Open Education Resources Book

High School Equivalency

Science

WEST HILLS COMMUNITY COLLEGE DISTRICT HIGH SCHOOL EQUIVALENCY PROGRAM

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High School Equivalency Program

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Information on what is on the HiSET Exam:

For information on what is on the HiSET exam, refer to the website link below:

https://hiset.ets.org/about/content

Chapter 1: Introduction

Science (from the Latin *scientia*, meaning "knowledge") can be defined as all the fields of study that attempt to comprehend the nature of the universe and all its parts.

You are getting ready to take your science test. You will be answering questions related to biology, life science, chemistry, physics, and Earth and space. This requires you to have a previous knowledge of basic concepts. The information on which each question is based is presented as a text, a graphic, a chart, a table, a diagram, a formula, or a combination of some of those. The following chapters will guide you through some of the basic concepts you need to know in order to be successful on your test.

How to Apply your Scientific Skills

Reading Strategy

1) First, you need to read the data. Sometimes a question could have the information in a paragraph and a graphic, for example. You must make sure you read all the data.
2) Read the question. This is one of the most important parts of the process: understanding what they are asking for.
3) While you read, you could have been thinking about the things you already know about the topic and making connections.
4) With your prior knowledge plus the new information, you can elaborate a conclusion.
5) Select the answer you consider the best one. There is only one correct answer.

Scientific Method

The **scientific method** is a method of research with defined steps that include experiments and careful observation. One of the most important aspects of this method is the testing of hypotheses by means of repeatable experiments.

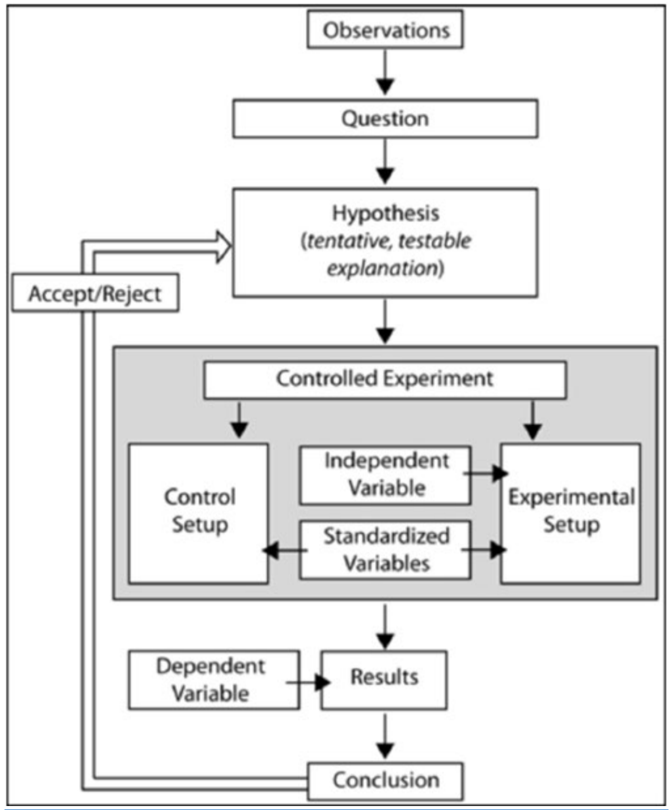

Figure 11. (CC BY-NC-SA)

To help illustrate the scientific method, an example that an entomologist (a biologist who specializes in insects) might use is given in italics below each step.

Step 1: Observations & Questions

Observe something in the natural world and ask a question about how it works. The part of the natural world that is observed and investigated is usually the area that the scientist specializes in. An entomologist for example, would ask questions about how insects function.

"The life cycle of a fruit fly is about 30 days (at 29 degrees Celsius). How do changes in temperature affect the life cycle of a fruit fly?"

Step 2: Hypothesis

Make a hypothesis (an educated guess) which attempts to answer the question. A useful hypothesis is a **testable** statement.

"Decreasing the temperature of a fruit fly's environment will increase the time it takes the fruit fly to complete its life cycle."

Step 3: Experiment

Design and carry out an experiment that can test the hypothesis. In other words, the experiment must be designed so that it will produce results that either clearly support or clearly falsify (disprove) the hypothesis. It helps to use “If-Then” predictions based on your hypothesis.

“Place 100 fruit flies at 18 degrees Celsius for one generation. Also place 100 fruit flies at 29 degrees Celsius for one generation. If the hypothesis is correct, then the fruit flies that develop at 18 degrees Celsius will complete their life cycle after those fruit flies that are placed at 29 degrees Celsius."

Step 4: Analyze Results and State Conclusions

Reject the hypothesis if the results are not consistent with the hypothesis or accept the hypothesis as possibly true if the results are consistent with the hypothesis. Notice that the hypothesis is not “proven to be true” even if the results do support it. This is because there may be explanations other than the hypothesis for the experimental result.

For example, if the fruit flies placed at 18 degrees Celsius do develop slower, it may be that their food is not as soft making it more difficult for the fruit flies to eat at the lower temperature, causing them to eat less food and thus grow slower.

If the experimental results do not support the hypothesis, the hypothesis may be modified, and additional experiments may be done to test the new or revised hypothesis.

Designing a Good Experiment

The most challenging part of the scientific method is usually the third step, designing and carrying out an experiment to test the hypothesis. A well-designed experiment should include all of the following characteristics:

1. An independent variable. The independent variable is the part of the experiment that the scientist changes or manipulates to see what effect occurs.

“The temperature is the independent variable, since that is what the experiment changes to see its effect.”

2. A dependent variable. The dependent variable is the part of the experiment that changes because of the change in the independent variable. In other words, the dependent variable is the effect that occurs from changing the independent variable.

“The length of the fruit flies' life cycle is the dependent variable, since the time of development is expected to change because of the temperature.”

3. An experimental group. The experimental group is the group of subjects where the independent variable is set to an unusual or test level.

"The fruit flies placed at 18 degrees Celsius are the experimental group, since the effect of lower temperature on the life cycle of fruit flies is what is being tested."

4. A control group. A control group is the group of subjects in the experiment that the experimental group is compared to. For the control group, the independent variable is set to a normal or usual level (which may be zero, if that is considered a normal level).

"The fruit flies kept at 29 degrees are the control group, since this is the optimal temperature for fruit fly development."

5. The experiment should contain repetition. This means that there should be more than one subject in the experimental group and the control group. Why? In general, the more repetition, the less likely that your results are due to random chance.

"The experimental group and the control group each contained 100 fruit flies."

6. The experiment should be well defined. One aspect of "well defined" is that the procedure (the steps) must be written down and clearly described. The true test of a well written experimental procedure is that another scientist could duplicate it exactly using just the written directions. Another aspect of "well defined" is that everything in the experiment, such as the materials, chemicals, equipment, environmental conditions, and the subjects (the organisms involved in the experiment), should be described as exactly as possible. All the factors that are kept equal in the experiment and control groups are called **standardized variables**. Another aspect of "well defined" is that all parts of the experiment should be quantified. This means they should be measured by numbers.

a) All fruit flies in this experiment are the same species (Drosophila melanogaster). All fruit flies were placed in plastic vials with standard cornmeal media and a cotton stopper. All fruit flies received artificial sunlight for 16 hours per day.

b) One group of 100 fruit flies (the experimental group) were placed in an incubator set to 18 degrees Celsius.

c) One group of 100 fruit flies (the control group) were placed in an incubator set to 29 degrees Celsius.

d) In order to accurately determine the length of the life cycle of the fruit flies, 100 adult flies were allowed to lay eggs for 2 days and then removed from vials. Vials were monitored daily to determine the stage of the life cycle of the offspring of the original adult fruit flies. The end of the life cycle was recorded as the time when half of the fruit flies had undergone eclosion (adults emerge from the pupa case).

What is a Scientific Theory?

"*It's just a theory*." Our everyday use of the term *theory* often implies a mere guess or something that is unproven. However, a scientific theory implies that something has been proven and is generally accepted as being true. A **scientific theory** is an explanation for natural events that is based on a large number of observations and has been verified multiple times. Theories help scientists to explain large amounts of data.

A theory differs from a hypothesis in that it is much broader in scope and supported by a much greater body of evidence. Remember, a hypothesis is an educated guess that is based upon observation but has not yet been proven.

Practice Activity

Analyze the following texts and answer the questions.

Smithers thinks that a special juice will increase the productivity of workers. He creates two groups of 50 workers each and assigns each group the same task (in this case, they're supposed to staple a set of papers). Group A is given the special juice to drink while they work. Group B is not given the special juice. After an hour, Smithers counts how many stacks of papers each group has made. Group A made 1,587 stacks; Group B made 2,113 stacks.

1. The set of papers that each group of workers has to staple is?
    A. The hypothesis
    B. The control group
    C. The independent variable
    D. The dependent variable

2. According to the text, what did Smithers do?
    A. Coordinated his employees in two groups
    B. Observed and asked questions
    C. Formulated a hypothesis and conducted an experiment
    D. Created a special juice

3. The special juice is:
    A. Part of the control group
    B. An observation
    C. The independent variable
    D. The dependent variable

4. The most productive group is:
    A. The control group
    B. The experimental group
    C. The experiment

D. The hypothesis

5. "Smithers thinks that a special juice will increase the productivity of workers." This is:
   A. An observation
   B. A thesis
   C. An experiment
   D. A hypothesis

In 1928, Sir Alexander Fleming was studying Staphylococcus bacteria growing in culture dishes. He noticed that a mold called Penicillium was also growing in some of the dishes. A clear area existed around the mold because all the bacteria that had grown in this area had died. In the culture dishes without the mold, no clear areas were present. Fleming hypothesized that the mold must be producing a chemical that killed the bacteria. He decided to isolate this substance and test it to see if it would kill bacteria. Fleming transferred the mold to a nutrient broth solution. This solution contained all the materials the mold needed to grow. After the mold grew, he removed it from the nutrient broth. Fleming then added the nutrient broth in which the mold had grown to a culture of bacteria. He observed that the bacteria died which was later used to develop antibiotics used to treat a variety of diseases.

6. According to the text, "a clear area existed around the mold because all the bacteria that had grown in this area had died." This is:
   A. A hypothesis
   B. An observation
   C. A thesis
   D. An experiment

7. "In the culture dishes without the mold, no clear areas were present." What does it mean?
   A. The experiment was a success
   B. It is just an observation
   C. This was the experimental group
   D. The culture dishes without the mold were the independent variable

8. The text talks about:
   A. How Sir Alexander Fleming studied Staphylococcus bacteria
   B. How Sir Alexander Fleming proved his thesis about Penicillium
   C. How Sir Alexander Fleming discovered Penicillium
   D. How Sir Alexander Fleming used to kill bacteria with broth

9. According to the text, in Fleming's experiment, what would the control group be?
   A. Culture dishes without the mold
   B. Culture dishes with mold
   C. The nutrient broth
   D. The Penicillium

10. In Fleming's experiment, what is independent variable?
    A. The broth
    B. The Penicillium
    C. The culture dishes
    E. The bacteria

Answers:

1) D
2) C
3) C
4) A
5) D
6) B
7) B
8) C
9) A
10) B

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Chapter 2: Life Science

Cells and Organisms

A cell is the smallest unit of a living thing. A living thing, like you, is called an organism. Thus, cells are the basic building blocks of all organisms.

In multicellular organisms, several cells of one particular kind interconnect with each other and perform shared functions to form tissues (for example, muscle tissue, connective tissue, and nervous tissue), several tissues combine to form an organ (for example, stomach, heart, or brain), and several organs make up an organ system (such as the digestive system, circulatory system, or nervous system). Several systems functioning together form an organism (such as an elephant, for example).

Cells fall into one of two broad categories: prokaryotic and eukaryotic. The predominantly single-celled organisms of the domains Bacteria and Archaea are classified as prokaryotes (*pro-* = before; -*karyon-* = nucleus). Animal cells, plant cells, fungi, and protists are eukaryotes (*eu-* = true).

Components of Prokaryotic Cells

All cells share four common components:

1. a plasma membrane, an outer covering that separates the cell's interior from its surrounding environment;
1. cytoplasm, consisting of a jelly-like region within the cell in which other cellular components are found;
2. DNA, the genetic material of the cell; and
3. ribosomes, particles that synthesize proteins.

