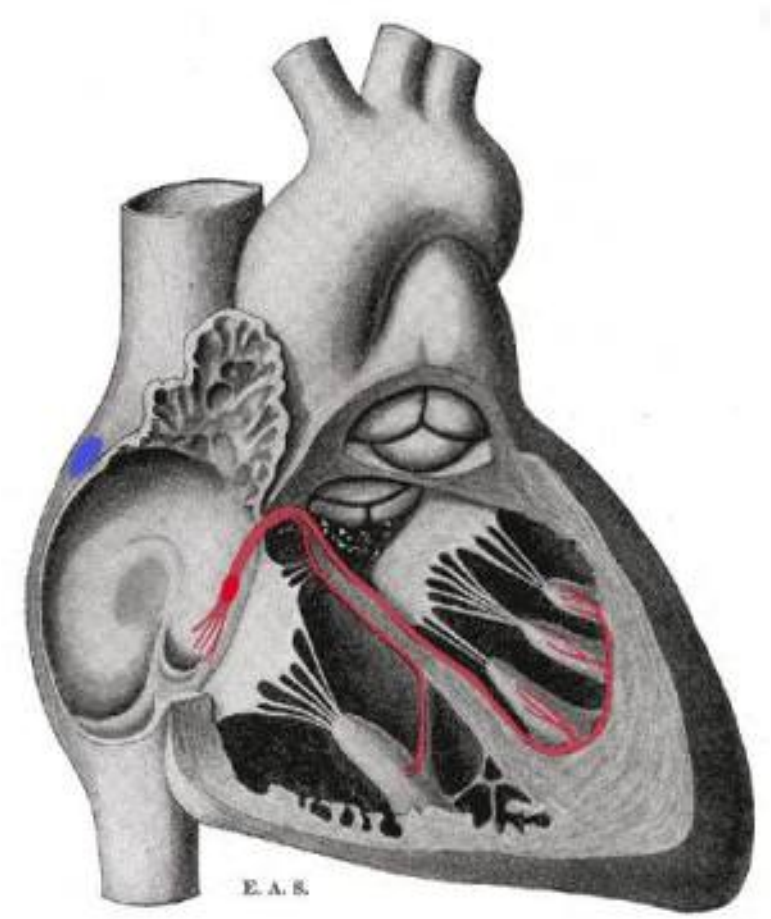


FIGURE 47.5

A schematic representation of the atrioventricular Bundle of His. The SA node is blue, and the AV node is red and visible in the right atrium. The AV node forms the Bundle of His. Sometimes the left and right Bundles of His are called Purkinje fibers.

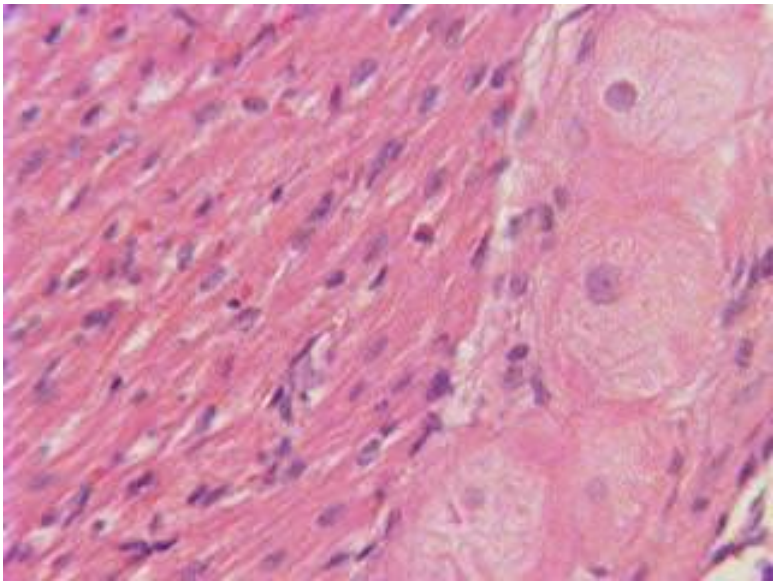


FIGURE 47.6

The larger round cells on the right are Purkinje fibers. Because of their specializations to rapidly conduct impulses (numerous sodium ion channels and mitochondria and fewer myofibrils than the surrounding muscle tissue), Purkinje fibers take up stain differently than the surrounding muscles cells, and, on a slide, they often appear lighter and larger than their neighbors.

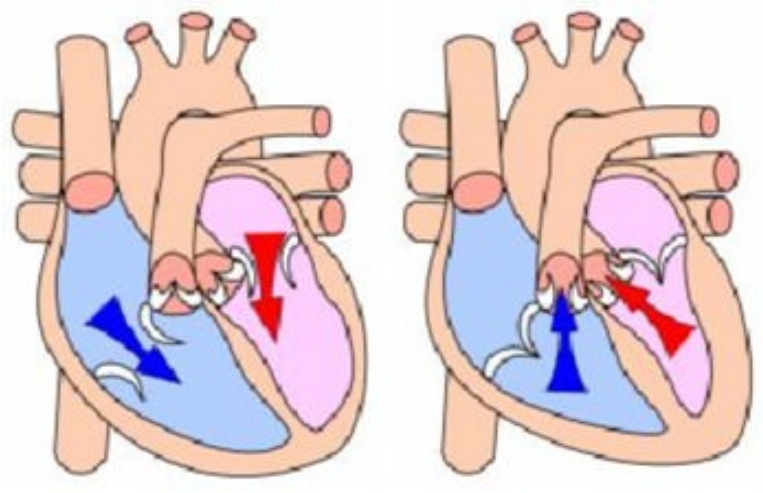


FIGURE 47.7

When the atria contract, the blood gets pushed into the ventricles, which are in diastole. When the ventricles contract (ventricular systole), the blood gets pushed out of the heart.

Summary

- The heart, blood vessels, and blood are the main components of the cardiovascular system, which moves nutrients, hormones, gases, and wastes to and from body cells and distributes heat to maintain homeostasis.
- Blood flows into the heart through the superior and inferior vena cava, enters the right atrium, and is pumped into the lungs by the right ventricle. Blood returns through the pulmonary vein, flows into the left atrium, and is pumped through the aorta to the rest of the body by the left ventricle.
- The rhythmic sequence of contractions of the heart is coordinated by two small groups of cardiac muscle cells called the sinoatrial (SA) and atrioventricular (AV) nodes, although the heart rate can be changed by nervous or hormonal signals, such as during exercise or when perceiving danger.
- The heartbeat is made up of two parts: muscle contraction (known as systole) and relaxation (known as diastole).

Review

1. Which ventricle wall is thicker, the left or the right?
2. Why are electrical pulses delayed slightly at the AV node before causing a contraction of the ventricles?
3. What is responsible for the "lub-dub" sound of a normal heartbeat?
4. Why is the heart felt to be usually on the left?
5. What affects heart rate?

Explore More

MEDIA

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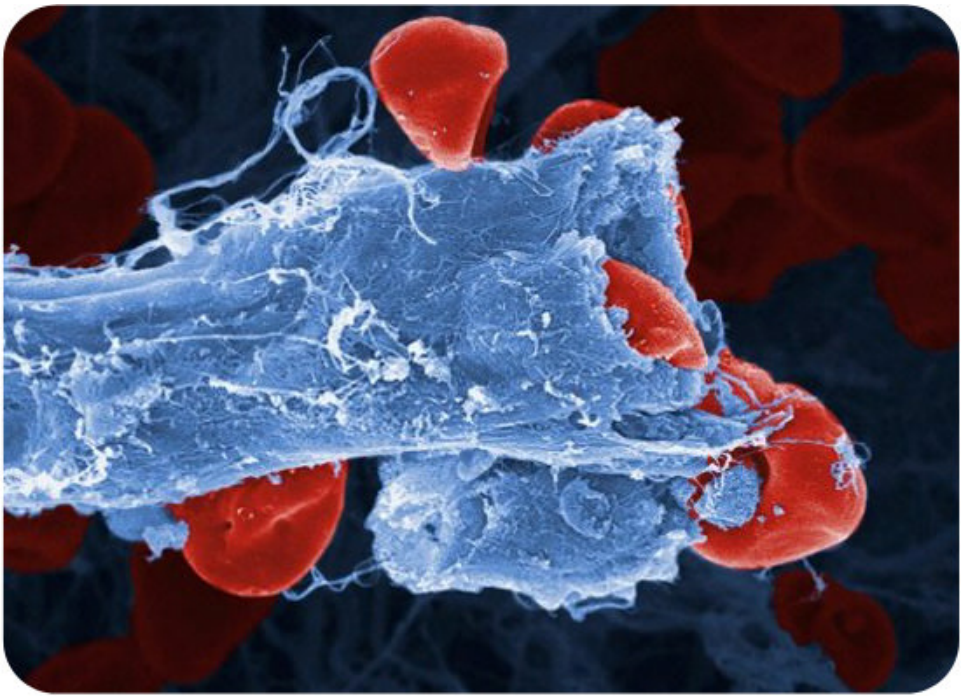
CONCEPT 48 Blood Vessels - Advanced

Learning Objectives

- Differentiate between the different types of blood vessels found in the body.
- Understand the role of blood vessels on blood pressure.



How does blood travel around the body?

This color-enhanced image was made with an electron microscope, so the objects it depicts are extremely small. This incredible photo shows red blood cells leaking out of a ruptured blood vessel. Blood vessels are part of the circulatory system; they are the "highway" system of the human body that transports materials to all of its cells. And the red blood cells that carry some of these materials are a little like trucks on the highway.

Blood Vessels

The blood vessels are part of the cardiovascular system and function to transport blood throughout the body. The two most important types are arteries and veins. Arteries carry blood away from the heart, while veins return blood to the heart.

Arteries, Veins and Capillaries

There are various kinds of blood vessels. The main types are listed below:

- **Arteries** are the large, muscular vessels that carry blood away from the heart.
- An **arteriole** is a small-diameter blood vessel that extends and branches out from an artery and leads to capillaries.

- **Veins** are vessels that carry blood toward the heart. The majority of veins in the body carry deoxygenated blood from the tissues back to the heart.
- A **venule** is a small vessel that allows deoxygenated blood to return from the capillaries to veins.
- **Capillaries** are the smallest of the body's blood vessels. They connect arterioles and venules and are important for the interchange of gases and other substances between blood and body cells.

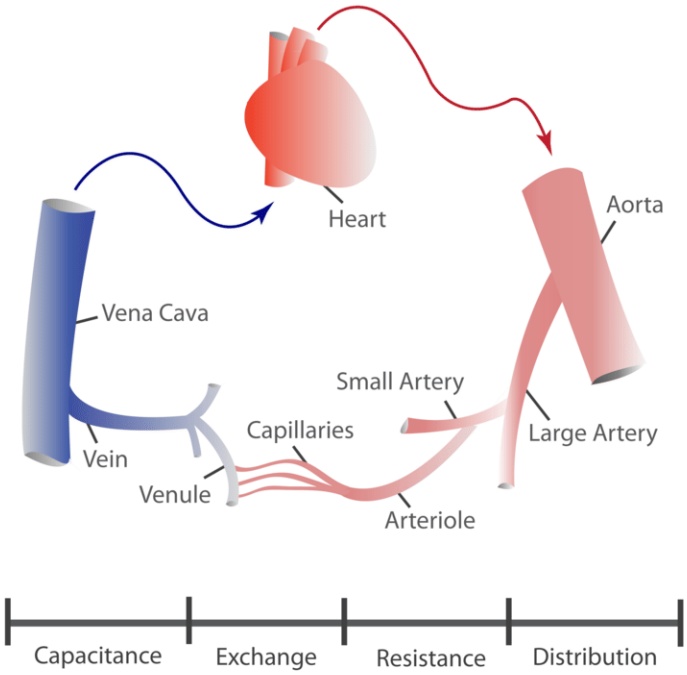


FIGURE 48.1
Blood vessels include arteries, veins, and capillaries.

The blood vessels all have a similar basic structure. The **endothelium** is a thin layer of cells that creates a smooth lining on the inside surface of blood vessels. Endothelial tissue is a specialized type of epithelium, one of the four types of tissue found in the body. Endothelial cells have an important structural role in blood vessels; they line the entire circulatory system, from the heart to the smallest capillary. Around the endothelium there is a layer of smooth muscle, which is well developed in arteries. Finally, there is a further layer of connective tissue that surrounds the smooth muscle. This connective tissue, which is mostly made up of collagen, contains nerves that innervate the smooth muscule layer. The connective tissue surrounding larger vessels also contains capillaries to bring nutrients to the tissue. Capillaries, the smallest blood vessels, are made up of a single layer of endothelium and a small amount of connective tissue.

Arteries and Arterioles

The arteries carry blood away from the heart. As shown in **Figure** 48.2, arteries have thick walls that have three major layers: an inner endothelial layer, a middle layer of smooth muscle, and an outer layer of stretchy connective tissue (mostly collagen). The elastic qualities of artery walls allow them to carry pressurized blood from the heart while maintaining blood pressure.

The aorta is the largest artery in the body. It receives blood directly from the left ventricle of the heart through the aortic valve. The aorta branches into smaller arteries, and these arteries branch in turn, becoming smaller in diameter, down to arterioles. The arterioles supply the capillaries that carry nutrients to the body's cells and tissues. The aorta

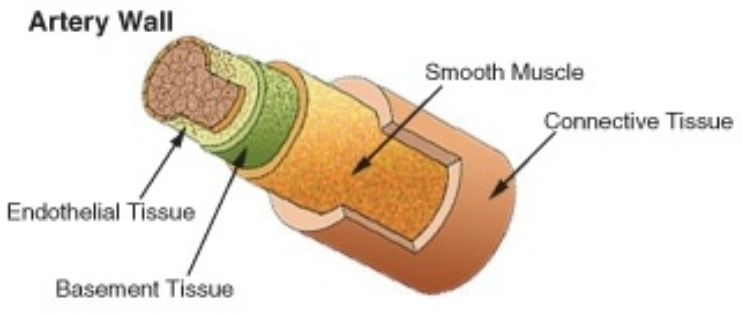


FIGURE 48.2
The structure of an artery wall.

is an elastic artery. When the left ventricle contracts to force blood into the aorta, it expands. This stretching gives the potential energy that will help maintain blood pressure during diastole, when the aorta contracts passively.

An arteriole is a small-diameter blood vessel that branches out from an artery and leads to capillaries. Arterioles have thin, muscular walls, composed of one or two layers of smooth muscle, and are the primary site of vascular resistance. **Vascular resistance** is the resistance to flow that blood must overcome to be pumped through the circulatory system. Increasing vascular resistance is one way your body can increase blood pressure.