However, prokaryotes differ from eukaryotic cells in several ways. A prokaryotic cell is a simple, single-celled (unicellular) organism that lacks a nucleus, or any other membrane-bound organelle. We will shortly come to see that this is significantly different in eukaryotes. Prokaryotic DNA is found in the central part of the cell: a darkened region called the nucleoid (Figure 3.2.1).

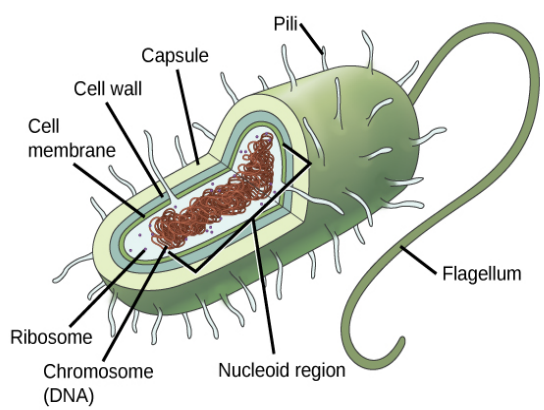


Figure 3.2.1**:** This figure shows the generalized structure of a prokaryotic cell.

Unlike Archaea and eukaryotes, bacteria have a cell wall made of peptidoglycan, comprised of sugars and amino acids, and many have a polysaccharide capsule (Figure 3.2.1). The cell wall acts as an extra layer of protection, helps the cell maintain its shape, and prevents dehydration. The capsule enables the cell to attach to surfaces in its environment. Some prokaryotes have flagella, pili, or fimbriae. Flagella are used for locomotion, while most pili are used to exchange genetic material during a type of reproduction called conjugation.

Eukaryotic Cells

Eukaryotic cells have a more complex structure than do prokaryotic cells. Organelles allow for various functions to occur in the cell at the same time. Before discussing the functions of organelles within a eukaryotic cell, let us first examine two important components of the cell: the plasma membrane and the cytoplasm.

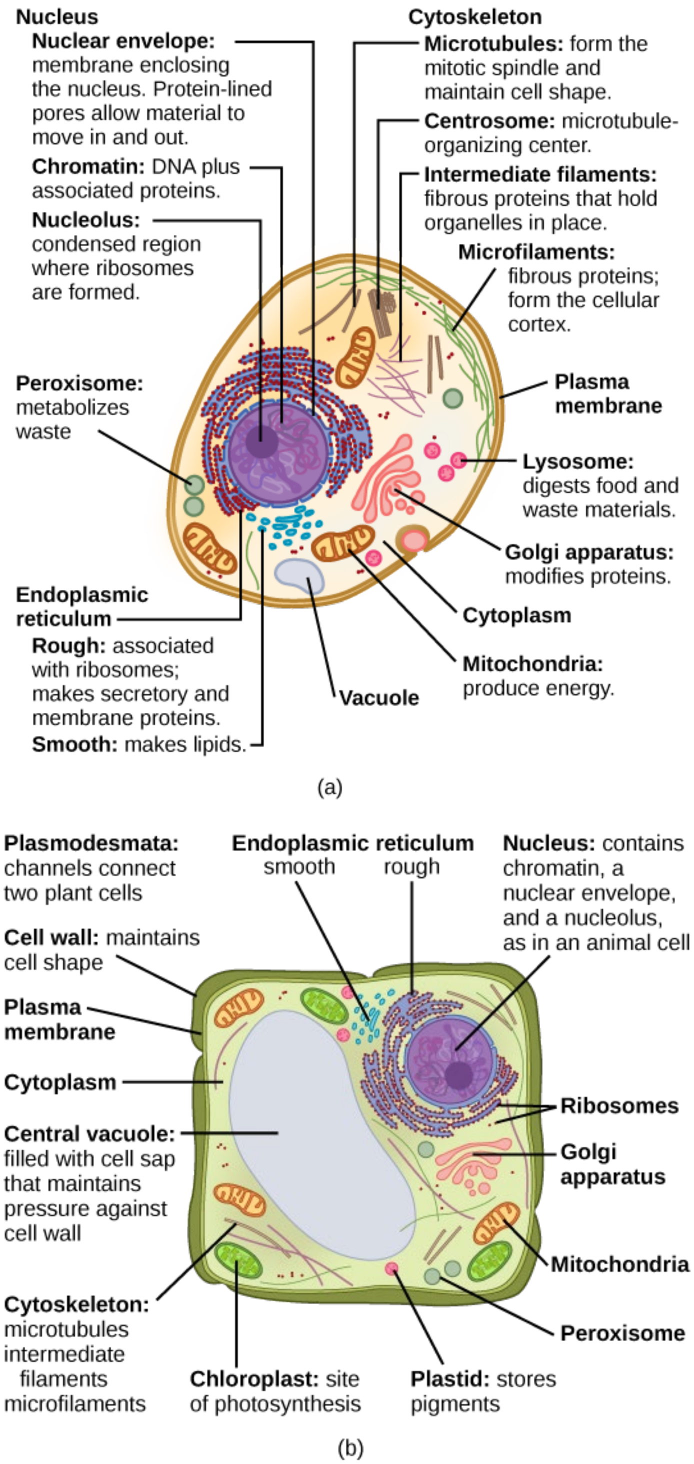


Figure 3.3.1: This figure shows (a) a typical animal cell and (b) a typical plant cell.

The Plasma Membrane

Like prokaryotes, eukaryotic cells have a plasma membrane made up of a phospholipid bilayer with embedded proteins that separates the internal contents of the cell from its surrounding environment. A phospholipid is a lipid molecule composed of two fatty acid chains, a glycerol backbone, and a phosphate group. The plasma membrane regulates the passage of some substances, such as organic molecules, ions, and water, preventing the passage of some to maintain internal conditions, while actively bringing in or removing others. Other compounds move passively across the membrane.

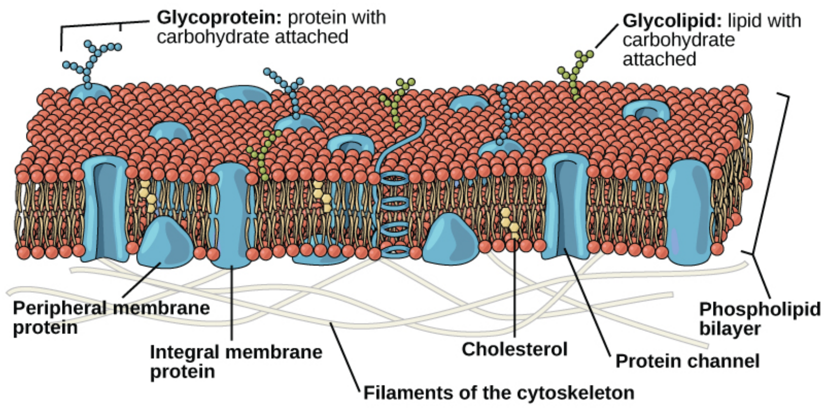


Figure 3.3.2**:** The plasma membrane is a phospholipid bilayer with embedded proteins. There are other components, such as cholesterol and carbohydrates, which can be found in the membrane in addition to phospholipids and protein.

People with celiac disease have an immune response to gluten, which is a protein found in wheat, barley, and rye. The immune response damages microvilli, and thus, afflicted individuals cannot absorb nutrients. This leads to malnutrition, cramping, and diarrhea. Patients suffering from celiac disease must follow a gluten-free diet.

Passive Transport

Plasma membranes must allow certain substances to enter and leave a cell, while preventing harmful material from entering and essential material from leaving. In other words, plasma membranes are selectively permeable—they allow some substances through but not others. The most direct forms of membrane transport are passive. **Passive transport** is a naturally occurring phenomenon and does not require the cell to expend energy to accomplish the movement. In passive transport, substances move from an area of higher concentration to an area of lower concentration in a process called diffusion. A physical space in which there is a different concentration of a single substance is said to have a concentration gradient.

Selective Permeability

Plasma membranes are asymmetric, meaning that despite the mirror image formed by the phospholipids, the interior of the membrane is not identical to the exterior of the membrane. Integral proteins that act as channels or pumps work in one direction. Carbohydrates, attached to lipids or proteins, are also found on the exterior surface of the plasma membrane. These carbohydrate complexes help the cell bind substances that the cell needs in the extracellular fluid. This adds considerably to the selective nature of plasma membranes.

Recall that plasma membranes have hydrophilic and hydrophobic regions. This characteristic helps the movement of certain materials through the membrane and hinders the movement of others. Lipid-soluble material can easily slip through the hydrophobic lipid core of the membrane. Substances such as the fat-soluble vitamins A, D, E, and K readily pass through the plasma membranes in the digestive tract and other tissues. Fat-soluble drugs also gain easy entry into cells and are readily transported into the body's tissues and organs. Molecules of oxygen and carbon dioxide have no charge and pass through by simple diffusion.

Diffusion

Diffusion is a passive process of transport. A single substance tends to move from an area of high concentration to an area of low concentration until the concentration is equal across the space. You are familiar with diffusion of substances through the air. For example, think about someone opening a bottle of perfume in a room filled with people. The perfume is at its highest concentration in the bottle and is at its lowest at the edges of the room. The perfume vapor will diffuse, or spread away, from the bottle, and gradually, more and more people will smell the perfume as it spreads. Materials move within the cell's cytosol by diffusion, and certain materials move through the plasma membrane by diffusion (Figure 3.5.13.5.1). Diffusion expends no energy. Rather the different concentrations of materials in different areas are a form of potential energy, and diffusion is the dissipation of that potential energy as materials move down their concentration gradients, from high to low.

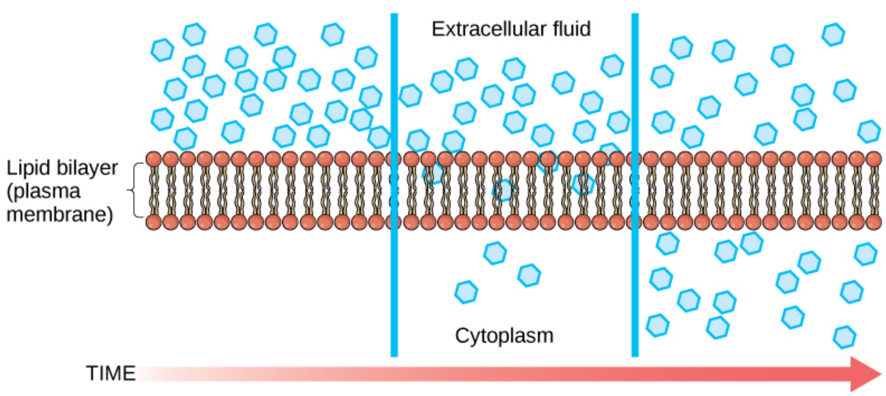


Figure 3.5.1**:** Diffusion through a permeable membrane follows the concentration gradient of a substance, moving the substance from an area of high concentration to one of low concentration. (Credit: modification of work by Mariana Ruiz Villarreal)

Each separate substance in a medium, such as the extracellular fluid, has its own concentration gradient, independent of the concentration gradients of other materials. Additionally, each substance will diffuse according to that gradient.

Several factors affect the rate of diffusion.

- Extent of the concentration gradient: The greater the difference in concentration, the more rapid the diffusion. The closer the distribution of the material gets to equilibrium, the slower the rate of diffusion becomes.
- Mass of the molecules diffusing: More massive molecules move more slowly, because it is more difficult for them to move between the molecules of the substance they are moving through; therefore, they diffuse more slowly.
- Temperature: Higher temperatures increase the energy and therefore the movement of the molecules, increasing the rate of diffusion.
- Solvent density: As the density of the solvent increases, the rate of diffusion decreases. The molecules slow down because they have a more difficult time getting through the denser medium.

Facilitated transport

In facilitated transport, also called facilitated diffusion, material moves across the plasma membrane with the assistance of transmembrane proteins down a concentration gradient (from high to low concentration) without the expenditure of cellular energy. However, the substances that undergo facilitated transport would otherwise not diffuse easily or quickly across the plasma membrane. The solution to moving polar substances and other substances across the plasma membrane rests in the proteins that span its surface. The material being transported is first attached to protein or glycoprotein receptors on the exterior surface of the plasma membrane. This allows the material that is needed by the cell to be removed from the extracellular fluid. The substances are then passed to specific integral proteins that facilitate their passage, because they form channels or pores that allow certain substances to pass through the membrane. The integral proteins involved in facilitated transport are collectively referred to as transport proteins, and they function as either channels for the material or carriers.

Osmosis

Osmosis is the diffusion of water through a semipermeable membrane according to the concentration gradient of water across the membrane. Whereas diffusion transports material across membranes and within cells, osmosis transports *only water* across a membrane and the membrane limits the diffusion of solutes in the water. Osmosis is a special case of diffusion. Water, like other substances, moves from an area of higher concentration to one of lower concentration. Imagine a beaker with a semipermeable membrane, separating the two sides or halves (Figure 3.5.2). On both sides of the membrane, the water level is the same, but there are different concentrations on each side of a dissolved substance, or solute, that cannot cross the membrane. If the volume of the water is the same, but the concentrations of solute are different, then there are also different concentrations of water, the solvent, on either side of the membrane.

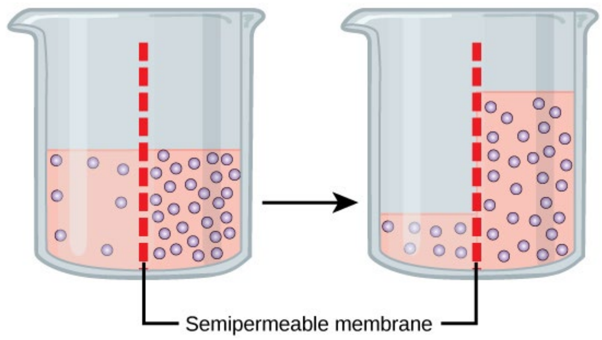


Figure 3.5.2**:** In osmosis, water always moves from an area of higher concentration (of water) to one of lower concentration (of water). In this system, the solute cannot pass through the selectively permeable membrane.

A principle of diffusion is that the molecules move around and will spread evenly throughout the medium if they can. However, only the material capable of getting through the membrane will diffuse through it. In this example, the solute cannot diffuse through the membrane, but the water can. Water has a concentration gradient in this system. Therefore, water will diffuse down its concentration gradient, crossing the membrane to the side where it is less concentrated. This diffusion of water through the membrane—osmosis—will continue until the concentration gradient of water goes to zero. Osmosis proceeds constantly in living systems.

Tonicity

Tonicity describes the amount of solute in a solution. The measure of the tonicity of a solution, or the total amount of solutes dissolved in a specific amount of solution, is called its osmolarity. Three terms—hypotonic, isotonic, and hypertonic—are used to relate the osmolarity of a cell to the osmolarity of the extracellular fluid that contains the cells. In a hypotonic solution, such as tap water, the extracellular fluid has a lower concentration of solutes than the fluid inside the cell, and water enters the cell. (In living systems, the point of reference is always the cytoplasm, so the prefix *hypo*- means that the extracellular fluid has a lower concentration of solutes, or a lower osmolarity, than the cell cytoplasm.) It also means that extracellular fluid has a higher concentration of water than does the cell. In this situation, water will follow its concentration gradient and enter the cell. This may cause an animal cell to burst or lyse.

In a hypertonic solution (the prefix *hyper*- refers to the extracellular fluid having a higher concentration of solutes than the cell's cytoplasm), the fluid contains less water than the cell does, such as seawater. Because the cell has a lower concentration of solutes, the water will leave the cell. In effect, the solute is drawing the water out of the cell. This may cause an animal cell to shrivel, or crenate.

In an isotonic solution, the extracellular fluid has the same osmolarity as the cell. If the concentration of solutes of the cell matches that of the extracellular fluid, there will be no net movement of water into or out of the cell. Blood cells in hypertonic, isotonic, and hypotonic solutions take on characteristic appearances (Figure 3.5.3).

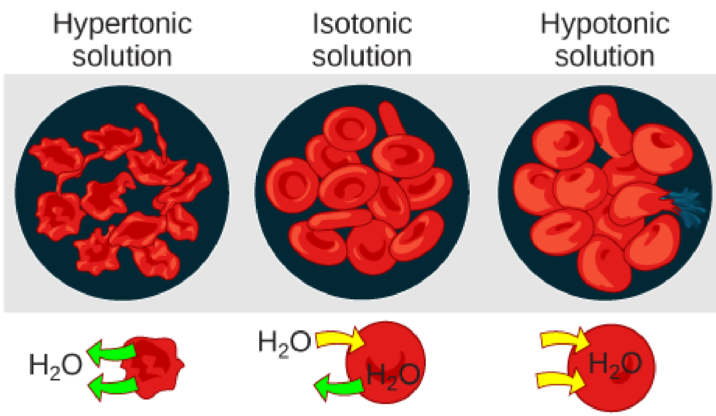


Figure 3.5.3**:** Osmotic pressure changes the shape of red blood cells in hypertonic, isotonic, and hypotonic solutions. (Credit: modification of work by Mariana Ruiz Villarreal)

Some organisms, such as plants, fungi, bacteria, and some protists, have cell walls that surround the plasma membrane and prevent cell lysis. The plasma membrane can only expand to the limit of the cell wall, so the cell will not lyse. In fact, the cytoplasm in plants is always slightly hypertonic compared to the cellular environment, and water will always enter a cell if water is available. This influx of water produces turgor pressure, which stiffens the cell walls of the plant (Figure 3.5.4). In nonwoody plants, turgor pressure supports the plant. If the plant cells become hypertonic, as occurs in drought or if a plant is not watered adequately, water will leave the cell. Plants lose turgor pressure in this condition and wilt.

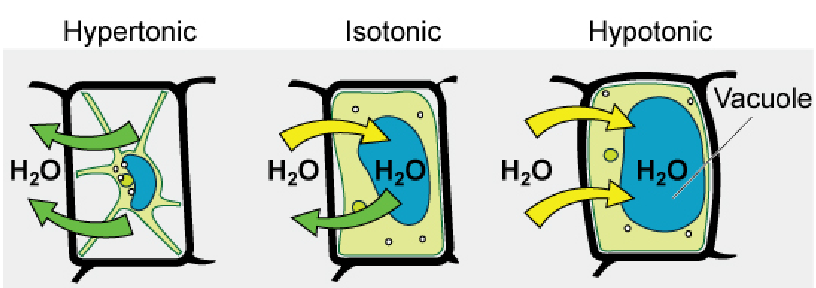


Figure 3.5.4**:** The turgor pressure within a plant cell depends on the tonicity of the solution that it is bathed in. (credit: modification of work by Mariana Ruiz Villarreal)

Active Transport

Active transport mechanisms require the use of the cell's energy, usually in the form of adenosine triphosphate (ATP). If a substance must move into the cell against its concentration gradient, that is, if the concentration of the substance inside the cell must be greater than its concentration in the extracellular fluid, the cell must use energy to move the substance. Some active transport mechanisms move small-molecular weight material, such as ions, through the membrane.

In addition to moving small ions and molecules through the membrane, cells also need to remove and take in larger molecules and particles. Some cells are even capable of engulfing entire unicellular microorganisms. You might have correctly hypothesized that the uptake and release of large particles by the cell requires energy. A large particle, however, cannot pass through the membrane, even with energy supplied by the cell.

The Cytoplasm

The cytoplasm comprises the contents of a cell between the plasma membrane and the nuclear envelope. It is made up of organelles suspended in the gel-like cytosol, the cytoskeleton, and various chemicals. Even though the cytoplasm consists of 70 to 80 percent water, it has a semi-solid consistency, which comes from the proteins within it. However, proteins are not the only organic molecules found in the cytoplasm. Glucose and other simple sugars, polysaccharides, amino acids, nucleic acids, fatty acids, and derivatives of glycerol are found there too. Ions of sodium, potassium, calcium, and many other elements are also dissolved in the cytoplasm. Many metabolic reactions, including protein synthesis, take place in the cytoplasm.

The Cytoskeleton

If you were to remove all the organelles from a cell, would the plasma membrane and the cytoplasm be the only components left? No. Within the cytoplasm, there would still be ions and organic molecules, plus a network of protein fibers that helps to maintain the shape of the cell, secures certain organelles in specific positions, allows cytoplasm and vesicles to move within the cell, and enables unicellular organisms to move independently. Collectively, this network of protein fibers is known as the cytoskeleton. There are three types of fibers within the cytoskeleton: microfilaments, also known as actin filaments, intermediate filaments, and microtubules (Figure 3.3.3).

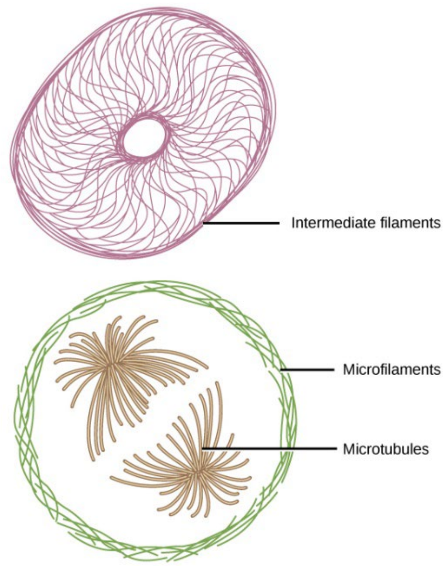


Figure 3.3.3**:** Microfilaments, intermediate filaments, and microtubules compose a cell's cytoskeleton.

Flagella and Cilia

Flagella (singular = flagellum) are long, hair-like structures that extend from the plasma membrane and are used to move an entire cell, (for example, sperm, *Euglena*). When present, the cell has just one flagellum or a few flagella. When cilia (singular = cilium) are present, however, they are many in number and extend along the entire surface of the plasma membrane. They are short, hair-like structures that are used to move entire cells (such as paramecium) or move substances along the outer surface of the cell (for example, the cilia of cells lining the fallopian tubes that move the ovum toward the uterus, or cilia lining the cells of the respiratory tract that move particulate matter toward the throat that mucus has trapped).

The Endomembrane System

The endomembrane system (*endo* = within) is a group of membranes and organelles (Figure 3.3.3) in eukaryotic cells that work together to modify, package, and transport lipids and proteins. It includes the nuclear envelope, lysosomes, and vesicles, the endoplasmic reticulum and Golgi apparatus. Although not technically *within* the cell, the plasma membrane is included in the endomembrane system because it interacts with the other endomembranous organelles.

The Nucleus

Typically, the nucleus is the most prominent organelle in a cell (Figure 3.3.1). The nucleus (plural = nuclei) houses the cell's DNA in the form of chromatin and directs the synthesis of ribosomes and proteins. Let us look at it in more detail (Figure 3.3.4).

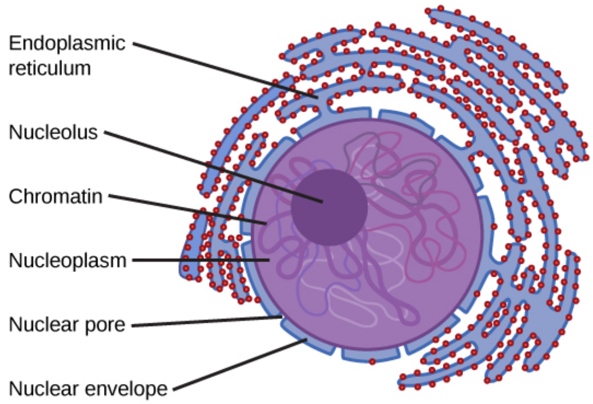


Figure 3.3.4**:** The outermost boundary of the nucleus is the nuclear envelope. Notice that the nuclear envelope consists of two phospholipid bilayers (membranes)—an outer membrane and an inner membrane—in contrast to the plasma membrane (Figure 3.3.2), which consists of only one phospholipid bilayer. (Credit: modification of work by NIGMS, NIH)

The nuclear envelope is punctuated with pores that control the passage of ions, molecules, and RNA between the nucleoplasm and the cytoplasm.

To understand chromatin, it is helpful to first consider chromosomes. Chromosomes are structures within the nucleus that are made up of DNA, the hereditary material, and proteins. This combination of DNA and proteins is called chromatin. In eukaryotes, chromosomes are linear structures. Every species has a specific number of chromosomes in the nucleus of its body cells. For example, in humans, the chromosome number is 46, whereas in fruit flies, the chromosome number is eight.

Chromosomes are only visible and distinguishable from one another when the cell is getting ready to divide. When the cell is in the growth and maintenance phases of its life cycle, the chromosomes resemble an unwound, jumbled bunch of threads.