Veins and Venuoles

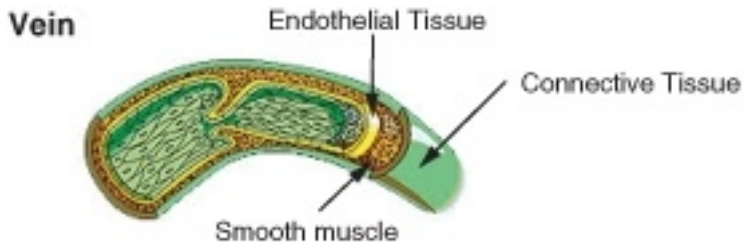


FIGURE 48.3
The internal structure of a vein.

Most veins return deoxygenated blood to the heart. The thick, outer layer of a vein is made up of collagen-containing connective tissue, as shown in **Figure** 48.3. The connective tissue is wrapped around bands of smooth muscle, while the interior is lined with endothelium. Most veins have one-way flaps called valves, shown in **Figure** 48.4, that prevent blood from flowing backward and pooling in the legs, feet, arms, or hands due to the pull of gravity. The location of veins can vary from person to person.

A venule is a small blood vessel that allows deoxygenated blood to return from the capillary beds to the larger blood vessels called veins. Venules have three layers: an inner endothelium composed of squamous epithelial cells that act as a membrane, a middle layer of muscle and elastic tissue, and an outer layer of fibrous connective tissue. The middle layer is poorly developed so that venules have thinner walls than arterioles.

Capillaries

Capillaries are the smallest of a body's blood vessels, measuring 5-10 μm in diameter. Their size is shown in relation to body cells in **Figure** 48.5. Capillaries connect arterioles and venules, and they are important for the exchange of oxygen, carbon dioxide, and other substances between blood and body cells.

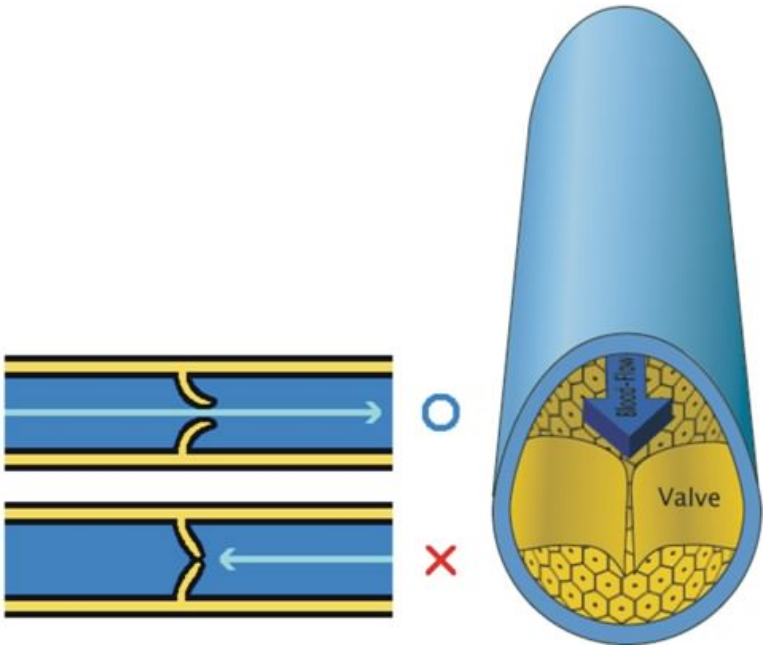


FIGURE 48.4

Valves found in veins prevent the blood from flowing backward and pooling in the lowest parts of the body such as the legs and feet.

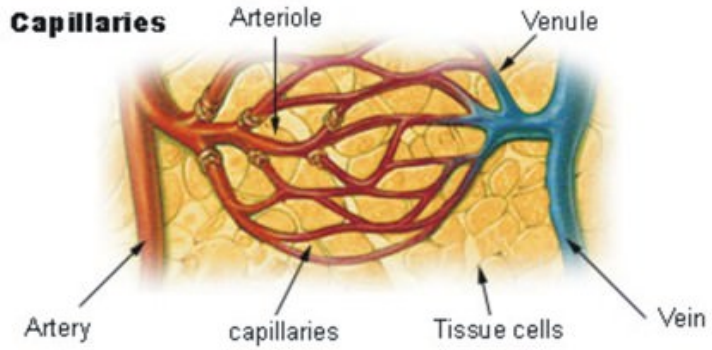


FIGURE 48.5

The structure of capillaries. Note their size in comparison to the cells around them.

The walls of capillaries are made of only a single layer of endothelial cells. This layer is so thin that molecules such as oxygen, water, and lipids can pass through them by diffusion and enter the body tissues. Waste products, such as carbon dioxide and urea, can diffuse back into the blood to be carried away for removal from the body. Capillaries are so small that the blood cells need to pass through them in a single file line. A capillary bed is the network of capillaries supplying an organ. The more metabolically active a tissue or organ is, the more capillaries it needs to get nutrients and oxygen.

Blood vessels are roughly grouped as arterial or venous. This grouping is determined by whether the blood in the vessel is flowing away from (arterial) or toward (venous) the heart. In general, the term arterial blood is used to describe blood high in oxygen, although the pulmonary arteries carry deoxygenated blood, and blood flowing in the pulmonary vein is rich in oxygen.

Roles of Blood Vessels

Blood vessels are not involved in regulating the transport of blood; the endocrine and nervous systems do that. However, arteries and veins can regulate their inner diameters by contractions of the smooth muscle layer. This widening or narrowing of the blood vessels changes the blood flow to the organs of the body. This process is controlled by the autonomic nervous system; it is not controlled consciously.

Vasodilation is a process by which blood vessels in the body become wider due to the relaxation of the smooth muscle in the vessel wall. This reduces blood pressure since there is more room for the blood to move through the vessel. Endothelium of blood vessels uses nitric oxide to signal the surrounding smooth muscle to relax, which dilates the artery and increases blood flow. Nitric oxide is a vasodilator.

Vasoconstriction is the constriction of blood vessels (narrowing or becoming smaller in cross-sectional area) by contracting the vascular smooth muscle in the vessel walls. Vasoconstriction is controlled by substances such as some hormones and neurotransmitters, which are called vasoconstrictors. For example, the “fight or flight” hormone epinephrine is a vasoconstrictor that is released by the adrenal glands.

Permeability of the endothelium is important for the release of nutrients to the tissue. Permeability is the ability of a membrane to allow certain molecules and ions to pass through it by diffusion. Permeability of the endothelium increases during an immune response, which allows white blood cells and other substances to get to the site of injury or irritation.

Oxygen, which is bound to hemoglobin in red blood cells for transport through the body, is the most critical nutrient carried by the blood. In all arteries apart from the pulmonary artery, hemoglobin is highly saturated (95-100%) with oxygen. In all veins apart from the pulmonary vein, the hemoglobin is desaturated at about 70%. (The values are reversed in the pulmonary circulation.)

Blood Vessels and Blood Pressure

Blood pressure refers to the force exerted by circulating blood on the walls of blood vessels. The pressure of the circulating blood gradually decreases as blood moves from the arteries, to the arterioles, to the capillaries, and to the veins. The term "blood pressure" generally refers to **arterial pressure,** which is the pressure in the larger arteries that take blood away from the heart. Arterial pressure results from the force that is applied to the blood by the contracting heart. When the heart contracts, the blood “presses” against the walls of the arteries.

The systolic arterial pressure is defined as the peak pressure in the arteries, which occurs near the beginning of the cardiac cycle; the diastolic arterial pressure is the lowest pressure (at the resting phase of the cardiac cycle).

Arterial pressure is most commonly measured by a **sphygmomanometer,** which is shown in **Figure** 48.6. The height of a column of mercury indicates the pressure of the circulating blood. Although many modern blood pressure devices no longer use mercury, values are still universally reported in millimeters of mercury (mmHg).

Blood Pressure Ranges

In the U.S., the healthy ranges for arterial pressure are the following:

- Systolic: less than 120 mm Hg.
- Diastolic: less than 80 mm Hg.

Blood pressure is usually written as systolic/diastolic mm Hg; for example, a reading of 120/80 mm Hg is said as "one hundred and twenty over eighty." These measures of arterial pressure are not static, but go through natural variations from one heartbeat to another and throughout the day (in a circadian rhythm). Factors such as age, gender, and race influence blood pressure values. Pressure also varies with exercise, emotional reactions, sleep, stress, nutritional factors, drugs, and disease.

FIGURE 48.6

The new and the “classic” ways to measure blood pressure. A digital sphygmomanometer, shown on the left, runs on electricity or batteries and measure blood pressure automatically. The cuff, which you can see behind the digital readout, is wrapped around the upper arm, just like the cuff of the older devices. The cuff then inflates automatically and measures blood pressure as the cuff deflates. The older, mechanical sphygmomanometer with a cuff, pressure reader, and stethoscope is shown on the right. The cuff is inflated and deflated manually while a medical technician listens for related changes in the sound of blood moving through arteries in the arm.

Studies have shown that people whose systolic pressure is around 115 mm Hg rather than 120 mm Hg have fewer health problems. Clinical trials have shown that people who have arterial pressures at the low end of these ranges have much better long term cardiovascular health. For this reason, some researchers say that 115/75 mm Hg should be the ideal measurement.

Hypertension is a condition in which a person’s blood pressure is chronically high. Hypertension is said to be present when a person’s systolic blood pressure is always 140 mm Hg or higher and/or their diastolic blood pressure is always 90 mm Hg or higher. Blood pressure readings between 120/80 mm Hg and 139/89 mm Hg are called prehypertension. Prehypertension is not a disease category; rather, it is a way to identify people who are at high risk of developing hypertension.

Arterioles and Blood Pressure

Arterioles have the greatest collective influence on both local blood flow and overall blood pressure. They are the primary "adjustable nozzles" in the blood system, across which the greatest pressure drop occurs. Heart output (cardiac output) and systemic vascular resistance, which refers to the collective resistance of all of the body’s arterioles, are the principal determinants of arterial blood pressure at any given moment.

MEDIA

Click image to the left or use the URL below.

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Summary

- Arteries are blood vessels that carry blood away from the heart, while veins are blood vessels that return blood to the heart.
- Blood vessels all have a similar basic structure: the endothelium forms the innermost layer, then a layer of smooth muscle, and finally a layer of connective tissue that surrounds the smooth muscle.
- The walls of capillaries are made of only a single layer of endothelial cells, so molecules such as oxygen, water, and lipids can pass through them by diffusion and enter the body tissues.
- In all arteries apart from the pulmonary artery, hemoglobin is highly saturated (95-100%) with oxygen. In all veins apart from the pulmonary vein, the hemoglobin is desaturated at about 70%. (The values are reversed in the pulmonary circulation.)
- Hypertension is said to be present when a person's systolic blood pressure is always 140 mm Hg or higher and/or their diastolic blood pressure is always 90 mm Hg or higher.

Review

1. What small blood vessels allows deoxygenated blood to return from the capillaries to the veins?
2. What kind of specialized tissue make up the endothelium?
3. How do veins ensure that blood does not flow backwards?
4. How thin are capillaries?
5. Give an example of a hormone that causes blood vessels to narrow.

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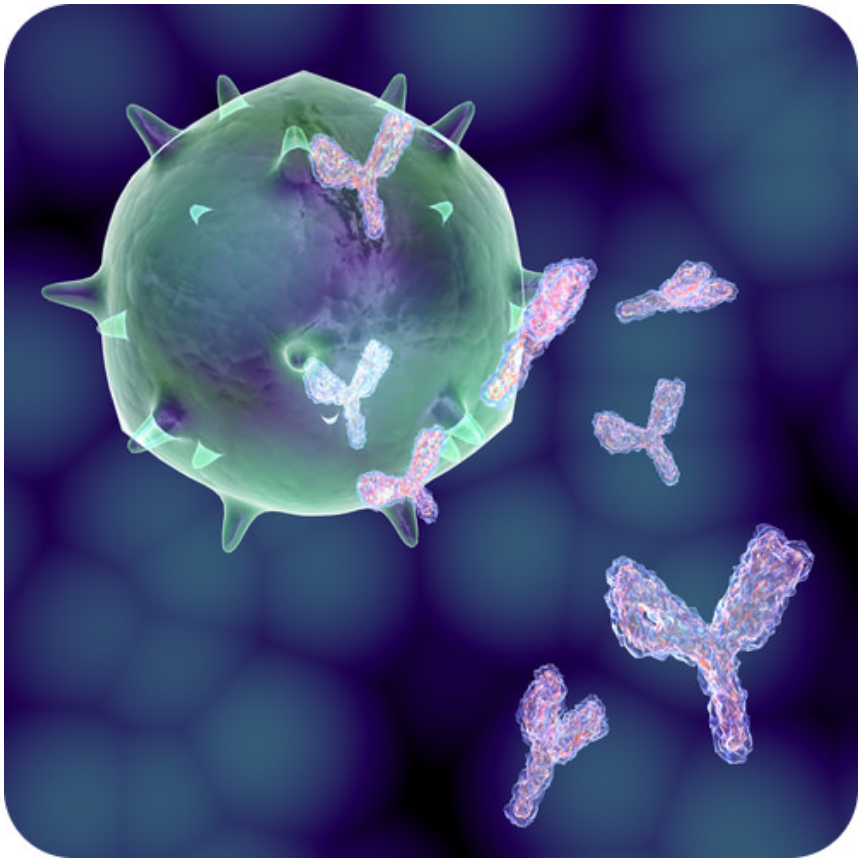
CONCEPT 49

The Humoral Immune Response - Advanced

Learning Objectives

- Understand the roles of B cells and antibodies in the humoral immune response.
- Learn how B cells are activated.
- Differentiate between two different types of activated B cells: plasma cells and memory cells.



What are those Y-shaped things floating around the cell?

They are antibodies, which are large proteins. And they signal specific antigens for destruction. It does help that the antigens are usually attached to pathogens.

Humoral Immune Response

B cells are responsible for the humoral immune response. The **humoral immune response** takes place in blood and lymph and involves the production of antibodies. **Antibodies** are large Y-shaped proteins called immunoglobulins (Ig) that recognize and bind to antigens. In humans (and other mammals) there are five types of immunoglobulins: IgA, IgD, IgE, IgG, and IgM. Antibodies are produced by activated B cells.

B Cell Activation

Naïve B cells are activated by an antigen in the sequence of events shown in **Figure** 49.1. A B cell encounters its matching antigen and engulfs it. The B cell then displays fragments of the antigen on its surface. This attracts a helper T cell (which you will read about below). The helper T cell binds to the B cell at the antigen site and releases cytokines. Cytokines are chemical signals used to communicate between cells. Cytokines from the helper T cell stimulate the B cell to develop into plasma cells or memory cells.

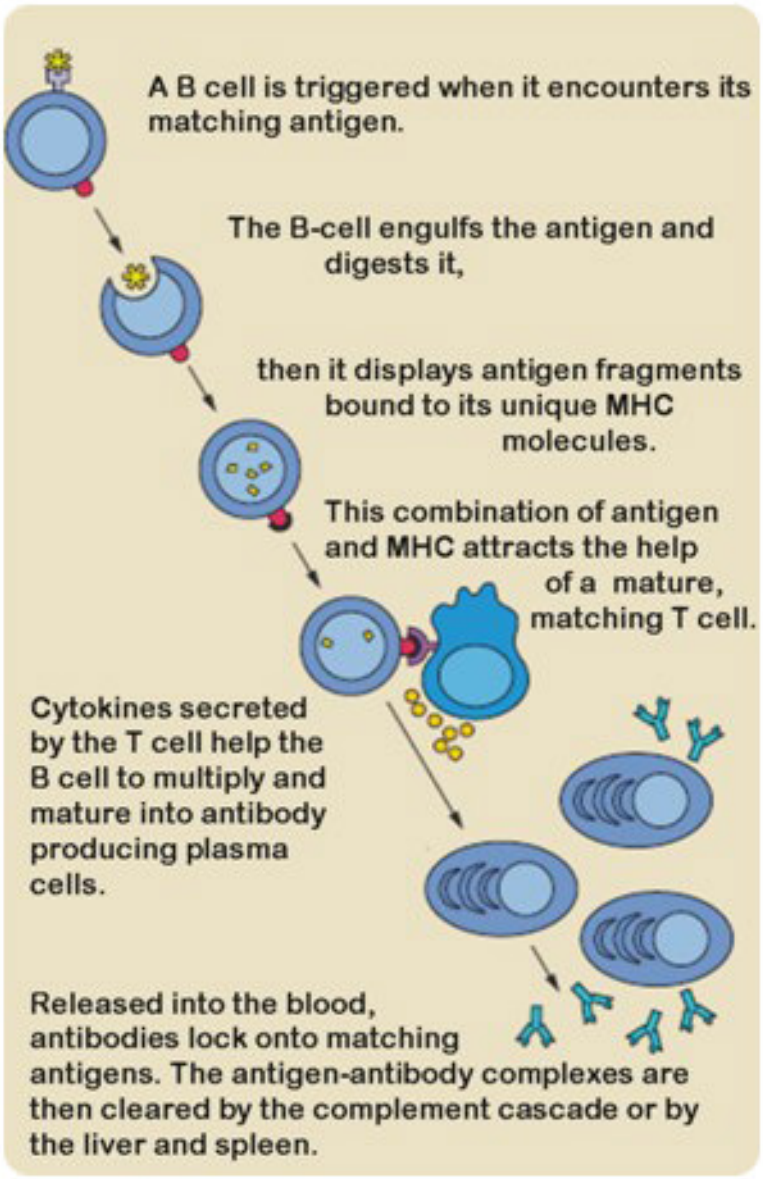


FIGURE 49.1

After engulfing an antigen, a naïve B cell presents the antigen to a mature T cell. The T cell, in turn, releases cytokines that activate the B cell. Once activated, the B cell can produce antibodies to that particular pathogen.

Plasma Cells and Antibody Production

Plasma cells are activated B cells that secrete antibodies. They are specialized to act like antibody factories. Antibodies produced by plasma cells circulate in the blood and lymph. Each antibody recognizes and binds to a specific antigen, depending on the plasma cell that produced it and other factors. An antibody usually binds to an antigen at an antigenic determinant. The binding of an antibody to its matching antigen forms an antigen-antibody

complex, as shown in **Figure** 49.2. An antigen-antibody complex flags a pathogen or foreign cell for destruction by phagocytosis. The liver removes antigen-antibody complexes from the blood, and the spleen removes them from the lymph.

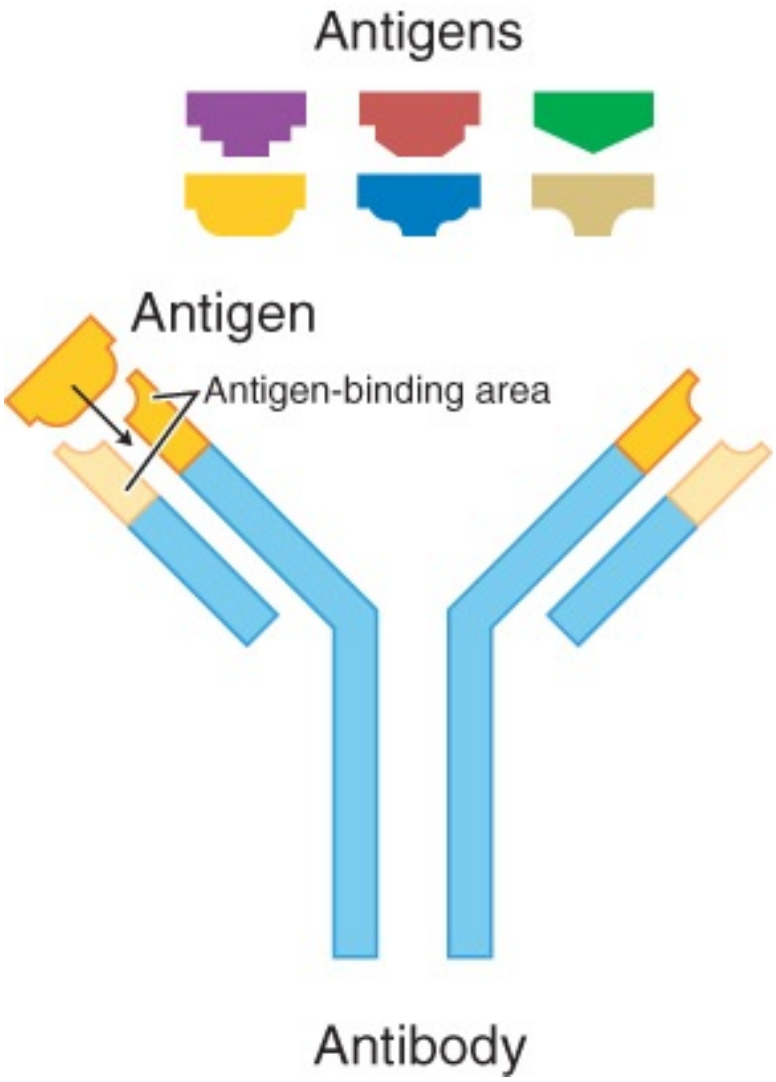


FIGURE 49.2

An antibody molecule has an area that "fits" one particular antigen. This area is where the antigen binds to the antibody, creating an antigen-antibody complex.

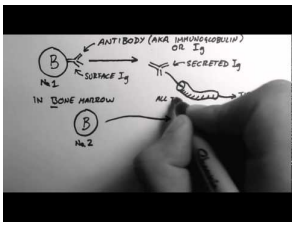
Memory Cells

Whereas most plasma cells live just a few days, memory cells live much longer. They may even survive for the lifetime of the individual. **Memory cells** are activated B (or T) cells that retain a "memory" of a specific pathogen long after an infection is over. They help launch a rapid response against the pathogen if it invades the body in the future. Memory B cells remain in the lymph, ready to produce specific antibodies against the same pathogen if it shows up in body fluids again. Vaccination relies on the longevity of memory cells that remain in the lymph nodes.

Clonal Selection Theory

When a B cell recognizes antigens on the surface of a pathogen, it becomes activated and goes through clonal selection. **Clonal selection** is a process in which lymphocytes proliferate, producing clones of themselves that all

target a specific antigen. The first group of newly cloned cells in the clonal selection of B cells are plasma cells. Each plasma cell can secrete up to 2,000 antibodies per second. The second group of cells produced are memory cells. Memory cells remain in the lymph nodes, awaiting second exposure to the same pathogen. If a second exposure occurs, memory cells initiate the secondary immune response, which is much quicker and stronger than the first. A second round of clonal selection ensues, and a larger number of antibodies are produced, often proving more effective against the pathogen.



MEDIA

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Summary

- B cell activation occurs after a B cell encounters a matching antigen.
- Helper T cells arrive and stimulate the B cell to develop into plasma cells or memory cells.
- An antigen-antibody complex flags a pathogen or foreign cell for destruction by phagocytosis. The liver removes antigen-antibody complexes from the blood, and the spleen removes them from the lymph.
- Memory cells live much longer in the body and are ready to launch a rapid response if the same pathogen appears again.

Review

1. What role do helper T cells play in the humoral immune response?
2. What happens after the antibody attaches to the antigen?
3. If your body encounters a pathogen for a second time, which cells quickly respond?

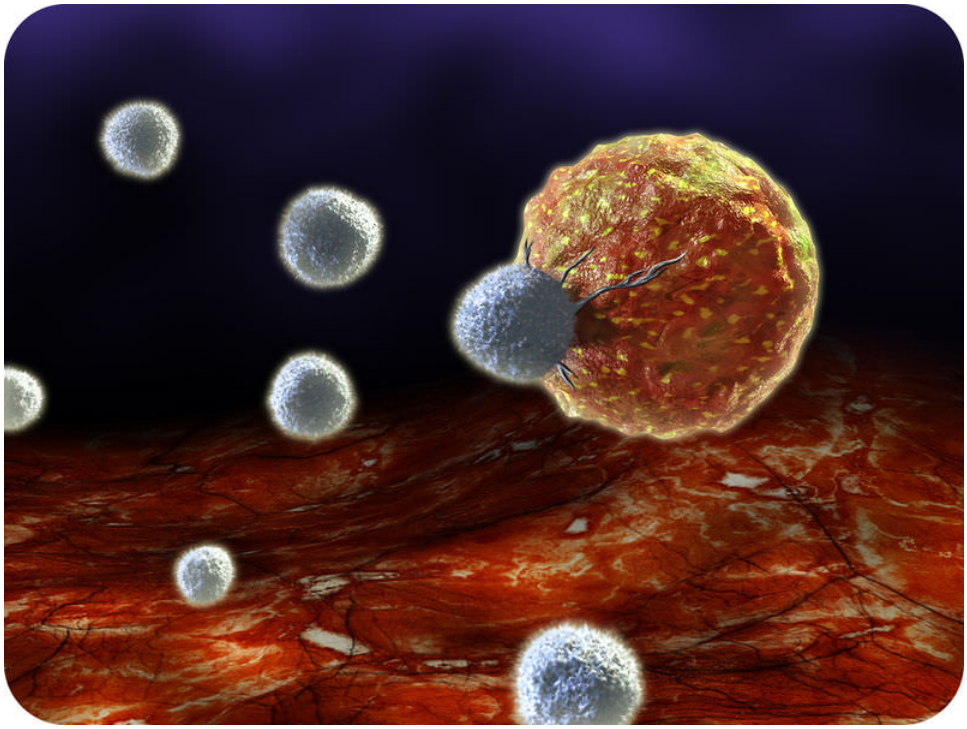
References

1. Courtesy of the National Institutes of Health and DO11.10. http://en.wikipedia.org/wiki/File:B_cell_activation.png . Public Domain
2. Fvasconcellos. http://en.wikipedia.org/wiki/Image:Antibody.svg . Public Domain

CONCEPT 50 Cell-Mediated Immune Response - Advanced

Learning Objectives

- Understand how T cells are activated.
- Differentiate between activated T cells and their functions.



Do cells really attack other cells?

They sure do. Depicted here is a group of T cells attacking a cancer cell. When they can, the T cells search out and destroy "bad" cells.

Cell-Mediated Immune Response

There are several different types of **T cells** including helper, cytotoxic, memory, and regulatory T cells. T cells are responsible for cell-mediated immunity. **Cell-mediated immunity** involves the destruction of body cells that are infected with pathogens or have become damaged or cancerous.

T Cell Activation

The different types of naïve T cells are activated in the same general way. The mechanism is shown in **Figure** 50.1. It involves B cells or leukocytes such as macrophages. These other cells engulf pathogens in phagocytosis and display parts of the pathogens' antigens on their surfaces. The cells are then called **antigen-presenting cells.** When a naïve T cell encounters one of these cells with an antigen matching its own, it begins the activation process. After T cells are activated, the various types of T cells play different roles in the immune response.

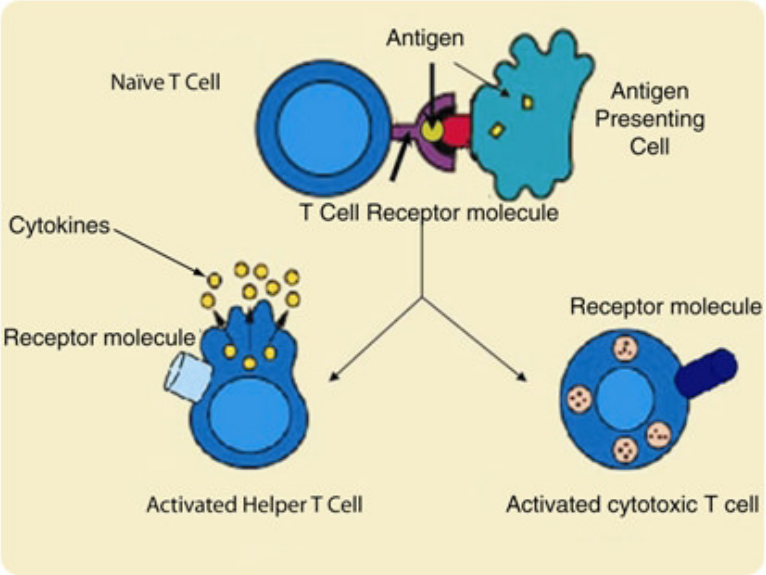


FIGURE 50.1

A naïve T cell is activated when it encounters a B cell or macrophage that has engulfed a pathogen and presents the pathogen's antigen on its surface.

Helper T Cells

Activated **helper T cells** do not kill pathogens or destroy infected cells, but they are still necessary for the immune response. In fact, they are considered to be the "managers" of the immune response. After activation, helper T cells divide rapidly and secrete cytokines. These chemical signals control the activity of other lymphocytes. Cytokines from helper T cells activate B cells. They also activate other T cells.