The Endoplasmic Reticulum

The endoplasmic reticulum (ER) (Figure 3.3.7) is a series of interconnected membranous tubules that collectively modify proteins and synthesize lipids. However, these two functions are performed in separate areas of the endoplasmic reticulum: the rough endoplasmic reticulum and the smooth endoplasmic reticulum, respectively.

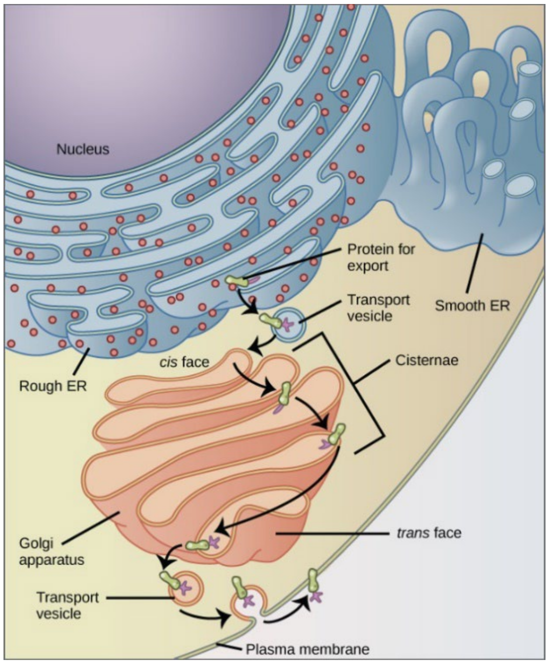


Figure 3.3.7**:** The endomembrane system works to modify, package, and transport lipids and proteins. (Credit: modification of work by Magnus Manske)

The Golgi Apparatus

Before reaching their destination, the lipids or proteins within the transport vesicles need to be sorted, packaged, and tagged so that they wind up in the right place. The sorting, tagging, packaging, and distribution of lipids and proteins take place in the Golgi apparatus (also called the Golgi body), a series of flattened membranous sacs (Figure 3.3.5).

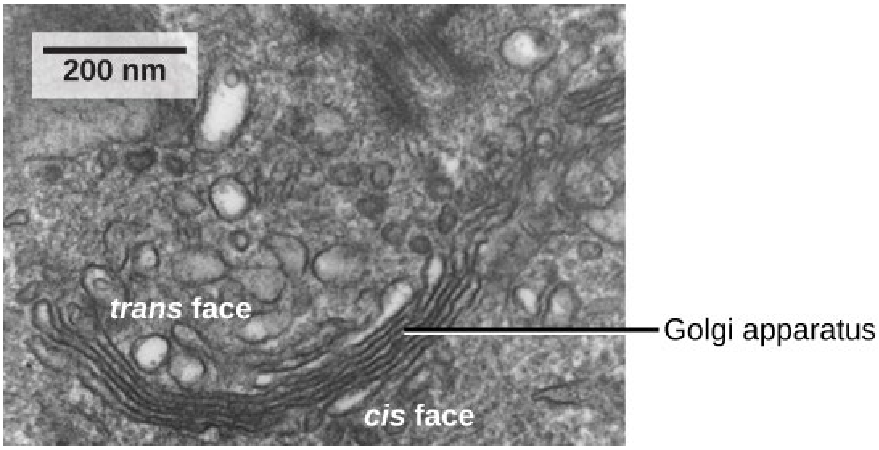


Figure 3.3.5**:** The Golgi apparatus in this transmission electron micrograph of a white blood cell is visible as a stack of semicircular flattened rings in the lower portion of this image. Several vesicles can be seen near the Golgi apparatus. (Credit: modification of work by Louisa Howard; scale-bar data from Matt Russell)

The Golgi apparatus has a receiving face near the endoplasmic reticulum and a releasing face on the side away from the ER, toward the cell membrane. The transport vesicles that form from the ER travel to the receiving face, fuse with it, and empty their contents into the lumen of the Golgi apparatus. As the proteins and lipids travel through the Golgi, they undergo further modifications. The most frequent modification is the addition of short chains of sugar molecules. The newly modified proteins and lipids are then tagged with small molecular groups to enable them to be routed to their proper destinations.

Finally, the modified and tagged proteins are packaged into vesicles that bud from the opposite face of the Golgi. While some of these vesicles (transport vesicles) deposit their contents into other parts of the cell where they will be used, others (secretory vesicles) fuse with the plasma membrane and release their contents outside the cell.

In plant cells, the Golgi has an additional role of synthesizing polysaccharides, some of which are incorporated into the cell wall and some of which are used in other parts of the cell.

Lysosomes

In animal cells, the lysosomes are the cell's "garbage disposal." Digestive enzymes within the lysosomes aid the breakdown of proteins, polysaccharides, lipids, nucleic acids, and even worn-out organelles. In single-celled eukaryotes, lysosomes are important for digestion of the food they ingest and the recycling of organelles. These enzymes are active at a much lower pH (more acidic) than those located in the cytoplasm. Many reactions that take place in the cytoplasm could not occur at a low pH, thus the advantage of compartmentalizing the eukaryotic cell into organelles is apparent.

Lysosomes also use their hydrolytic enzymes to destroy disease-causing organisms that might enter the cell. A good example of this occurs in a group of white blood cells called macrophages, which are part of your body's immune system. In a process known as phagocytosis, a section of the plasma membrane of the macrophage invaginates (folds in) and engulfs a pathogen. The invaginated section, with the pathogen inside, then pinches itself off from the plasma membrane and becomes a vesicle. The vesicle fuses with a lysosome. The lysosome's hydrolytic enzymes then destroy the pathogen (Figure 3.3.6).

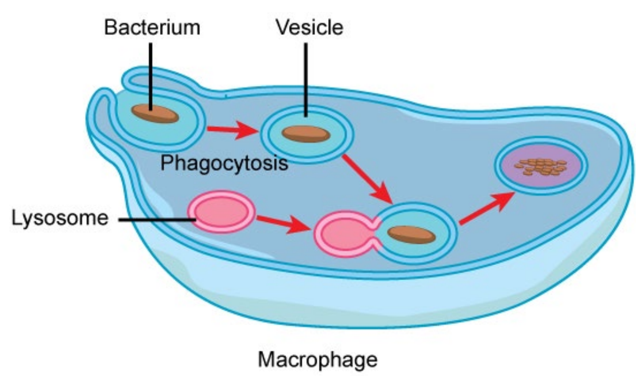


Figure 3.3.6**:** A macrophage has phagocytized a potentially pathogenic bacterium into a vesicle, which then fuses with a lysosome within the cell so that the pathogen can be destroyed. Other organelles are present in the cell, but for simplicity, are not shown.

Vesicles and Vacuoles

Vesicles and vacuoles are membrane-bound sacs that function in storage and transport. Vacuoles are somewhat larger than vesicles, and the membrane of a vacuole does not fuse with the membranes of other cellular components. Vesicles can fuse with other membranes within the cell system. Additionally, enzymes within plant vacuoles can break down macromolecules.

Ribosomes

Ribosomes are the cellular structures responsible for protein synthesis. When viewed through an electron microscope, free ribosomes appear as either clusters or single tiny dots floating freely in the cytoplasm. Ribosomes may be attached to either the cytoplasmic side of the plasma membrane or the cytoplasmic side of the endoplasmic reticulum (Figure 3.3.7). Electron microscopy has shown that ribosomes consist of large and small subunits. Ribosomes are enzyme complexes that are responsible for protein synthesis.

Because protein synthesis is essential for all cells, ribosomes are found in practically every cell, although they are smaller in prokaryotic cells. They are particularly abundant in immature red blood cells for the synthesis of hemoglobin, which functions in the transport of oxygen throughout the body.

Mitochondria

Mitochondria (singular = mitochondrion) are often called the “powerhouses” or “energy factories” of a cell because they are responsible for making adenosine triphosphate (ATP), the cell’s main energy-carrying molecule. The formation of ATP from the breakdown of glucose is known as cellular respiration. Mitochondria are oval-shaped, double-membrane organelles (Figure 3.3.8) that have their own ribosomes and DNA. Each membrane is a phospholipid bilayer embedded with proteins. The inner layer has folds called cristae, which increase the surface area of the inner membrane. The area surrounded by the folds is called the mitochondrial matrix. The cristae and the matrix have different roles in cellular respiration.

In keeping with our theme of form following function, it is important to point out that muscle cells have a very high concentration of mitochondria because muscle cells need a lot of energy to contract.

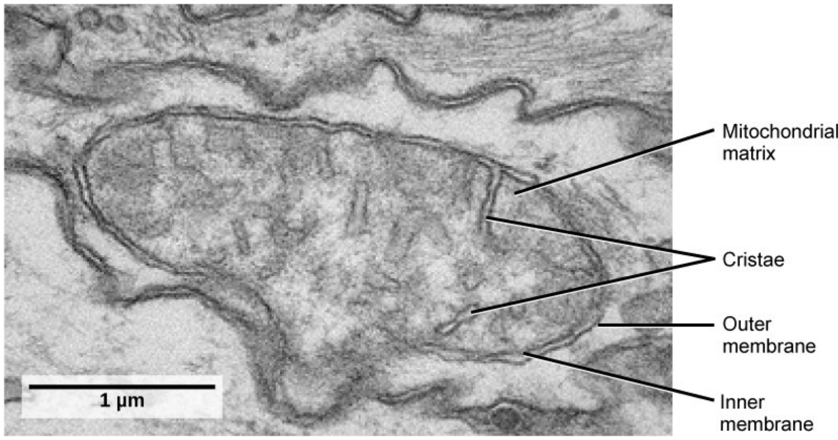


Figure 3.3.8**:** This transmission electron micrograph shows a mitochondrion as viewed with an electron microscope. Notice the inner and outer membranes, the cristae, and the mitochondrial matrix. (Credit: modification of work by Matthew Britton; scale-bar data from Matt Russell)

Peroxisomes

Peroxisomes are small, round organelles enclosed by single membranes. They carry out oxidation reactions that break down fatty acids and amino acids. They also detoxify many poisons that may enter the body. Alcohol is detoxified by peroxisomes in liver cells. A byproduct of these oxidation reactions is hydrogen peroxide, H_2O_2, which is contained within the peroxisomes to prevent the chemical from causing damage to cellular components outside of the organelle. Hydrogen peroxide is safely broken down by peroxisomal enzymes into water and oxygen.

Animal Cells versus Plant Cells

Despite their fundamental similarities, there are some striking differences between animal and plant cells (see Table 3.3.1). Animal cells have centrioles, centrosomes (discussed under the cytoskeleton), and lysosomes, whereas plant cells do not. Plant cells have a cell wall, chloroplasts, plasmodesmata, and plastids used for storage, and a large central vacuole, whereas animal cells do not.

The Cell Wall

In Figure 3.3.1**b**, the diagram of a plant cell, you see a structure external to the plasma membrane called the cell wall. The cell wall is a rigid covering that protects the cell, provides structural support, and gives shape to the cell. Fungal and protist cells also have cell walls.

While the chief component of prokaryotic cell walls is peptidoglycan, the major organic molecule in the plant cell wall is cellulose, a polysaccharide made up of long, straight chains of glucose units. When nutritional information refers to dietary fiber, it is referring to the cellulose content of food.