Most activated helper T cells die out once a pathogen has been cleared from the body. However, some helper T cells remain in the lymph as memory cells. These **memory cells** are ready to produce large numbers of antigen-specific helper T cells if they are exposed to the same antigen again in the future.

Cytotoxic T Cells

Helper T cells are needed to activate **cytotoxic T cells.** Activated cytotoxic T cells destroy tumor cells, damaged cells, and cells infected with viruses. They are also involved in the rejection of transplanted organs. Once activated, a cytotoxic T cell divides rapidly and produces an "army" of cells identical to itself. These cells travel throughout the body "searching" for more cells carrying their specific antigen. Whenever they encounter such cells, they destroy them. Illustrated in **Figure** 50.2 is how a cytotoxic T cell destroys a body cell infected with viruses. The cytotoxic T cell releases toxins, such as the protein perforin, that form pores, or holes, in the infected cell's membrane. T cell enzymes are then able to enter the infected cell and promote **apoptosis,** or programmed cell death. The infected cell bursts, destroying both the cell and the viruses inside it.

After cytotoxic T cells bring a viral infection under control, most of the cytotoxic T cells die off. However, some of them remain as memory cells. If the same pathogen tries to infect the body again, the memory cells mount an effective immune response by producing a new army of antigen-specific cytotoxic T cells.

Regulatory T Cells

Regulatory T cells shut down cell-mediated immunity toward the end of an immune response. They also try to suppress any T cells that react against self antigens as though they were foreign. This occurs in autoimmune diseases. There is ongoing research regarding the role of regulatory T cells in treating cancer, allergies, and facilitating

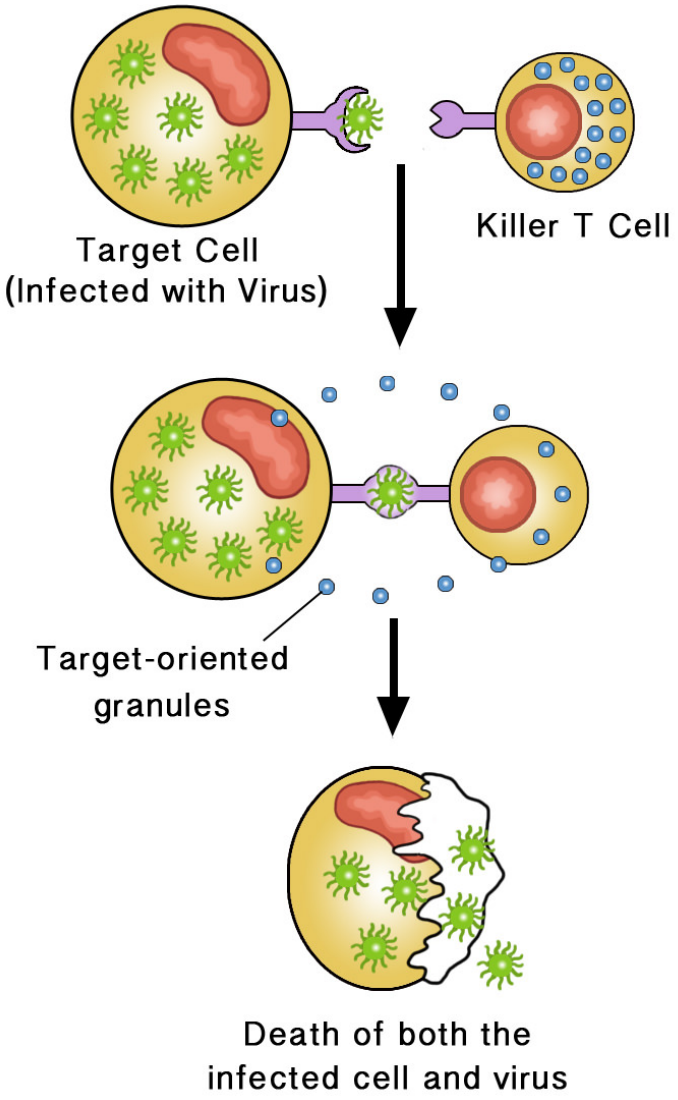
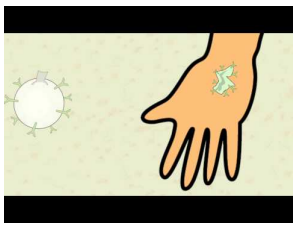


FIGURE 50.2

A cytotoxic T cell releases toxins that destroy an infected body cell and the viruses it contains.

organ transplants.



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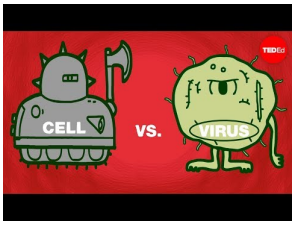
Summary

- T cells are responsible for cell-mediated immunity, which involves the destruction of body cells that are infected with pathogens or have become damaged or cancerous.
- T cells are activated when they encounter an antigen-presenting cell matching their own receptor.
- Activated helper T cells "manage" the activity of other lymphocytes by secreting cytokines.
- Cytotoxic T cells promote apoptosis, or programmed cell death, for infected/cancerous cells.
- Regulatory T cells shut down the cell-mediated response and suppress any T cells that react against self antigens as though they were foreign.

Review

1. What cells are necessary to activate T cells?
2. Which T cells are involved in both the humoral immune response and the cell-mediated immune response?
3. How do cytotoxic T cells destroy infected/cancerous cells?
4. Autoimmune diseases might be caused by what kind of malfunctioning T cells?

Explore More



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References

1. Original work of the US Federal Government. http://commons.wikimedia.org/wiki/File:Antigen_presentation.jpg . Public Domain
2. Laura Guerin. CK-12 . CC BY-NC 3.0

CONCEPT 51

Circulation and the Lymphatic System

Learning Objectives

- List the components of the lymphatic system.
- Describe the functions of the lymphatic system.
- Explain how the cardiovascular and the lymphatic systems work together.

Are your blood vessels leaky?

None of your blood vessels are leaking this badly, or you'd be in the hospital! But your blood vessels do leak a little bit. Water and solutes pass out of the blood vessels and help form the fluid that bathes your body's tissues. Ultimately the fluid that is lost from the blood vessels is returned through the lymphatic system.

The Lymphatic System and Circulation

The **lymphatic system** is a network of vessels and tissues that carry a clear fluid called **lymph.** The lymphatic system (**Figure** 51.1) spreads all around the body and filters and cleans the lymph of any debris, abnormal cells, or pathogens. **Lymph vessels** are tube-shaped, just like blood vessels, with about 500-600 lymph nodes (in an adult) attached. The lymphatic system works with the cardiovascular system to return body fluids to the blood. The lymphatic system and the cardiovascular system are often called the body's two "circulatory systems."

Organs of the lymphatic system include the tonsils, thymus gland and spleen. The thymus gland produces T cells or T-lymphocytes (see below) and the spleen and tonsils help in fighting infections. The spleen's main function is to filter the blood, removing unwanted red blood cells. The spleen also detects viruses and bacteria and triggers the release of pathogen fighting cells.

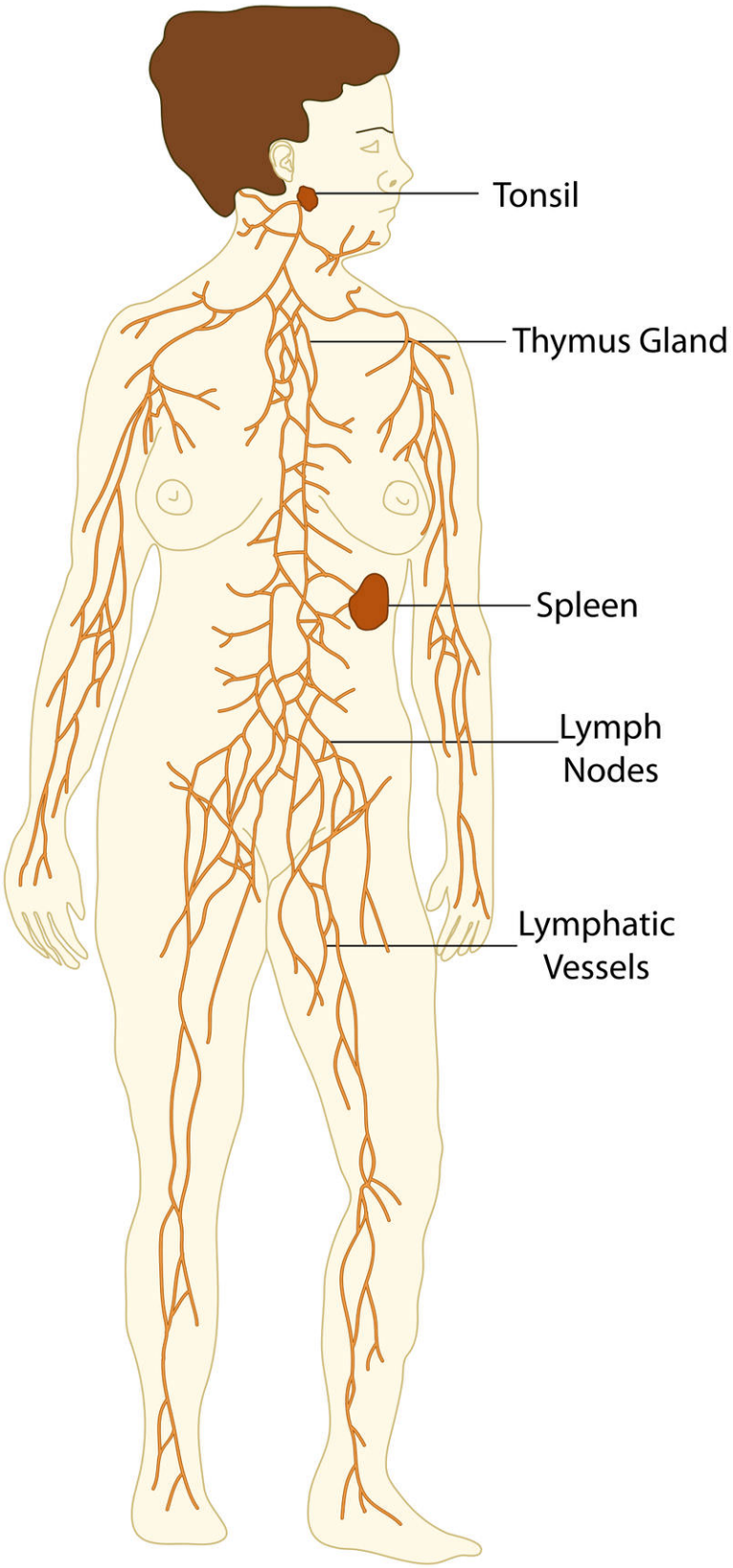

FIGURE 51.1

The lymphatic system helps return fluid that leaks from the blood vessels back to the cardiovascular system.

Role of the Lymphatic System in Circulation

You may think that your blood vessels have thick walls without any leaks, but that's not true. Blood vessels can leak just like any other pipe. The lymphatic system makes sure leaked blood returns back to the bloodstream.

When a small amount of fluid leaks out from the blood vessels, it collects in the spaces between cells and tissues. Some of the fluid returns to the cardiovascular system, and the rest is collected by the lymph vessels of the lymphatic system (**Figure** 51.2). The fluid that collects in the lymph vessels is called lymph. The lymphatic system then returns the lymph to the cardiovascular system. Unlike the cardiovascular system, the lymphatic system is not closed (meaning it is an open circulatory system that releases and collects fluid) and has no central pump (or heart). Lymph moves slowly in lymph vessels. It is moved along in the lymph vessels by the squeezing action of smooth muscles and skeletal muscles.

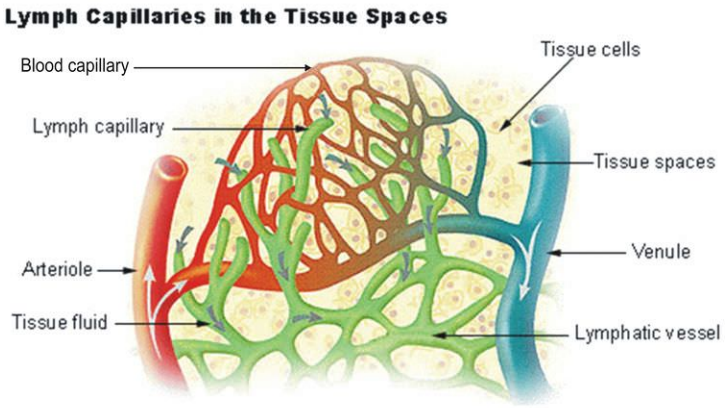

FIGURE 51.2

Lymph capillaries collect fluid that leaks out from blood capillaries. The lymphatic vessels return the fluid to the cardiovascular system.

Role of the Lymphatic System in the Body's Defenses

The lymphatic system also plays an important role in the immune system. For example, the lymphatic system makes white blood cells that protect the body from diseases. Cells of the lymphatic system produce two types of white blood cells, T cells and B cells, that are involved in fighting specific pathogens. Lymph nodes, which are scattered throughout the lymphatic system, act as filters or traps for foreign particles and are important in the proper functioning of the immune system. The role of the lymphatic system in the immune response is discussed in additional concepts.

Summary

- The lymphatic system works with the cardiovascular system to return body fluids to the blood.
- The lymph, the clear liquid found in the lymphatic system, is moved along in the lymph vessels by the squeezing action of smooth muscles and skeletal muscles.

Explore More

Use the resource below to answer the questions that follow.

- **Lymphatic System** at http://www.youtube.com/watch?v=BX8fBlme9vQ (10:35)

MEDIA

Click image to the left or use the URL below.

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1. Where are lymphatic vessels found?
2. What are the functions of the lymphatic system?
3. What is interstitial fluid?
4. What causes circulation in the lymphatic system?
5. What are the functions of lymph nodes?
6. What effect does removing a person's spleen have on the functioning of the body?

Review

1. What is the role of the lymphatic system?
2. Describe the role of the spleen.
3. How does the lymph circulate through the body?
4. Where does lymph come from?