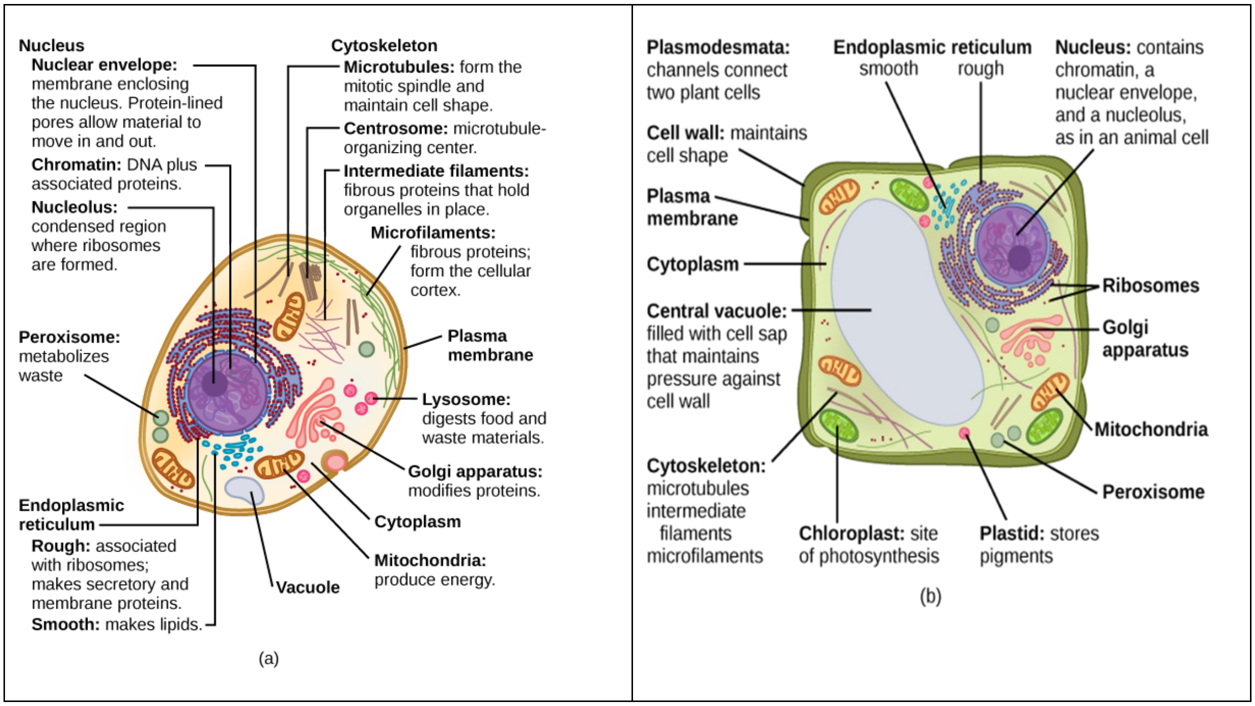


Figure 3.3.1: This figure shows (a) a typical animal cell and (b) a typical plant cell.

Chloroplasts

Like mitochondria, chloroplasts also have their own DNA and ribosomes. Chloroplasts function in photosynthesis and can be found in eukaryotic cells such as plants and algae. In photosynthesis, carbon dioxide, water, and light energy are used to make glucose and oxygen. This is the major difference between plants and animals: Plants (autotrophs) can make their own food, like glucose, whereas animals (heterotrophs) must rely on other organisms for their organic compounds or food source.

Like mitochondria, chloroplasts have outer and inner membranes, but within the space enclosed by a chloroplast's inner membrane is a set of interconnected and stacked, fluid-filled membrane sacs called thylakoids (Figure 3.3.9). Each stack of thylakoids is called a granum (plural = grana). The fluid enclosed by the inner membrane and surrounding the grana is called the stroma.

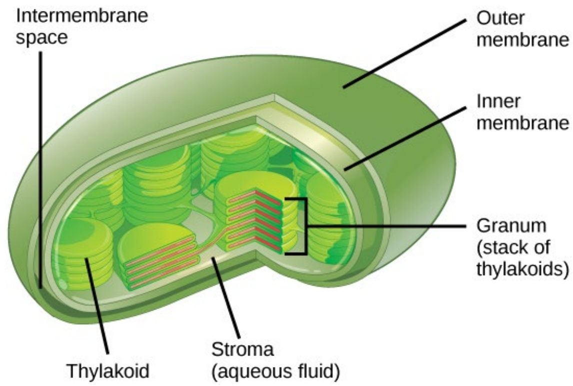


Figure 3.3.9**:** This simplified diagram of a chloroplast shows the outer membrane, inner membrane, thylakoids, grana, and stroma.

The chloroplasts contain a green pigment called chlorophyll, which captures the energy of sunlight for photosynthesis. Like plant cells, photosynthetic protists also have chloroplasts. Some bacteria also perform photosynthesis, but they do not have chloroplasts. Their photosynthetic pigments are in the thylakoid membrane within the cell itself.

The Central Vacuole

Previously, we mentioned vacuoles as essential components of plant cells. If you look at figure 3.3.1 (b), you will see that plant cells each have a large, central vacuole that occupies most of the cell. The central vacuole plays a key role in regulating the cell's concentration of water in changing environmental conditions. In plant cells, the liquid inside the central vacuole provides turgor pressure, which is the outward pressure caused by the fluid inside the cell. Have you ever noticed that if you forget to water a plant for a few days, it wilts? That is because as the water concentration in the soil becomes lower than the water concentration in the plant, water moves out of the central vacuoles and cytoplasm and into the soil. As the central vacuole shrinks, it leaves the cell wall unsupported. This loss of support to the cell walls of a plant results in the wilted appearance. Additionally, this fluid has a very bitter taste, which discourages consumption by insects and animals. The central vacuole also functions to store proteins in developing seed cells.

Extracellular Matrix of Animal Cells

Most animal cells release materials into the extracellular space. The primary components of these materials are glycoproteins and protein collagen. Collectively, these materials are called the extracellular matrix (Figure 3.3.10). Not only does the extracellular matrix hold the cells together to form a tissue, but it also allows the cells within the tissue to communicate with each other.

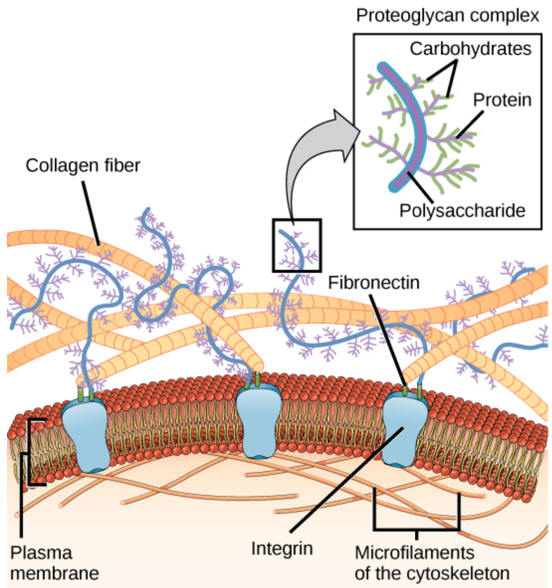


Figure 3.3.10**:** The extracellular matrix consists of a network of substances secreted by cells.

Blood clotting provides an example of the role of the extracellular matrix in cell communication. When the cells lining a blood vessel are damaged, they display a protein receptor called tissue factor. When tissue factor binds with another factor in the extracellular matrix, it causes platelets to adhere to the wall of the damaged blood vessel, stimulates adjacent smooth muscle cells in the blood vessel to contract (thus constricting the blood vessel), and initiates a series of steps that stimulate the platelets to produce clotting factors.

Intercellular Junctions

Cells can also communicate with each other by direct contact, referred to as intercellular junctions. There are some differences in the ways plant and animal cells do this. Plasmodesmata (singular = plasmodesma) are junctions between plant cells, whereas animal cell contacts include tight and gap junctions, and desmosomes.

In general, long stretches of the plasma membranes of neighboring plant cells cannot touch one another because they are separated by the cell walls surrounding each cell. Plasmodesmata are numerous channels that pass between the cell walls of adjacent plant cells, connecting their cytoplasm and enabling signal molecules and nutrients to be transported from cell to cell (Figure 3.3.11**a**).

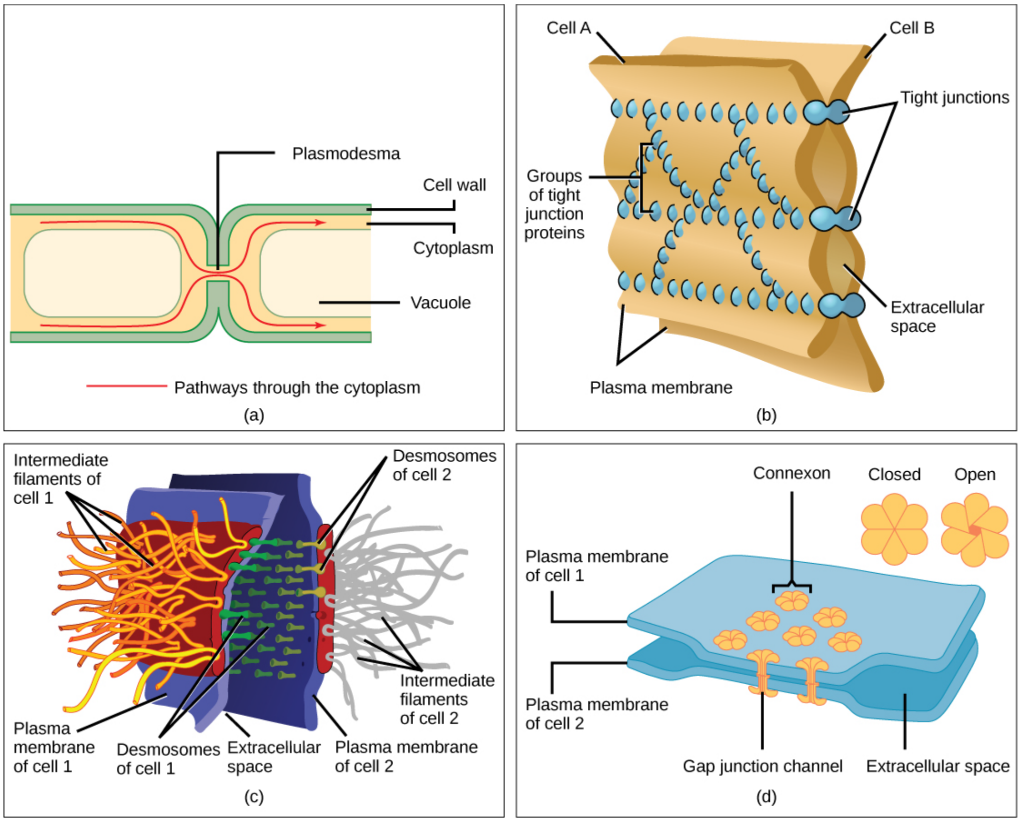


Figure 3.3.11**:** There are four kinds of connections between cells. (a) A plasmodesma is a channel between the cell walls of two adjacent plant cells. (b) Tight junctions join adjacent animal cells. (c) Desmosomes join two animal cells together. (d) Gap junctions act as channels between animal cells. (Credit b, c, d: modification of work by Mariana Ruiz Villareal)

A tight junction is a watertight seal between two adjacent animal cells (Figure 3.3.11**b**). Proteins hold the cells tightly against each other. This tight adhesion prevents materials from leaking between the cells. Tight junctions are typically found in the epithelial tissue that lines internal organs and cavities and composes most of the skin. For example, the tight junctions of the epithelial cells lining the urinary bladder prevent urine from leaking into the extracellular space.

Also found only in animal cells are desmosomes, which act like spot welds between adjacent epithelial cells (Figure 3.3.11**c**). They keep cells together in a sheet-like formation in organs and tissues that stretch, like the skin, heart, and muscles.

Gap junctions in animal cells are like plasmodesmata in plant cells in that they are channels between adjacent cells that allow for the transport of ions, nutrients, and other substances that enable cells to communicate (Figure 3.3.11 d). Structurally, however, gap junctions and plasmodesmata differ.

Table 3.3.1**:** This table provides the components of prokaryotic and eukaryotic cells and their respective functions.

Cell Component	Function	Present in Prokaryotes?	Present in Animal Cells?	Present in Plant Cells?
Plasma membrane	Separates cell from external environment; controls passage of organic molecules, ions, water, oxygen, and wastes into and out of the cell	Yes	Yes	Yes
Cytoplasm	Provides structure to cell; site of many metabolic reactions; medium in which organelles are found	Yes	Yes	Yes
Nucleoid	Location of DNA	Yes	No	No
Nucleus	Cell organelle that houses DNA and directs synthesis of ribosomes and proteins	No	Yes	Yes
Ribosomes	Protein synthesis	Yes	Yes	Yes
Mitochondria	ATP production/cellular respiration	No	Yes	Yes
Peroxisomes	Oxidizes and breaks down fatty acids and amino acids, and detoxifies poisons	No	Yes	Yes
Vesicles and vacuoles	Storage and transport; digestive function in plant cells	No	Yes	Yes

Table 3.3.1**:** This table provides the components of prokaryotic and eukaryotic cells and their respective functions.

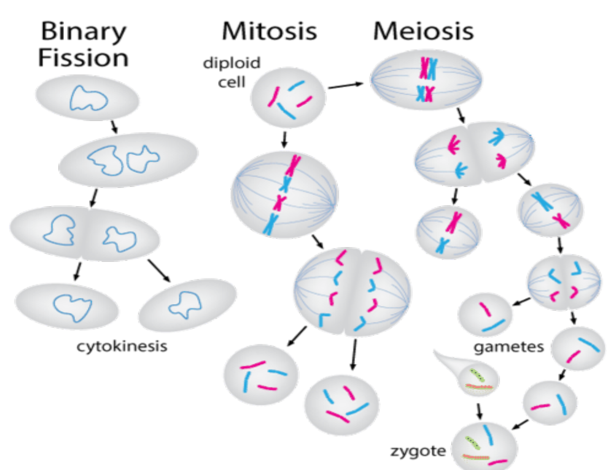
Cell Component	Function	Present in Prokaryotes?	Present in Animal Cells?	Present in Plant Cells?
Centrosome	Unspecified role in cell division in animal cells; organizing center of microtubules in animal cells	No	Yes	No
Lysosomes	Digestion of macromolecules; recycling of worn-out organelles	No	Yes	No
Cell wall	Protection, structural support and maintenance of cell shape	Yes, primarily peptidoglycan in bacteria but not Archaea	No	Yes, primarily cellulose
Chloroplasts	Photosynthesis	No	No	Yes
Endoplasmic reticulum	Modifies proteins and synthesizes lipids	No	Yes	Yes
Golgi apparatus	Modifies, sorts, tags, packages, and distributes lipids and proteins	No	Yes	Yes
Cytoskeleton	Maintains cell's shape, secures organelles in specific positions, allows cytoplasm and vesicles to move within the cell, and enables unicellular organisms to move independently	Yes	Yes	Yes

Table 3.3.1**:** This table provides the components of prokaryotic and eukaryotic cells and their respective functions.				
Cell Component	Function	Present in Prokaryotes?	Present in Animal Cells?	Present in Plant Cells?
Flagella	Cellular locomotion	Some	Some	No, except for some plant sperm
Cilia	Cellular locomotion, movement of particles along extracellular surface of plasma membrane, and filtration	No	Some	No

Mitosis and Meiosis

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



A comparison between binary fission, mitosis, and meiosis.

	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

Mitosis

Mitosis is divided into a series of phases—prophase, prometaphase, metaphase, anaphase, and telophase—that result in the division of the cell nucleus (Figure 6.2.2).

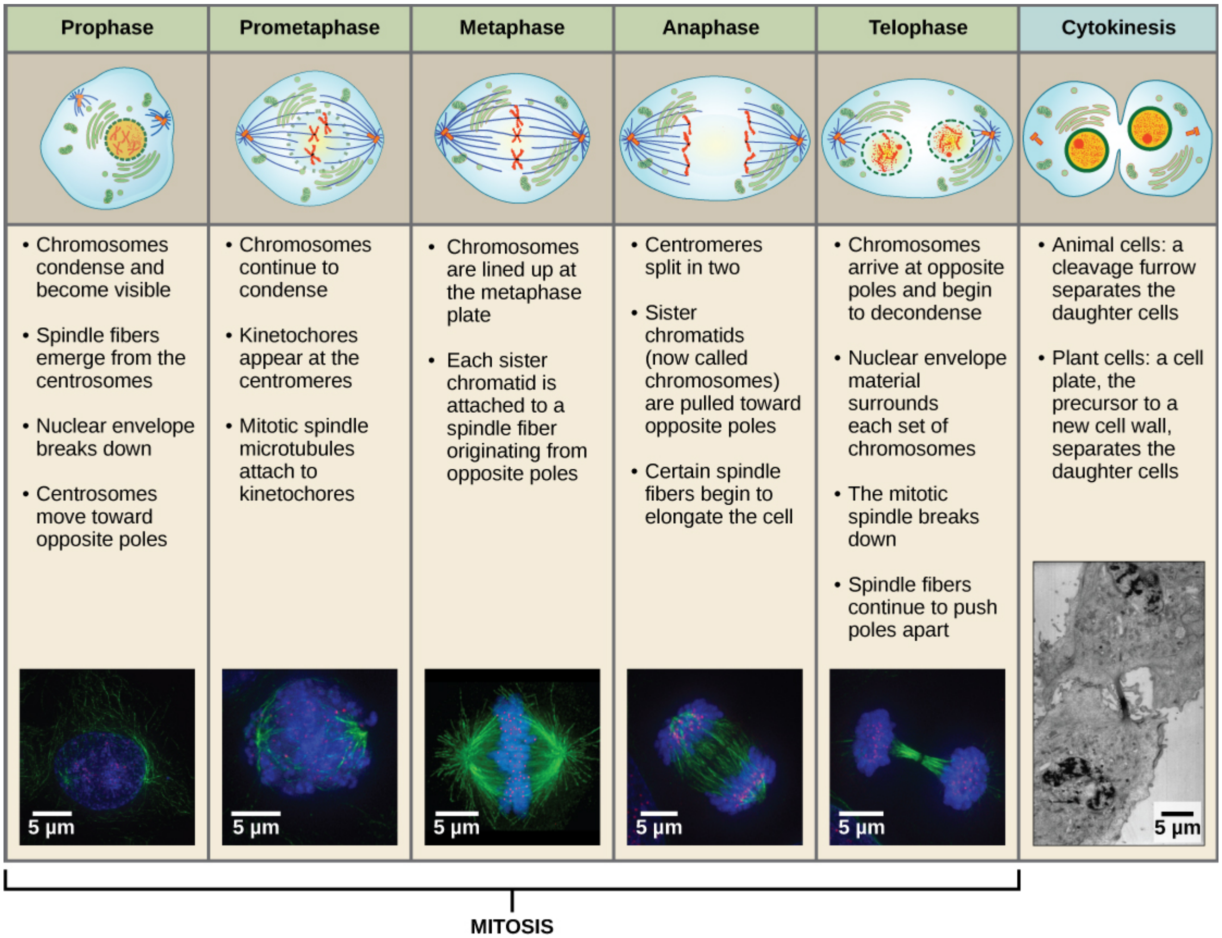


Figure 6.2.2**:** Animal cell mitosis is divided into five stages—prophase, prometaphase, metaphase, anaphase, and telophase—visualized here by light microscopy with fluorescence. Mitosis is usually accompanied by cytokinesis, shown here by a transmission electron microscope. (credit "diagrams": modification of work by Mariana Ruiz Villareal; credit "mitosis micrographs": modification of work by Roy van Heesbeen; credit "cytokinesis micrograph": modification of work by the Wadsworth Center, NY State Department of Health; donated to the Wikimedia foundation; scale-bar data from Matt Russell)

Heredity

Meiosis

Sexual reproduction requires fertilization, a union of two cells from two individual organisms. If those two cells each contain one set of chromosomes, then the resulting cell contains two sets of chromosomes. The number of sets of chromosomes in a cell is called its **ploidy level**. **Haploid cells** contain one set of chromosomes. Cells containing two sets of chromosomes are **called diploid**. If the reproductive cycle is to continue, the diploid cell must somehow reduce its number of chromosome sets before fertilization can occur again, or there will be a continual doubling in the number of chromosome sets in every generation. So, in addition to fertilization, sexual reproduction includes a nuclear division, known as **meiosis**, that reduces the number of chromosome sets.

Most animals and plants are diploid, containing two sets of chromosomes; in each somatic cell (the nonreproductive cells of a multicellular organism), the nucleus contains two copies of each chromosome that are referred to as homologous chromosomes. Somatic cells are sometimes referred to as "body" cells. Homologous chromosomes are matched pairs containing genes for the same traits in identical locations along their length. Diploid organisms inherit one copy of each homologous chromosome from each parent; all together, they are considered a full set of chromosomes. In animals, haploid cells containing a single copy of each homologous chromosome are found only within gametes. Gametes fuse with another haploid gamete to produce a diploid cell.

The nuclear division that forms haploid cells, which is called meiosis, is related to mitosis. As you have learned, mitosis is part of a cell reproduction cycle that results in identical daughter nuclei that are also genetically identical to the original parent nucleus. In mitosis, both the parent and the daughter nuclei contain the same number of chromosome sets—diploid for most plants and animals. Meiosis employs many of the same mechanisms as mitosis. However, the starting nucleus is always diploid and the nuclei that result at the end of a meiotic cell division are haploid. To achieve the reduction in chromosome number, meiosis consists of one round of chromosome duplication and two rounds of nuclear division. Because the events that occur during each of the division stages are analogous to the events of mitosis, the same stage names are assigned. However, because there are two rounds of division, the stages are designated with an "I" or "II." Thus, meiosis I is the first round of meiotic division and consists of prophase I, prometaphase I, and so on. Meiosis I reduces the number of chromosome sets from two to one. Genetic information is also mixed during this division to create unique recombinant chromosomes. Meiosis II, in which the second round of meiotic division takes place in a way that is similar to mitosis, includes prophase II, prometaphase II, and so on.

Interphase

Meiosis is preceded by an interphase consisting of the G_1, S, and G_2 phases, which are nearly identical to the phases preceding mitosis. The G_1 phase is the first phase of interphase and is focused on cell growth. In the S phase, the DNA of the chromosomes is replicated. Finally, in the G_2 phase, the cell undergoes the final preparations for meiosis.

During DNA duplication of the S phase, each chromosome becomes composed of two identical copies (called sister chromatids) that are held together at the centromere until they are pulled apart during meiosis II. In an animal cell, the centrosomes that organize the microtubules of the meiotic spindle also replicate. This prepares the cell for the first meiotic phase. (The spindle is a structure made of microtubules, strong fibers that are part of the cell's "skeleton.")

Meiosis I

Early in prophase I, the chromosomes can be seen clearly microscopically. As the nuclear envelope begins to break down, the proteins associated with homologous chromosomes bring the pair close to each other. The tight pairing of the homologous chromosomes is called synapsis. In synapsis, the genes on the chromatids of the homologous chromosomes are precisely aligned with each other. An exchange of chromosome segments between non-sister homologous chromatids occurs and is called crossing over. This process is revealed visually after the exchange as chiasmata (singular = *chiasma*) (Figure 7.2.1).

As prophase I progresses, the close association between homologous chromosomes begins to break down, and the chromosomes continue to condense, although the homologous chromosomes remain attached to each other at chiasmata. The number of chiasmata varies with the species and the length of the chromosome. At the end of prophase, I, the pairs are held together only at chiasmata (Figure 7.2.1) and are called tetrads because the four sister chromatids of each pair of homologous chromosomes are now visible.

Crossover events are the first source of genetic variation produced by meiosis. A single crossover event between homologous non-sister chromatids leads to a reciprocal exchange of equivalent DNA between a maternal chromosome and a paternal chromosome. Now, when that sister chromatid is moved into a gamete, it will carry some DNA from one parent of the individual and some DNA from the other parent. The recombinant sister chromatid has a combination of maternal and paternal genes that did not exist before the crossover.

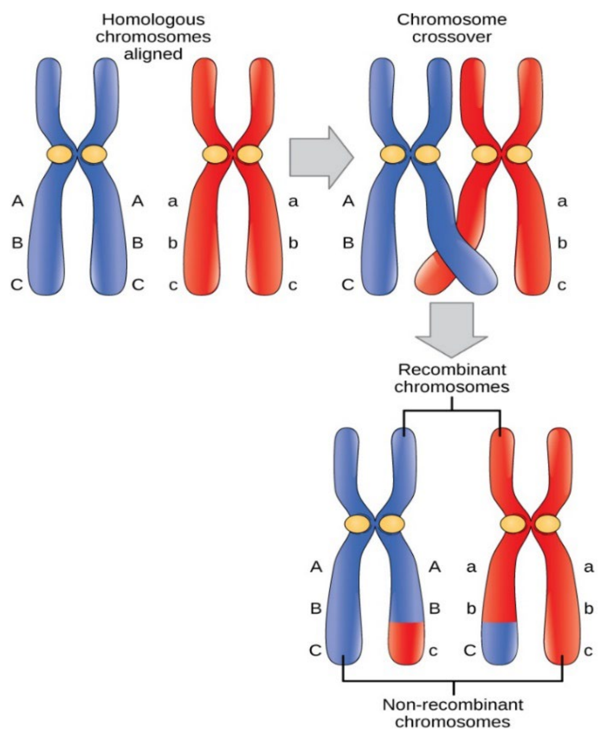


Figure 7.2.1**:** In this illustration of the effects of crossing over, the blue chromosome came from the individual's father and the red chromosome came from the individual's mother. Crossover occurs between non-sister chromatids of homologous chromosomes. The result is an exchange of genetic material between homologous chromosomes. The chromosomes that have a mixture of maternal and paternal sequence are called recombinant and the chromosomes that are completely paternal or maternal are called non-recombinant.