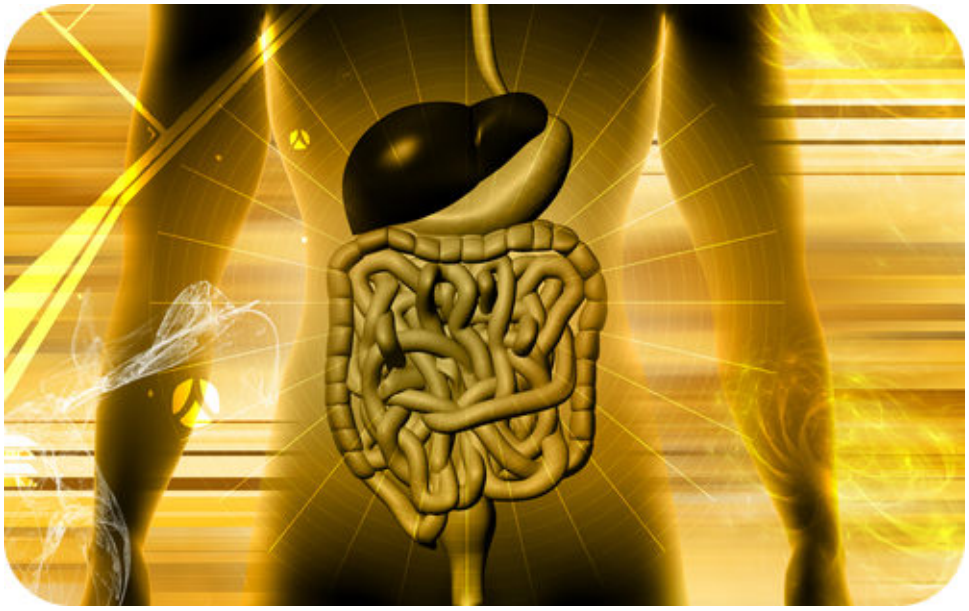
References

1. User:The Emirr/Wikimedia Commons. Illustration of the parts of the lymphatic system . CC BY 3.0
2. Courtesy of the U.S. National Cancer Institute's Surveillance, Epidemiology and End Results (SEER) Program. Lymph capillaries collect the flood the leaks from blood capillaries and is slowly returned to the cardi ovascular system .

CONCEPT 52 Digestive System Organs - Advanced

Learning Objectives

- Learn about the different organs that make up the digestive system.
- Understand the importance of the liver and its role in maintaining a healthy body.



Specifically, our energy comes from what?

The respiratory and circulatory systems work together to provide cells with the oxygen they need for cellular respiration. Cells also need glucose for cellular respiration. Glucose is a simple sugar that comes from the food we eat. To get glucose from food, digestion must occur. This process is carried out by the digestive system.

Organs and Functions of the Digestive System

Suppose you are studying and having trouble concentrating. You decide to eat an apple for energy. How does energy stored in the apple get into your cells? What organs and processes break down the apple into nutrients that the body can use for fuel? What organs and processes let the nutrients enter your bloodstream so that they can travel to the cells where they are needed? The basic processes involved are digestion and absorption. The organs involved are the organs of the digestive system.

Organs that make up the digestive system are shown in **Figure** 52.1. Most of the organs form the gastrointestinal tract. Other digestive organs are called accessory organs. As you read about the organs below, refer to **Figure** 52.1 for reference.

Gastrointestinal Tract

The **gastrointestinal (GI) tract** is a long tube that connects the mouth with the anus. It is more than 9 meters long in adults. The GI tract can be divided into an upper and lower part. The upper GI tract includes the mouth, esophagus,

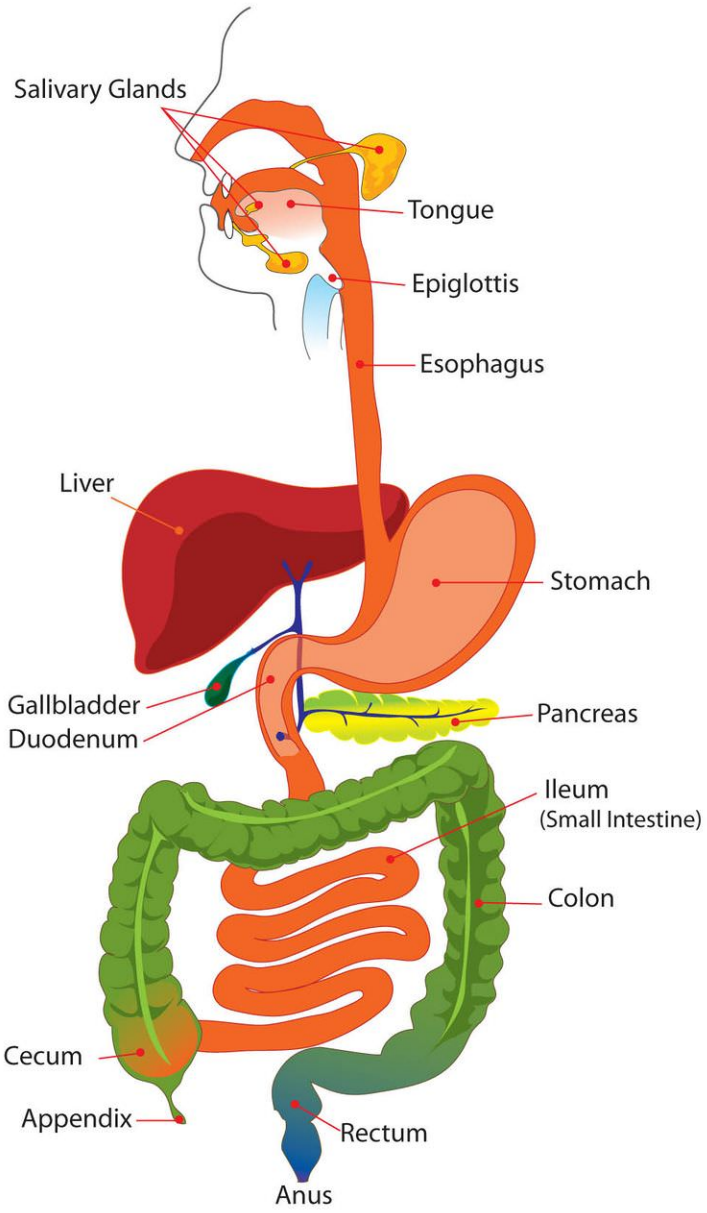


FIGURE 52.1
Organs of the digestive system.

and stomach. The lower GI tract includes the small and large intestines. Food enters the mouth, passes through the upper and lower GI tracts, and then exits the body as feces through the anus.

The organs of the GI tract are covered by two layers of muscles that enable peristalsis. **Peristalsis** is a rapid, involuntary, wave-like contraction of muscles. It pushes food through the GI tract. The inside of GI tract is lined with mucous membranes. Mucous membranes are moist tissues that can secrete and absorb substances. The ability to secrete and absorb substances is necessary for the functions of the digestive system.

Accessory Organs of the Digestive System

In the lower GI tract, additional organs play important roles in digestion. They are called accessory organs. Food does not pass through them, but they make or store substances needed for digestion. The accessory organs are the

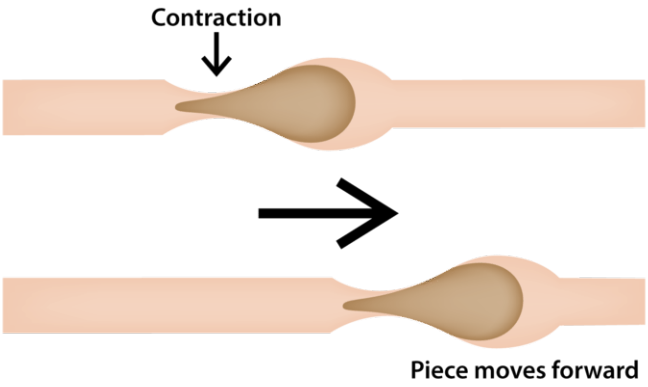


FIGURE 52.2

Peristalsis pushes food through the GI tract.

liver, gall bladder, and pancreas.

- The liver is a large organ next to the stomach. It produces digestive substances that are carried by ducts, or tubes, to the small intestine and gall bladder.
- The gall bladder is a small pear-shaped structure below the liver. It stores substances from the liver until they are needed by the small intestine.
- The pancreas is a gland below the stomach. It produces digestive substances that are carried by a duct to the small intestine.

The Liver

The liver is a vital organ that has many functions including detoxification of blood, protein synthesis, and production of biochemicals necessary for digestion. The liver is also involved in glucose balance. The liver produces bile, which breaks down lipids.

The liver performs several roles in carbohydrate metabolism, which help in the balance of blood glucose levels:

- Gluconeogenesis: the synthesis of glucose from certain amino acids, lactate, or glycerol.
- Glycogenolysis: the breakdown of glycogen into glucose.
- Glycogenesis: the formation of glycogen from glucose.

The liver is one of the most important organs in the body when it comes to blood filtering and detoxification. The liver is involved in getting rid of foreign substances and toxins, especially from the gut. The toxins are usually excreted in bile or urine. Breaking down toxins is referred to as **drug metabolism** and is usually done using specialized enzymes produced in the liver. Most of the blood being filtered by the liver is from the portal vein, which carries blood from the intestines. The liver can remove a broad range of microorganisms, such as bacteria, fungi, viruses, and parasites, from the blood. Infections and parasites can come from contaminated water and food and then find their way into your gut and blood stream. Luckily, the blood then goes to the liver for filtering.

The liver also performs several roles in lipid metabolism including cholesterol synthesis and the production of triglycerides (fats). The liver produces coagulation factors I (fibrinogen), II (prothrombin), V, VII, IX, X, and XI as well as protein C, protein S, and antithrombin.

Functions of the Digestive System

The digestive system has three main functions: digestion of food, absorption of nutrients, and elimination of solid waste. Digestion is the process of breaking down food into components the body can absorb. There are two types of

digestion: mechanical and chemical.

- Mechanical digestion is the physical breakdown of chunks of food into smaller pieces. It takes place mainly in the mouth and stomach.
- Chemical digestion is the chemical breakdown of large complex food molecules into smaller, simpler nutrient molecules that can be absorbed by the blood. It takes place mainly in the small intestine.

Chemical digestion could not take place without the help of digestive enzymes. **Enzymes** are substances that speed up chemical reactions. Digestive enzymes speed up the reactions of chemical digestion. Digestive enzymes are secreted by glands in the mucous membranes of the mouth, stomach, small intestine, and pancreas. Different digestive enzymes help break down different types of food molecules such as carbohydrates, proteins, and lipids.

The name of a digestive enzyme typically ends with the suffix *-ase*' (which means "enzyme"). The rest of the name refers to the type of food molecules the enzyme helps digest. For example, the enzyme lipase helps digest lipid molecules, and the enzyme lactase helps digest molecules of the sugar lactose.

After food is digested, the resulting nutrients are absorbed. **Absorption** is the process in which substances pass into the blood stream where they can circulate throughout the body. Absorption occurs mainly in the small intestine. Any remaining indigestible matter that cannot be absorbed passes into the large intestine as waste. The waste later passes out of the body through the anus in the process of elimination.

MEDIA

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Summary

- The upper GI tract includes the mouth, esophagus, and stomach. The lower GI tract includes the small and large intestines.
- The inside of GI tract is lined with mucous membranes. Mucous membranes are moist tissues that can secrete and absorb substances.
- The liver performs gluconeogenesis, glycogenolysis, and glycogenesis in carbohydrate metabolism.
- The liver is one of the most important organs in the body when it comes to blood filtering and detoxification. The toxins are usually excreted in bile or urine.
- The liver also performs several roles in lipid metabolism including cholesterol synthesis and the production of triglycerides (fats).
- Mechanical digestion is the physical breakdown of chunks of food into smaller pieces.
- Chemical digestion is the chemical breakdown of large complex food molecules into smaller, simpler nutrient molecules that can be absorbed by the blood.
- Chemical digestion could not take place without the help of digestive enzymes. Digestive enzymes speed up the reactions of chemical digestion.

Review

1. What organs are included in the upper and lower GI tracts?

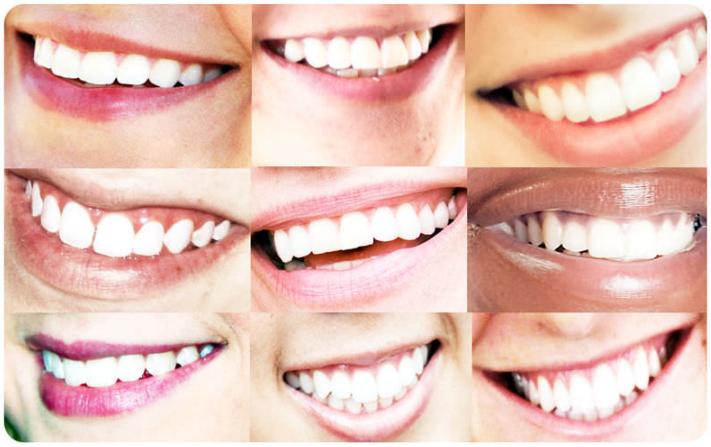
2. What are the accessory organs in the GI tract?
3. What organ produces bile?
4. What are the three main functions of the digestive system?
5. What is the difference between mechanical digestion and chemical digestion?

References

1. Mariana Ruiz. Organs of the digestive system. . Public Domain
2. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0

CONCEPT 53 Digestion of Food

Digestion



What's the first step in the digestion process?

It all starts with the mouth. Food goes in, you chew it up, swallow it, then what happens? The process of turning that food into energy and proteins and other things necessary for life begins. But it all starts with the mouth.

The Start of Digestion: Mouth to Stomach

Does the sight or aroma of your favorite food make your mouth water? When this happens, you are getting ready for digestion.

FIGURE 53.1

Teeth are important for mechanical digestion.

Mouth

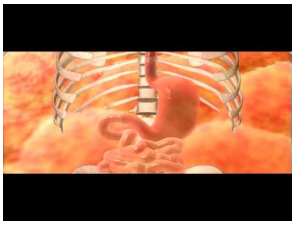
The mouth is the first digestive organ that food enters. The sight, smell, or taste of food stimulates the release of digestive enzymes by **salivary glands** inside the mouth. The major salivary enzyme is **amylase**. It begins the **chemical digestion** of carbohydrates by breaking down starch into sugar.

The mouth also begins the process of **mechanical digestion**. Sharp teeth in the front of the mouth cut or tear food when you bite into it (see figure above). Broad teeth in the back of the mouth grind food when you chew. Food is easier to chew because it is moistened by saliva from the salivary glands. The tongue helps mix the food with saliva and also helps you swallow. After you swallow, the chewed food passes into the pharynx.

Stomach

The **stomach** is a sac-like organ in which food is further digested both mechanically and chemically. (To see an animation of how the stomach digests food, go to the link below.) Churning movements of the stomach's thick, muscular walls complete the mechanical breakdown of food. The churning movements also mix food with digestive fluids secreted by the stomach. One of these fluids is hydrochloric acid. It kills bacteria in food and gives the stomach the low (acidic) pH needed by digestive enzymes that work in the stomach. The main enzyme is **pepsin**, which chemically digests protein.