The key event in prometaphase I is the attachment of the spindle fiber microtubules to the kinetochore proteins at the centromeres. The microtubules assembled from centrosomes at opposite poles of the cell grow toward the middle of the cell. At the end of prometaphase I, each tetrad is attached to microtubules from both poles, with one homologous chromosome attached at one pole and the other homologous chromosome attached to the other pole. The homologous chromosomes are still held together at chiasmata. In addition, the nuclear membrane has broken down entirely.

During metaphase I, the homologous chromosomes are arranged in the center of the cell with the kinetochores facing opposite poles. The orientation of each pair of homologous chromosomes at the center of the cell is random.

This randomness, called independent assortment, is the physical basis for the generation of the second form of genetic variation in offspring. Consider that the homologous chromosomes of a sexually reproducing organism are originally inherited as two separate sets, one from each parent. Using humans as an example, one set of 23 chromosomes is present in the egg donated by the mother. The father provides the other set of 23 chromosomes in the sperm that fertilizes the egg. In metaphase I, these pairs line up at the midway point between the two poles of the cell. Because there is an equal chance that a microtubule fiber will encounter a maternally or paternally inherited chromosome, the arrangement of the tetrads at the metaphase plate is random. Any maternally inherited chromosome may face either pole. Any paternally inherited chromosome may also face either pole. The orientation of each tetrad is independent of the orientation of the other 22 tetrads.

In each cell that undergoes meiosis, the arrangement of the tetrads is different. The number of variations depends on the number of chromosomes making up a set. There are two possibilities for orientation (for each tetrad); thus, the possible number of alignments equals 2^n where n is the number of chromosomes per set. Humans have 23 chromosome pairs, which results in over eight million (2^{23}) possibilities. This number does not include the variability previously created in the sister chromatids by crossover. Given these two mechanisms, it is highly unlikely that any two haploid cells resulting from meiosis will have the same genetic composition (Figure 7.2.2).

To summarize the genetic consequences of meiosis I: the maternal and paternal genes are recombined by crossover events occurring on each homologous pair during prophase I; in addition, the random assortment of tetrads at metaphase produces a unique combination of maternal and paternal chromosomes that will make their way into the gametes.

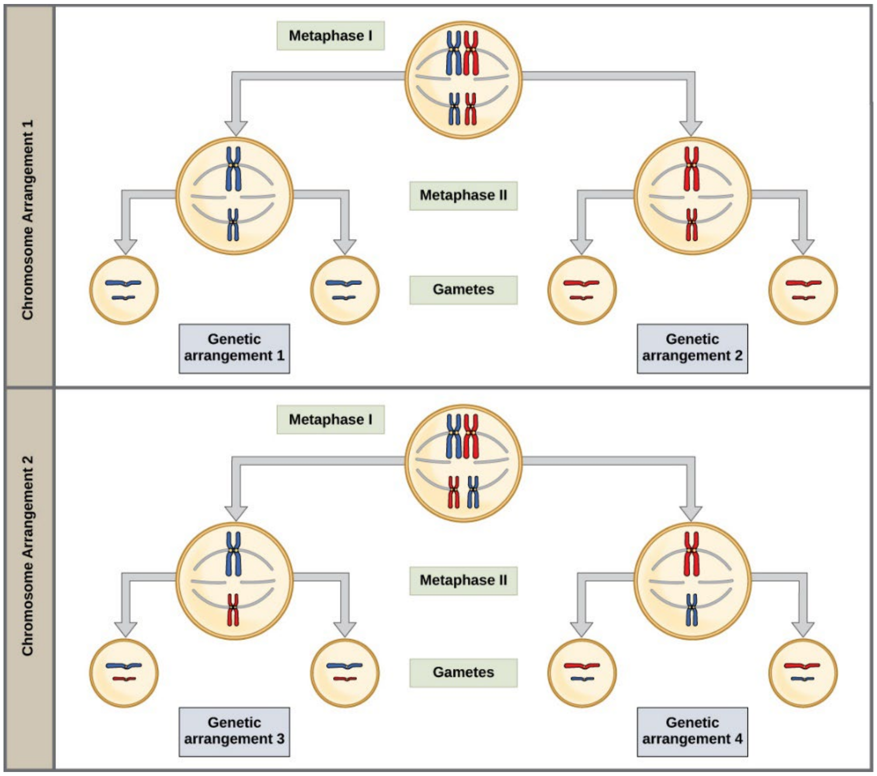


Figure 7.2.2**:** To demonstrate random, independent assortment at metaphase I, consider a cell with n = 2. In this case, there are two possible arrangements at the equatorial plane in metaphase I, as shown in the upper cell of each panel. These two possible orientations lead to the production of genetically different gametes. With more chromosomes, the number of possible arrangements increases dramatically.

In **anaphase I**, the spindle fibers pull the linked chromosomes apart. The sister chromatids remain tightly bound together at the centromere. It is the chiasma connections that are broken in anaphase I as the fibers attached to the fused kinetochores pull the homologous chromosomes apart (Figure 7.2.3).

In **telophase I**, the separated chromosomes arrive at opposite poles. The remainder of the typical telophase events may or may not occur depending on the species. In some organisms, the chromosomes decondense and nuclear envelopes form around the chromatids in telophase I.

Cytokinesis, the physical separation of the cytoplasmic components into two daughter cells, occurs without reformation of the nuclei in other organisms. In nearly all species, cytokinesis separates the cell contents by either a cleavage furrow (in animals and some fungi), or a cell plate that will ultimately lead to formation of cell walls that separate the two daughter cells (in plants). At each pole, there is just one member of each pair of the homologous chromosomes, so only one full set of the chromosomes is present. This is why the cells are considered haploid—there is only one chromosome set, even though there are duplicate copies of the set because each homolog still consists of two sister chromatids that are still attached to each other. However, although the sister chromatids were once duplicates of the same chromosome, they are no longer identical at this stage because of crossovers.

Meiosis II

In meiosis II, the connected sister chromatids remaining in the haploid cells from meiosis I will be split to form four haploid cells. In some species, cells enter a brief interphase, or interkinesis, that lacks an S phase, before entering meiosis II. Chromosomes are not duplicated during interkinesis. The two cells produced in meiosis I go through the events of meiosis II in synchrony. Overall, meiosis II resembles the mitotic division of a haploid cell.

In prophase II, if the chromosomes decondensed in telophase I, they condense again. If nuclear envelopes were formed, they fragment into vesicles. The centrosomes duplicated during interkinesis move away from each other toward opposite poles, and new spindles are formed. In prometaphase II, the nuclear envelopes are completely broken down, and the spindle is fully formed. Each sister chromatid forms an individual kinetochore that attaches to microtubules from opposite poles. In metaphase II, the sister chromatids are maximally condensed and aligned at the center of the cell. In anaphase II, the sister chromatids are pulled apart by the spindle fibers and move toward opposite poles.

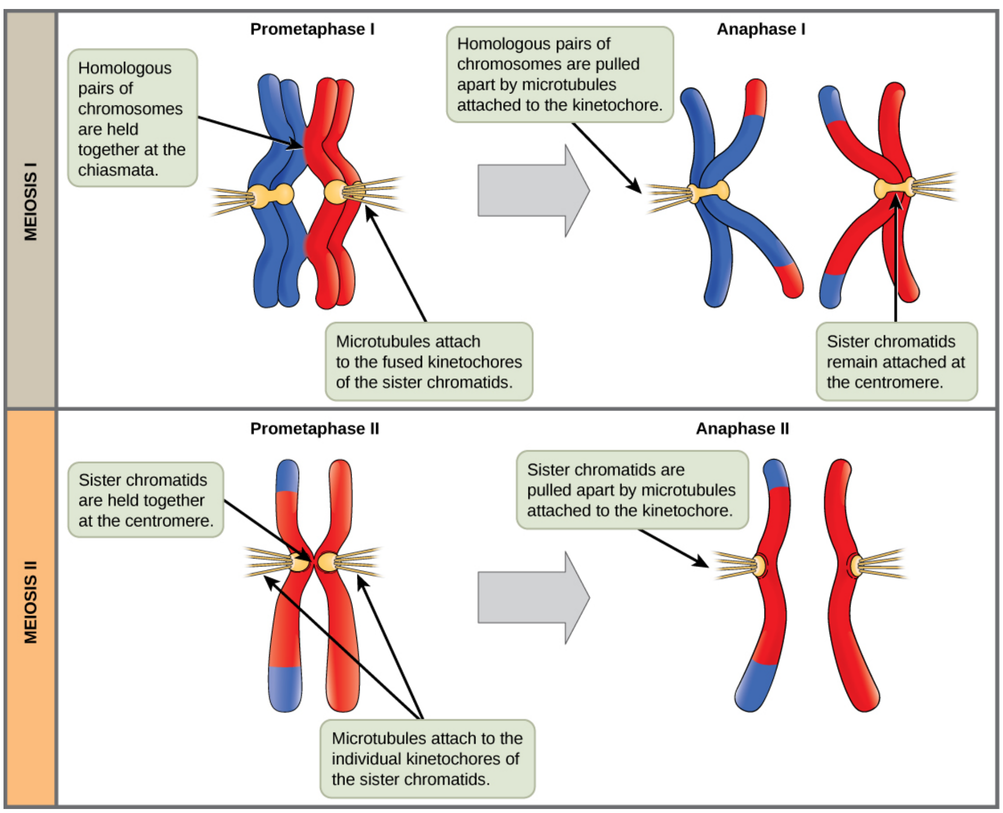


Figure 7.2.3**:** In prometaphase I, microtubules attach to the fused kinetochores of homologous chromosomes. In anaphase I, the homologous chromosomes are separated. In prometaphase II, microtubules attach to individual kinetochores of sister chromatids. In anaphase II, the sister chromatids are separated.

In **telophase II**, the chromosomes arrive at opposite poles and begin to decondense. Nuclear envelopes form around the chromosomes. Cytokinesis separates the two cells into four genetically unique haploid cells. At this point, the nuclei in the newly produced cells are both haploid and have only one copy of the single set of chromosomes. The cells produced are genetically unique because of the random assortment of paternal and maternal homologs and because of the recombination of maternal and paternal segments of chromosomes—with their sets of genes—that occurs during crossover.

Comparing Meiosis and Mitosis

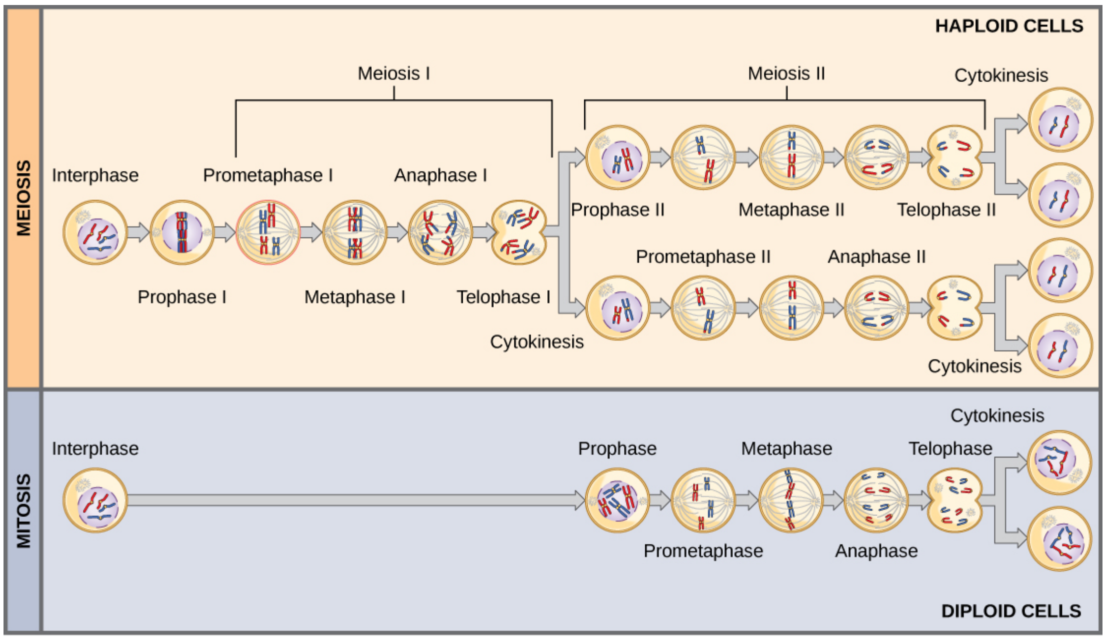
Mitosis and meiosis, which are both forms of division of the nucleus in eukaryotic cells, share some similarities, but also exhibit distinct differences that lead to their very different outcomes. Mitosis is a single nuclear division that results in two nuclei, usually partitioned into two new cells. The nuclei resulting from a mitotic division are genetically identical to the original. They have the same number of sets of chromosomes: one in the case of haploid cells, and two in the case of diploid cells. On the other hand, meiosis is two nuclear divisions that result in four nuclei, usually partitioned into four new cells. The nuclei resulting from meiosis are never genetically identical, and they contain only one chromosome set—this is half the number of the original cell, which was diploid (Figure 7.2.4).