This video describes the stomach through its structure, functions, and overall digesting process. See http://www.youtube.com/watch?v=URHBBE3RKEs for additional information.



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The stomach stores the partly digested food until the small intestine is ready to receive it. When the small intestine is empty, a sphincter opens to allow the partially digested food to enter the small intestine.

The following interactive animation demonstrates the processes that occur in the stomach.

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URL: http://www.ck12.org/flx/render/embeddedobject/145

Watch the video at: http://www.ck12.org/flx/render/embeddedobject/145

What Does the Digestive System Do?

Nutrients in the foods you eat are needed by the cells of your body. How do the nutrients in foods get to your body cells? What organs and processes break down the foods and make the nutrients available to cells? The organs are those of the digestive system. The processes are digestion and absorption.

The **digestive system** is the body system that breaks down food and absorbs nutrients. It also gets rid of solid food waste. The main organs of the digestive system are shown in figure below.

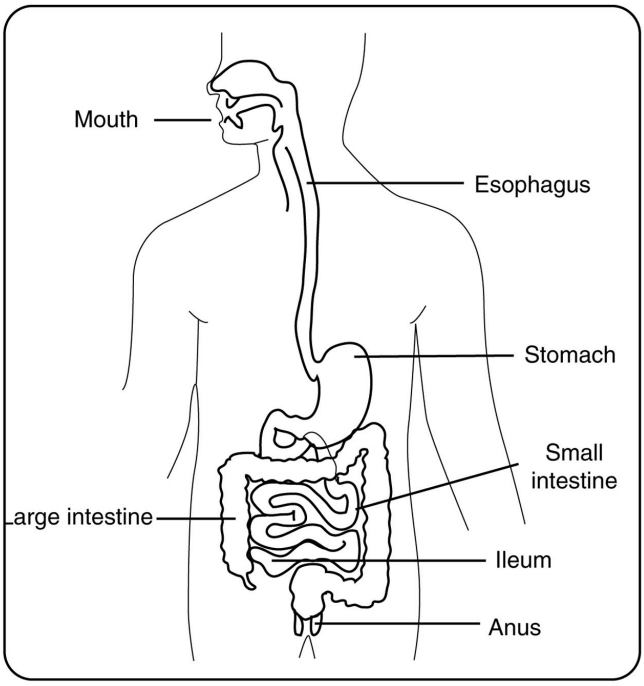


FIGURE 53.2

This drawing shows the major organs of the digestive system. Trace the path of food through the organs of the digestive system as you read about them in this lesson.

Digestion is the process of breaking down food into nutrients. There are two types of digestion, mechanical and chemical. In **mechanical digestion**, large chunks of food are broken down into small pieces. This is a physical process. In **chemical digestion**, large food molecules are broken down into small nutrient molecules. This is a chemical process.

Absorption is the process that allows substances you eat to be taken up by the blood. After food is broken down into small nutrient molecules, the molecules are absorbed by the blood. After absorption, the nutrient molecules travel in the bloodstream to cells throughout the body.

Some substances in food cannot be broken down into nutrients. They remain behind in the digestive system after the nutrients are absorbed. Any substances in food that cannot be digested and absorbed pass out of the body as solid waste. The process of passing solid food waste out of the body is called elimination.

The Role of Enzymes in Digestion

Chemical digestion could not take place without the help of digestive enzymes. An **enzyme** is a protein that speeds up chemical reactions in the body. Digestive enzymes speed up chemical reactions that break down large food molecules into small molecules.

Did you ever use a wrench to tighten a bolt? You could tighten a bolt with your fingers, but it would be difficult and slow. If you use a wrench, you can tighten a bolt much more easily and quickly. Enzymes are like wrenches. They make it much easier and quicker for chemical reactions to take place. Like a wrench, enzymes can also be used over and over again. But you need the appropriate size and shape of the wrench to efficiently tighten the bolt, just like each enzyme is specific for the reaction it helps.

Digestive enzymes are released, or secreted, by the organs of the digestive system. Examples of digestive enzymes are:

- Amylase, produced in the mouth. It helps break down large starches molecules into smaller sugar molecules.
- Pepsin, produced in the stomach. Pepsin helps break down proteins into amino acids.
- Trypsin, produced in the pancreas. Trypsin also breaks down proteins.
- Pancreatic lipase, produced in the pancreas. It is used to break apart fats.
- Deoxyribonuclease and ribonuclease, produced in the pancreas. They are enzymes that break bonds in nucleic acids like DNA and RNA.

Bile salts are bile acids that help to break down fat. Bile acids are made in the liver. When you eat a meal, bile is secreted into the intestine, where it breaks down the fats. Bile acids also help to remove cholesterol from the body.

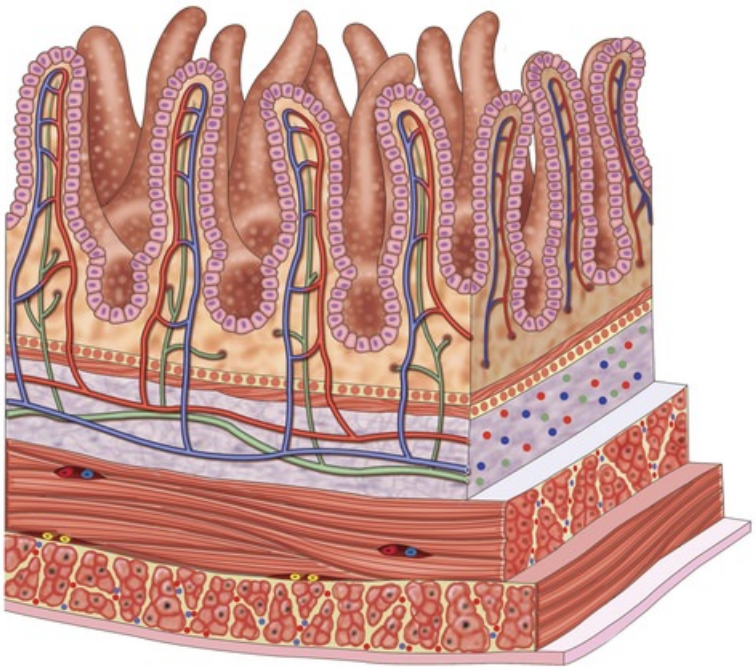
Hormones and Digestion

If you are a typical teenager, you like to eat. For your body to break down, absorb and spread the nutrients throughout your body, your digestive system and endocrine system need to work together. The endocrine system sends hormones around your body to communicate between cells like chemical messengers.

Digestive hormones are made by cells lining the stomach and small intestine. These hormones cross into the blood where they can affect other parts of the digestive system. Some of these hormones are listed below.

- Gastrin, which signals the secretion of gastric acid.
- Cholecystokinin, which signals the secretion of pancreatic enzymes.
- Secretin, which signals secretion of water and bicarbonate from the pancreas.
- Ghrelin, which signals when you are hungry.
- Gastric inhibitory polypeptide, which stops or decreases gastric secretion. It also causes the release of insulin in response to high blood glucose levels.

Small Intestine



These projections absorb. Absorb what?

Imagine the inside walls of the 23 feet of your small intestine covered with these finger-like projections. Why? What's their purpose, and why is the small intestine so long? These projections absorb. Absorb what? Minerals and nutrients from food. And the length of the small intestine allows as much of these important substances to be absorbed as possible.

Digestion and Absorption: The Small Intestine

The **small intestine** is a narrow tube about 7 meters (23 feet) long in adults. It is the site of most chemical digestion and virtually all absorption. The small intestine consists of three parts: the duodenum, jejunum and ileum (see the opening figure).

Digestion in the Small Intestine

The **duodenum** is the first and shortest part of the small intestine. Most chemical digestion takes place here, and many digestive enzymes are active in the duodenum (see table below). Some are produced by the duodenum itself. Others are produced by the pancreas and secreted into the duodenum.

TABLE 53.1: Digestive Enzymes Active in the Duodenum

Enzyme	What It Digests	Where It Is Made
Amylase	carbohydrates	salivary glands, pancreas
Trypsin	proteins	salivary glands, pancreas
Lipase	lipids	salivary glands and pancreas, duodenum
Maltase	carbohydrates	duodenum
Peptidase	proteins	duodenum

How does the pancreas "know" when to secrete enzymes into the small intestine? The pancreas is controlled by compounds called hormones. Hormones are chemical messengers in the body. They regulate many body functions, including secretion of digestive enzymes. When food enters the stomach, a hormone called gastrin is secreted by the stomach. Gastrin, in turn, stimulates the pancreas to secrete its digestive enzymes.

The liver produces fluid called bile, which is secreted into the duodenum. Some bile goes to the gall bladder, where it is stored and becomes more concentrated. In the duodenum, bile breaks up large globules of lipids into smaller globules that are easier for lipase enzymes to break down chemically.

Bile also reduces the acidity of the chyme entering from the highly acidic stomach. This is important for digestion, because digestive enzymes in the duodenum require a neutral environment in order to work. The pancreas also contributes to the neutral environment of the duodenum by secreting bicarbonate, a basic substance that neutralizes acid.

Summary

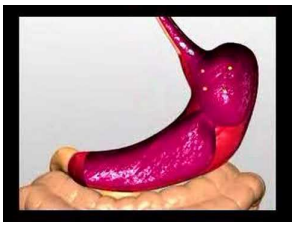
- Virtually all absorption of nutrients takes place in the small intestine, which has a very large inner surface area because it is covered with millions of microscopic villi.

Review

1. Name the parts of the small intestine.
2. Where are most nutrients absorbed?
3. What is digested by trypsin, by lipase, and by maltase?
4. Describe the functions of the three parts of the small intestine.
5. What role do villi play in absorption?

Enzymes and Digestion

This is an animation about digestive enzymes in the duodenum.



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URL: http://www.ck12.org/flx/render/embeddedobject/134435

Watch the video at: https://www.youtube.com/watch?v=bNMsNHqxszc

Digestion from the Inside

Learn about food digestion by watching this video, which directly follows food through its path in the body.

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URL: http://www.ck12.org/flx/render/embeddedobject/134437

Watch the video at: https://www.youtube.com/watch?v=Uzl6M1YlU3w

Digestion 2

This animation shows the parts of the body digesting different foods.

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URL: http://www.ck12.org/flx/render/embeddedobject/134439

Watch the video at: https://www.youtube.com/watch?v=IxNpXO8gGFM

References

1. Stefan Andrej Shambora. Teeth illustration.
2. . MSLS-17-10-digestive-system.

CONCEPT 54 Human Excretory System

Excretion

What do you do with your waste?

Toxic waste must be disposed of properly or there can be serious consequences. Now, your waste should not be as colorful or toxic as shown here (if it is, get yourself to a doctor as soon as possible), but it still needs to be removed from you. And that is the role of the excretory system. The excretory system gets rid of waste and excess water.

If you exercise on a hot day, you are likely to lose a lot of water in sweat. Then, for the next several hours, you may notice that you do not pass **urine** as often as normal and that your urine is darker than usual. Do you know why this happens? Your body is low on water and trying to reduce the amount of water lost in urine. The amount of water lost in urine is controlled by the **kidneys**, the main organs of the excretory system.

Excretion is the process of removing wastes and excess water from the body. It is one of the major ways the body maintains homeostasis. Although the kidneys are the main organs of excretion, several other organs also excrete wastes. They include the large intestine, liver, skin, and lungs. All of these organs of excretion, along with the kidneys, make up the **excretory system**. The roles of the excretory organs other than the kidney are summarized below:

- The large intestine eliminates solid wastes that remain after the digestion of food.
- The liver breaks down excess amino acids and toxins in the blood.
- The skin eliminates excess water and salts in sweat.
- The lungs exhale water vapor and carbon dioxide.

Summary

- Excretion is the process of removing wastes and excess water from the body. It is one of the major ways the body maintains homeostasis.
- Organs of excretion make up the excretory system. They include the kidneys, large intestine, liver, skin, and lungs.

Explore More

Use this resource to answer the questions that follow.

MEDIA

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Watch the video at: http://www.youtube.com/watch?v=ibe6Hthv5Uk .

1. What organs comprise the excretory system?

2. Describe the structure of the kidney.

3. What is the role of the kidney?
4. Where does urine come from?

Review

1. What is excretion?
2. List organs of the excretory system and their functions.

Structure and Functions of Kidney

Your kidneys filter and remove wastes from your blood.

The Kidneys

The kidneys are a pair of bean-shaped organs just above the waist. They are important organs with many functions in the body, including producing hormones, absorbing minerals, and filtering blood and producing urine.

A cross-section of a kidney is shown in **Figure** 55.2. The function of the kidney is to filter blood and form urine. **Urine** is the liquid waste product of the body that is excreted by the urinary system. Wastes in the blood come from the normal breakdown of tissues, such as muscles, and from food. The body uses food for energy. After the body has taken the nutrients it needs from food, some of the wastes are absorbed into the blood. If the kidneys did not remove them, these wastes would build up in the blood and damage the body.

Kidneys and Nephrons

The actual removal of wastes from the blood occurs in tiny units inside the kidneys called nephrons. **Nephrons** are the structural and functional units of the kidneys. A single kidney may have more than a million nephrons! This is further discussed in the *Urinary System* concept.

Kidneys and Homeostasis

The kidneys play many vital roles in **homeostasis**. They work with many other organ systems to do this. For example, they work with the circulatory system to filter blood, and with the urinary system to remove wastes.

The kidneys filter all the blood in the body many times each day and produce a total of about 1.5 liters of **urine**. The kidneys control the amount of water, ions, and other substances in the blood by excreting more or less of them in urine. The kidneys also secrete **hormones** that help maintain homeostasis. **Erythropoietin**, for example, is a kidney hormone that stimulates bone marrow to produce red blood cells when more are needed. They also secrete renin, which regulates blood pressure, and calcitriol, the active form of vitamin D, which helps maintain calcium for bones. The kidneys themselves are also regulated by hormones. For example, **antidiuretic hormone** from the hypothalamus stimulates the kidneys to produce more concentrated urine when the body is low on water.

Other Functions

In addition to filtering blood and producing urine, the kidneys are also involved in maintaining the water level in the body, and regulating red blood cell levels and blood pressure.

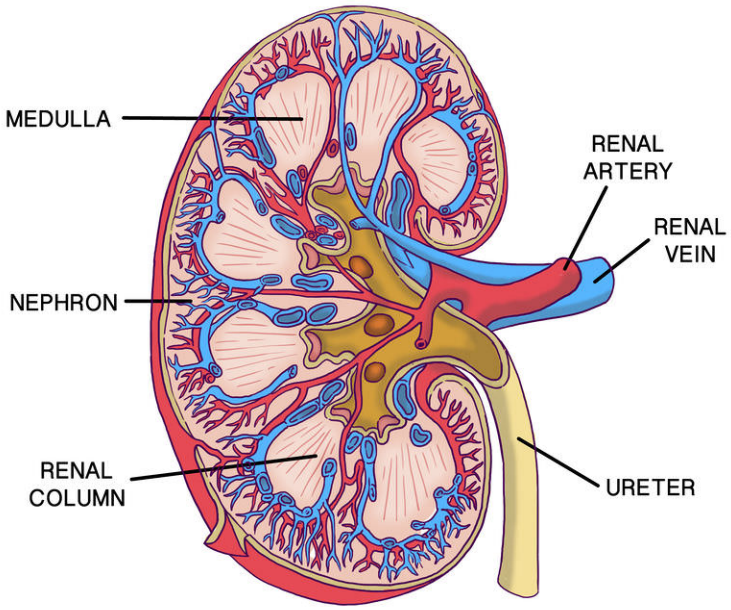


FIGURE 54.1

Each kidney is supplied by a renal artery and renal vein.

- As the kidneys are mainly involved in the production of urine, they react to changes in the body's water level throughout the day. As water intake decreases, the kidneys adjust accordingly and leave water in the body instead of helping remove it through the urine, maintaining the water level in the body.
- The kidneys also need constant pressure to filter the blood. When the blood pressure drops too low, the kidneys increase the pressure. One way is by producing angiotensin, a blood vessel-constricting protein. This protein also signals the body to retain sodium and water. Together, the constriction of blood vessels and retention of sodium and water help restore normal blood pressure.
- When the kidneys don't get enough oxygen, they send out a signal in the form of the hormone erythropoietin, which stimulates the bone marrow to produce more oxygen-carrying red blood cells.

Summary

- The kidneys maintain homeostasis by controlling the amount of water, ions, and other substances in the blood.
- Kidneys also secrete hormones that have other homeostatic functions.

Explore More

- **The Structure of the Kidney** at http://www.wisc-online.com/Objects/ViewObject.aspx?ID=NUR2503 .

Review

1. What is the nephron? How many nephrons are in each kidney?
2. Explain how the kidneys maintain homeostasis.
3. What is the role of antidiuretic hormone?

Kidneys

Why are the kidneys important?

These kidney beans are named after a very important organ in your body. Though you probably can live without these beans, you can't live without at least one kidney. The kidneys have several essential functions. For example, kidneys filter your blood, removing wastes and regulating the amount of water in your body.

- They maintain the volume of body fluids.
- They maintain the balance of salt ions in body fluids.
- They excrete harmful nitrogen-containing molecules, such as urea, ammonia, and uric acid.

There are many blood vessels in the kidneys (**Figure** 55.2). The kidneys remove urea and other wastes from the blood through tiny filtering units called nephrons. **Nephrons** (**Figure** 54.2) are tiny, tube-shaped structures found inside each kidney. Each kidney has up to a million nephrons. Each nephron collects a small amount of fluid and waste from a small group of capillaries.

Nitrogen-containing wastes, together with water and other wastes, form the **urine** as it passes through the nephrons and the kidney. The fluid within nephrons is carried out into a larger tube in the kidney called a **ureter**, which carries it to the bladder (**Figure** 54.2).

The kidneys never stop filtering waste products from the blood, so they are always producing urine. The amount of urine your kidneys produce is dependent on the amount of fluid in your body. Your body loses water through sweating, breathing, and urination. The water and other fluids you drink every day help to replace the lost water. This water ends up circulating in the blood because blood plasma is mostly water.

Formation of Urine

The process of urine formation is as follows:

1. Blood flows into the kidney through the renal artery. The renal artery connects to capillaries inside the kidney. Capillaries and nephrons lie very close to each other in the kidney.

2. The blood pressure within the capillaries causes water, salts, sugars, and urea to leave the capillaries and move into the nephron.

3. The water and salts move along through the tube-shaped nephron to a lower part of the nephron.

4. The fluid that remains in the nephron at this point is called urine.

5. The blood that leaves the kidney in the renal vein has much less waste than the blood that entered the kidney.

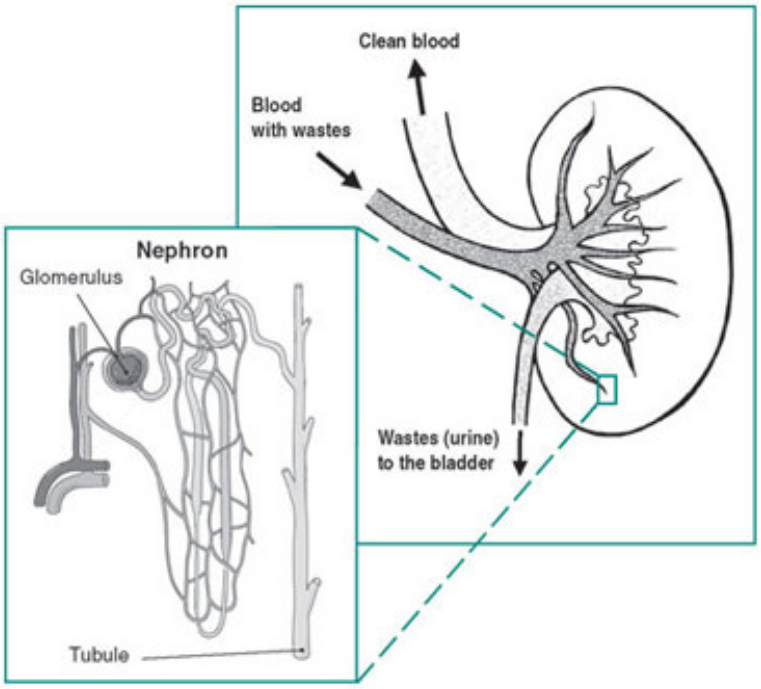


FIGURE 54.2

The location of nephrons in the kidney. The fluid collects in the nephron tubules and moves to the bladder through the ureter.

6. The urine is collected in the ureters and is moved to the urinary bladder, where it is stored.

Nephrons filter about $\frac{1}{4}$ cup of body fluid per minute. In a 24-hour period, nephrons filter 180 liters of fluid, and 1.5 liters of the fluid is released as urine. Urine enters the bladder through the ureters. Similar to a balloon, the walls of the bladder are stretchy. The stretchy walls allow the bladder to hold a large amount of urine. The bladder can hold about $1\frac{1}{2}$ to $2\frac{1}{2}$ cups of urine but may also hold more if the urine cannot be released immediately.

How do you know when you have to urinate? **Urination** is the process of releasing urine from the body. Urine leaves the body through the urethra. Nerves in the bladder tell you when it is time to urinate. As the bladder first fills with urine, you may notice a feeling that you need to urinate. The urge to urinate becomes stronger as the bladder continues to fill up.

Brain Control of Urination

The filtering action of the kidneys is controlled by the **pituitary gland**. The pituitary gland is about the size of a pea and is found below the brain (**Figure** 54.3). The pituitary gland releases hormones that help the kidneys to filter water from the blood.

The movement of water back into blood is controlled by a hormone called **antidiuretic hormone** (ADH). ADH is one of the hormones released from the pituitary gland in the brain. One of the most important roles of ADH is to control the body's ability to hold onto water. If a person does not drink enough water, ADH is released. It causes the blood to reabsorb water from the kidneys. If the kidneys remove less water from the blood, what will the urine look like? It will look darker, because there is less water in it.

When a person drinks a lot of water, then there will be a lot of water in the blood. The pituitary gland will then release a lower amount of ADH into the blood. This means less water will be reabsorbed by the blood. The kidneys then produce a large volume of urine. What color will this urine be?

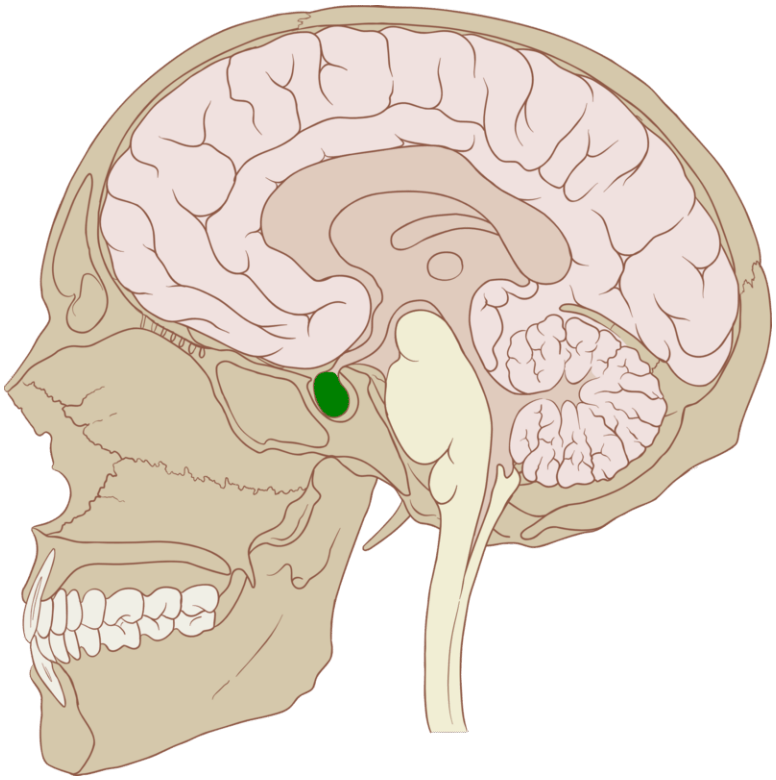


FIGURE 54.3

The pituitary gland (green) is found directly below the brain and releases hormones that control how urine is produced.

Summary

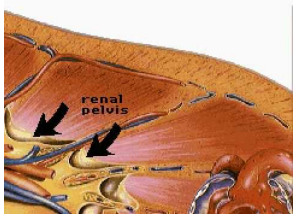
- Water and waste molecules move out of the blood capillaries and into the nephrons of the kidney to form the urine.
- ADH is the hormone released by the pituitary gland and controls how water is reabsorbed by the blood from the kidneys.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

Anatomy of a Kidney



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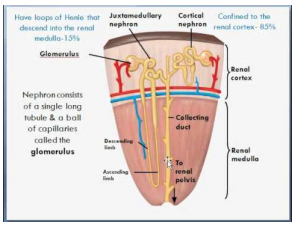
Watch the video at: http://www.youtube.com/watch?v=Pz5DHAv_Mw4

1. What is a nephron? What is its function in the kidney?

2. What happens in the coiled tubules in the kidney?
3. Where is the cortex of the kidney? What structures are located there?
4. Where is the medulla in the kidney? What structures are located there?

Explore More II

Kidney Anatomy and Physiology



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URL: http://www.ck12.org/flx/render/embeddedobject/57529

Watch the video at: http://www.youtube.com/watch?v=7nesHuVEe8M

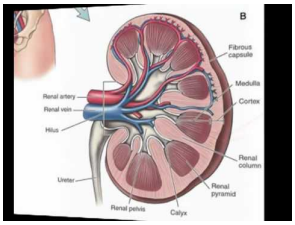
1. Where does the ureter lead to?
2. What exits the tubules in the outer medulla? What effect does this have on the fluid moving through the tubules?
3. What exits the tubules on the ascending limb? What effect does this have on the fluid moving through the tubules?
4. What controls the permeability of the collecting ducts?

Review

1. What is the nephron?
2. Through what blood vessel does blood enter the kidney?
3. What causes wastes to leave the blood?
4. What is the difference between the blood that enters and leaves the kidney?
5. What does antidiuretic hormone (ADH) do?

Urinary System - The Kidneys

Brief overview of the basic structure and function of the urinary system and kidneys



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URL: http://www.ck12.org/flx/render/embeddedobject/76195

Watch the video at: https://www.youtube.com/watch?v=zEpUQkQ-uKM

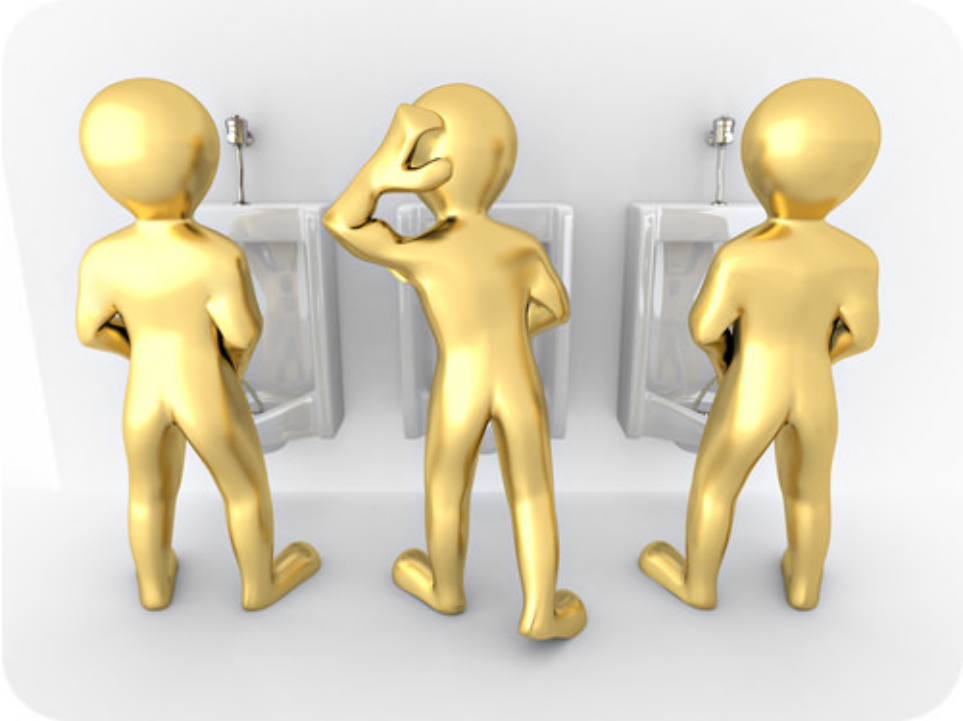
References

1. Laura Guerin. Kidney cutaway .
2. Courtesy of the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), National Institutes of Health (NIH). Many nephrons make up your kidney .
3. Patrick J. Lynch, modified by CK-12 Foundation. The pituitary gland helps regulate the production of urine .

CONCEPT 55 Kidneys and Excretion - Advanced

Learning Objectives

- Differentiate between the different organs that comprise the urinary system.
- Understand the role of the nephrons in filtration and reabsorption.



How is it determined what's waste and what's not?

Shown above is a major process of maintaining homeostasis. Getting rid of waste and excess water. Such a basic process is actually very complex. It involves an intricate exchange of materials through the kidneys.

Kidneys and Excretion

The **kidneys** are part of the urinary system. The kidneys work together with other organs of the urinary system in the function of excretion. The urinary system is shown in **Figure** 55.1.

Urinary System

In addition to the kidneys, the urinary system includes the **ureters, bladder,** and **urethra.** The main function of the urinary system is to filter waste products and excess water from the blood and remove them from the body. The two kidneys, which are described in detail below, filter the blood and form urine. Urine is the liquid waste product of the body that is excreted by the urinary system.

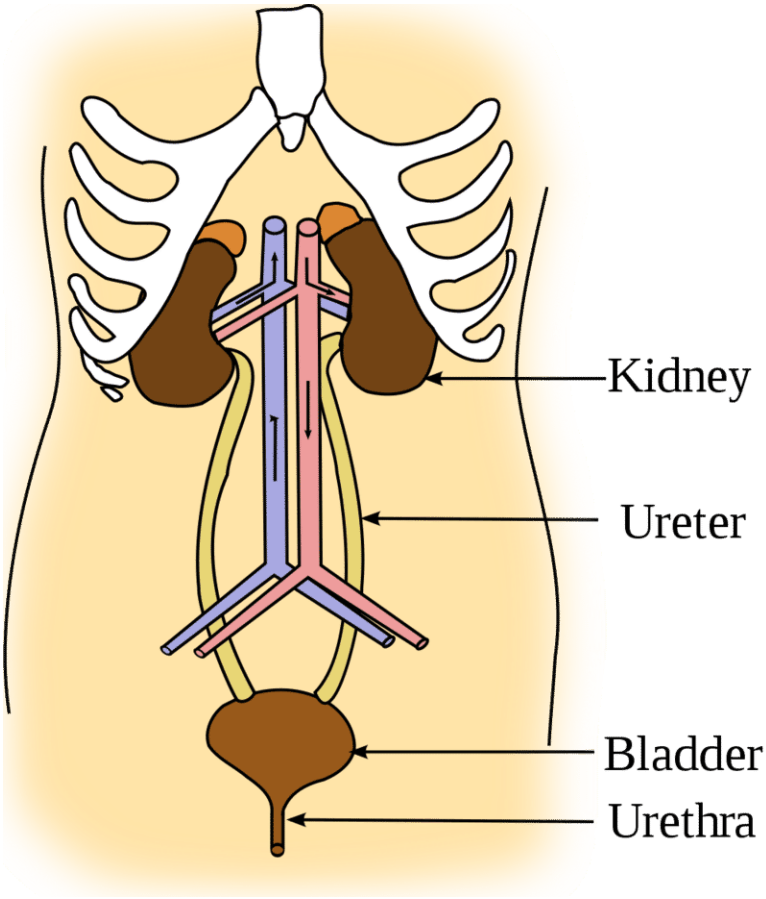


FIGURE 55.1

Components of the Urinary System. The kidneys are the chief organs of the urinary system.

From the kidneys, urine enters the ureters, which carry it to the bladder. Each ureter is a muscular tube about 25 centimeters long. Peristaltic movements of the muscles of the ureter send urine to the bladder in small spurts.

The bladder is a hollow organ that stores urine. It can stretch to hold up to 500 milliliters. When the bladder is about half full, the stretching of the bladder sends nerve impulses to the sphincter that controls the opening to the urethra. In response to the impulses, the sphincter relaxes and lets urine flow into the urethra.

The urethra is a muscular tube that carries urine out of the body. Urine leaves the body through another sphincter in the process of urination. This sphincter and the process of urination are normally under conscious control.

Kidneys

The kidneys participate in whole-body homeostasis. As mentioned above, one of the primary roles of the kidneys is to remove nitrogenous wastes. The kidneys are a pair of bean-shaped, reddish-brown organs about the size of a fist. They are located just above the waist at the back of the abdominal cavity, on either side of the spine. As shown in **Figure** 55.2, the kidneys are protected by the ribcage. They are also protected by a covering of tough connective tissue and two layers of fat, which help cushion them.

Located on top of each kidney is an adrenal gland, also shown in **Figure** 55.2. The two adrenal glands secrete several hormones. Hormones are chemical messengers in the body that regulate many body functions. The adrenal hormone aldosterone helps regulate kidney functions.

In **Figure** 55.2, you can see that the kidney has three layers. The outer layer is the renal cortex, and the middle layer is the renal medulla. The inner layer, the renal pelvis, is where the renal artery enters the kidney and the renal vein

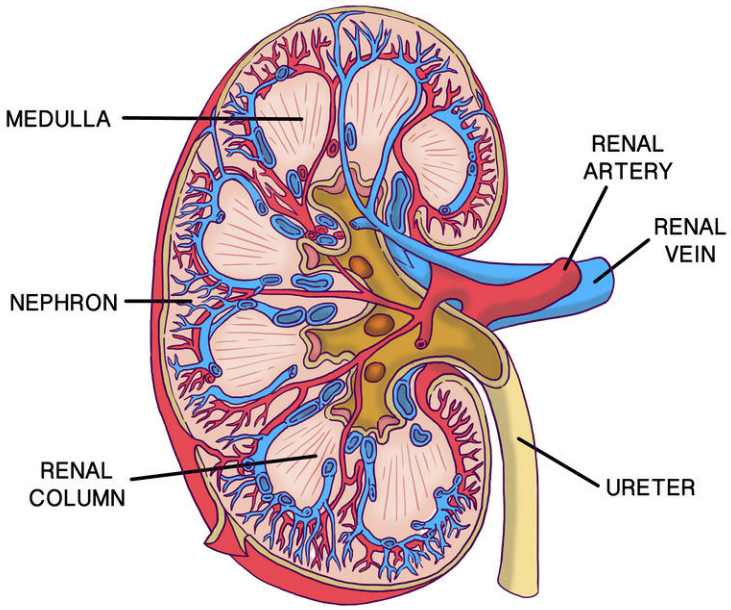


FIGURE 55.2

The Kidney. Each kidney is supplied by a renal artery and a renal vein.

exits the kidney. The renal artery carries blood to the kidney to be filtered, and the renal vein carries the filtered blood away from the kidney. Structures in the kidney called nephrons are also seen in **Figure** 55.2. Each nephron extends from the cortex down into the medulla.

Nephrons

Nephrons are the structural and functional units of the kidneys. A single kidney may have more than a million nephrons. The diagram in **Figure** 55.3 represents an individual nephron and shows its main structures and functions. The structures include the glomerulus, Bowman's capsule, and the renal tubule.

- The glomerulus is a cluster of arteries that filters substances out of the blood.
- Bowman's capsule is a cup-shaped structure around the glomerulus that collects the filtered substances.
- The renal tubule is a long, narrow tube surrounded by capillaries that reabsorbs many of the filtered substances and secretes other substances.

Filtration, Reabsorption, and Secretion

The renal arteries, which carry blood into the kidneys, branch into the capillaries of the glomerulus of each nephron. The pressure of blood moving through these capillaries forces some of the water and dissolved substances in the blood through the capillary walls and into Bowman's capsule. Bowman's capsule is composed of layers. The space between the layers, called Bowman's space, fills with the filtered substances.

The process of filtering substances from blood in the glomerulus is called filtration. The fluid that collects in Bowman's space is called filtrate. It is composed of water, salts, glucose, amino acids, and urea. Larger structures in the blood—including protein molecules, blood cells, and platelets—do not pass into Bowman's space. Instead, they stay in the main circulation.

From Bowman's space, the filtrate passes into the renal tubule. The main function of the renal tubule is **reabsorption.** Reabsorption is the return of needed substances in the filtrate back to the bloodstream. It is necessary because some

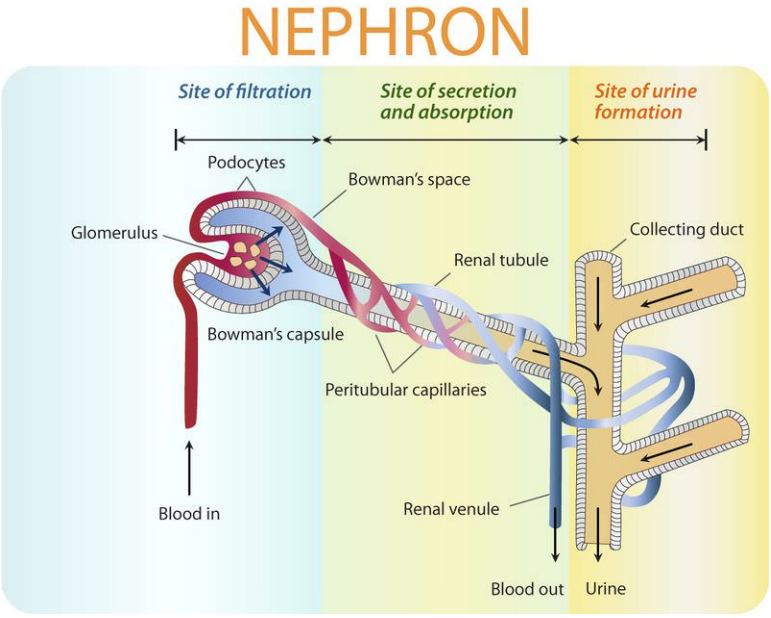


FIGURE 55.3

Nephron structures and functions.

of the substances removed from the blood by filtration—including water, salts, glucose, and amino acids—are needed by the body. About 75 percent of these substances are reabsorbed in the renal tubule.

As shown in **Figure** 55.4, the renal tubule is divided into three parts: the proximal tubule, the Loop of Henle, and the distal tubule.

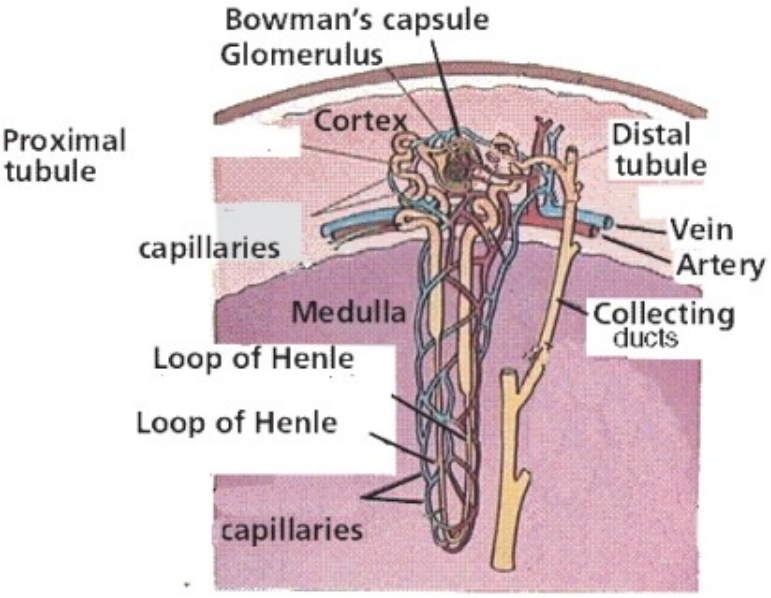


FIGURE 55.4

Parts of the renal tubule and other nephron structures.

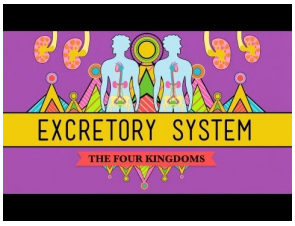
- Filtrate first enters the proximal tubule. This is where the most reabsorption takes place. Tiny projections called microvilli line the proximal tubule and increase the surface area for reabsorption. From the proximal tubule, the filtrate passes through the loop of Henle.

- The loop of Henle carries the filtrate from the cortex down into the medulla and then back up to the cortex again. Its primary purpose is to reabsorb water and salt from the fluid filtrate. The remaining fluid enters the distal tubule.
- The distal tubule carries the fluid, now called tubular fluid, from the loop of Henle to a collecting duct. As it transports the fluid, the distal tubule also reabsorbs or secretes substances such as calcium and sodium. The process of secreting substances into the tubular fluid is called secretion.

Urine Formation

The collecting ducts are the site of urine formation. This process is crucial for water conservation in the body. The collecting ducts reabsorb water from tubular fluid and return it to the blood. The remaining fluid, called urine, has both a smaller volume and a greater concentration than tubular fluid. From the collecting ducts, urine enters a ureter and is eventually excreted from the body.

The reabsorption of water by the collecting ducts is controlled by a negative feedback mechanism. The mechanism involves a hormone secreted by the pituitary gland, called antidiuretic hormone (ADH). ADH makes the collecting ducts more permeable to water, allowing more water to be reabsorbed from tubular fluid. When there is not enough water in the blood, more ADH is secreted, more water is reabsorbed from tubular fluid, and less water is excreted in urine. The opposite happens when there is too much water in the blood.



MEDIA

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Summary

- The urinary system is composed of the kidney, ureters, bladder, and urethra.
- The main function of the urinary system is to filter waste products and excess water from the blood and remove them from the body.
- Located on top of each kidney is an adrenal gland. The adrenal hormone aldosterone helps regulate kidney functions.
- The kidney has three layers: the outer renal cortex, the renal medulla, and the inner renal pelvis where the renal artery and vein enter and exit the kidney respectively.
- Bowman's capsule is composed of layers. The space between the layers, called Bowman's space, fills with the filtered substances (known as filtrate).
- The process of filtering substances from blood in the glomerulus is called filtration.
- The renal tubule is divided into three parts: the proximal tubule, the Loop of Henle, and the distal tubule. Most reabsorption happens in the renal tubule.
- The collecting ducts are the site of urine formation; they reabsorb water from tubular fluid and return it to the blood.

Review

1. Which organs compose the urinary system?

2. When does your bladder send nerve pulses to initiate urination?
3. What is the function of the adrenal gland?
4. How is the reabsorption of water controlled?
5. Which part of the renal tubule is responsible for the most reabsorption?
6. What is the role of the loop of Henle and the distal tubule (which are parts of the renal tubule)?

References

1. Courtesy of National Cancer Institute/SEER Training Modules. http://commons.wikimedia.org/wiki/File:Illu_urinary_system.svg . Public Domain
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