The differences in the outcomes of meiosis and mitosis occur because of differences in the behavior of the chromosomes during each process. Most of these differences in the processes occur in meiosis I, which is a very different nuclear division than mitosis. In meiosis I, the homologous chromosome pairs become associated with each other, are bound together, experience chiasmata and crossover between sister chromatids, and line up along the metaphase plate in tetrads with spindle fibers from opposite spindle poles attached to each kinetochore of a homolog in a tetrad. All these events occur only in meiosis I, never in mitosis.

Homologous chromosomes move to opposite poles during meiosis I so the number of sets of chromosomes in each nucleus-to-be is reduced from two to one. For this reason, meiosis I is referred to as a reduction division. There is no such reduction in ploidy level in mitosis.

Meiosis II is much more analogous to a mitotic division. In this case, duplicated chromosomes (only one set of them) line up at the center of the cell with divided kinetochores attached to spindle fibers from opposite poles. During anaphase II, as in mitotic anaphase, the kinetochores divide, and one sister chromatid is pulled to one pole and the other sister chromatid is pulled to the other pole. If it were not for the fact that there had been crossovers, the two products of each meiosis II division would be identical as in mitosis; instead, they are different because there has always been at least one crossover per chromosome. Meiosis II is not a reduction division because, although there are fewer copies of the genome in the resulting cells, there is still one set of chromosomes, as there was at the end of meiosis I.

Cells produced by mitosis will function in different parts of the body as a part of growth or replacing dead or damaged cells. They may even be involved in asexual reproduction in some organisms. Cells produced by meiosis in a diploid-dominant organism such as an animal will only participate in sexual reproduction.



						OUTCOME
PROCESS	DNA synthesis	Synapsis of homologous chromosomes	Crossover	Homologous chromosomes line up at metaphase plate	Sister chromatids line up at metaphase plate	Number and genetic composition of daughter cells
MEIOSIS	Occurs in S phase of interphase	During prophase I	During prophase I	During metaphase I	During metaphase II	Four haploid cells at the end of meiosis II
MITOSIS	Occurs in S phase of interphase	Does not occur in mitosis	Does not occur in mitosis	Does not occur in mitosis	During metaphase	Two diploid cells at the end of mitosis

Figure 7.2.4: Meiosis and mitosis are both preceded by one round of DNA replication; however, meiosis includes two nuclear divisions. The four daughter cells resulting from meiosis are haploid and genetically distinct. The daughter cells resulting from mitosis are diploid and identical to the parent cell.

Inherited disorders can arise when chromosomes behave abnormally during meiosis. Chromosome disorders can be divided into two categories: abnormalities in chromosome number and chromosome structural rearrangements. Because even small segments of chromosomes can span many genes, chromosomal disorders are characteristically dramatic and often fatal.

Disorders in Chromosome Number

The isolation and microscopic observation of chromosomes forms the basis of cytogenetics and is the primary method by which clinicians detect chromosomal abnormalities in humans. A karyotype is the number and appearance of chromosomes, including their length, banding pattern, and centromere position. To obtain a view of an individual's karyotype, cytologists photograph the chromosomes and then cut and paste each chromosome into a chart, or karyogram (Figure 7.3.1).

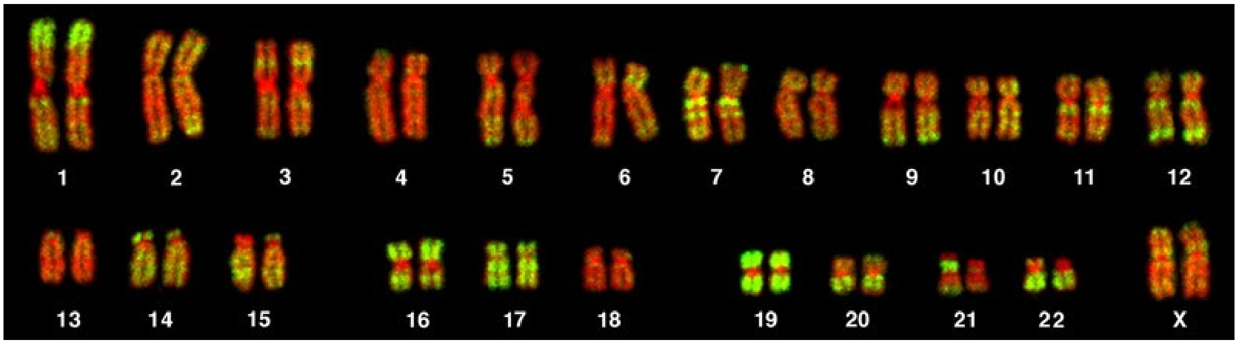


Figure 7.3.1**:** This karyogram shows the chromosomes of a female human immune cell during mitosis. (Credit: Andreas Bolzer, et al)

Nondisjunctions, Duplications, and Deletions

Of all the chromosomal disorders, abnormalities in chromosome number are the most easily identifiable from a karyogram. Disorders of chromosome numbers include the duplication or loss of entire chromosomes, as well as changes in the number of complete sets of chromosomes. They are caused by nondisjunction, which occurs when pairs of homologous chromosomes or sister chromatids fail to separate during meiosis. The risk of nondisjunction increases with the age of the parents.

Nondisjunction can occur during either meiosis I or II, with different results (Figure 7.3.2). If homologous chromosomes fail to separate during meiosis I, the result is two gametes that lack that chromosome and two gametes with two copies of the chromosome. If sister chromatids fail to separate during meiosis II, the result is one gamete that lacks that chromosome, two normal gametes with one copy of the chromosome, and one gamete with two copies of the chromosome.

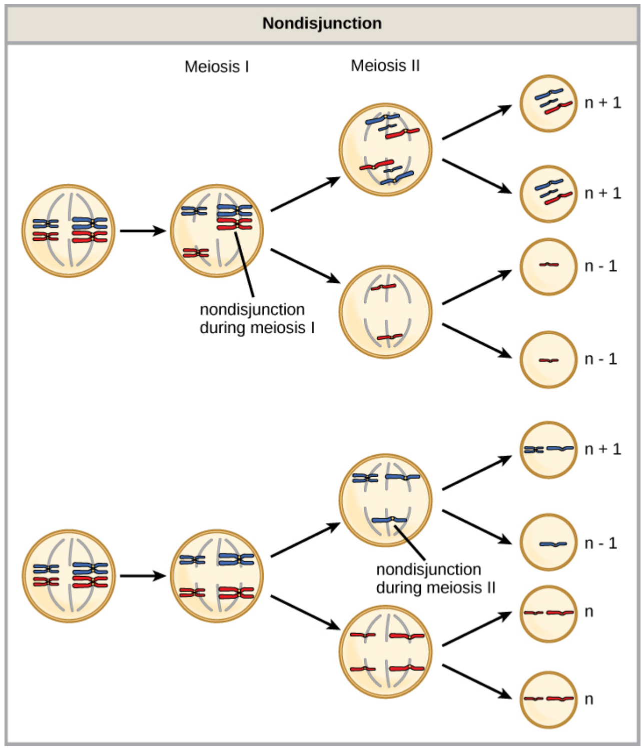


Figure 7.3.2**:** Following meiosis, each gamete has one copy of each chromosome. Nondisjunction occurs when homologous chromosomes (meiosis I) or sister chromatids (meiosis II) fail to separate during meiosis.

An individual with the appropriate number of chromosomes for their species is called euploid; in humans, euploidy corresponds to 22 pairs of autosomes and one pair of sex chromosomes. An individual with an error in chromosome number is described as aneuploid, a term that includes monosomy (loss of one chromosome) or trisomy (gain of an extra chromosome). Monosomic human zygotes missing any one copy of an autosome invariably fail to develop to birth because they have only one copy of essential genes. Most autosomal trisomies also fail to develop to birth; however, duplications of some of the smaller chromosomes (13, 15, 18, 21, or 22) can result in offspring that survive for several weeks to many years. Trisomic individuals suffer from a different type of genetic imbalance: an excess in gene dose. Cell functions are calibrated to the amount of gene product produced by two copies (doses) of each gene; adding a third copy (dose) disrupts this balance. The most common trisomy is that of chromosome 21, which leads to Down syndrome. Individuals with this inherited disorder have characteristic physical features and developmental delays in growth and cognition. The incidence of Down syndrome is correlated with maternal age, such that older women are more likely to give birth to children with Down syndrome (Figure 7.3.3).

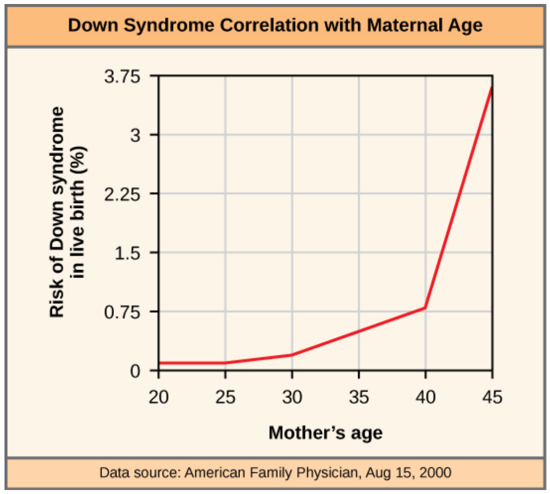


Figure 7.3.3**:** The incidence of having a fetus with trisomy 21 increases dramatically with maternal age.

Mendel

Johann Gregor Mendel (1822–1884) was a lifelong learner, teacher, scientist, and man of faith. As a young adult, he joined the Augustinian Abbey of St. Thomas in Brno in what is now the Czech Republic. Supported by the monastery, he taught physics, botany, and natural science courses at the secondary and university levels. In 1856, he began a decade-long research pursuit involving inheritance patterns in honeybees and plants, ultimately settling on pea plants as his primary model system (a system with convenient characteristics that is used to study a specific biological phenomenon to gain understanding to be applied to other systems). In 1865, Mendel presented the results of his experiments with nearly 30,000 pea plants to the local natural history society. He demonstrated that traits are transmitted faithfully from parents to offspring in specific patterns. In 1866, he published his work, Experiments in Plant Hybridization,1 in the proceedings of the Natural History Society of Brünn.

Mendel performed hybridizations, which involve mating two true-breeding individuals that have different traits. In the pea, which is naturally self-pollinating, this is done by manually transferring pollen from the anther of a mature pea plant of one variety to the stigma of a separate mature pea plant of the second variety.

Plants used in first-generation crosses were called P, or parental generation plants (Figure 8.1.2). Mendel collected the seeds produced by the P plants that resulted from each cross and grew them the following season. These offspring were called the F_1, or the first filial (filial = daughter or son) generation. Once Mendel examined the characteristics in the F_1 generation of plants, he allowed them to self-fertilize naturally. He then collected and grew the seeds from the F_1 plants to produce the F_2, or second filial generation. Mendel's experiments extended beyond the F_2 generation to the F_3 generation, F_4 generation, and so on, but it was the ratio of characteristics in the P, F_1, and F_2 generations that were the most intriguing and became the basis of Mendel's postulates.

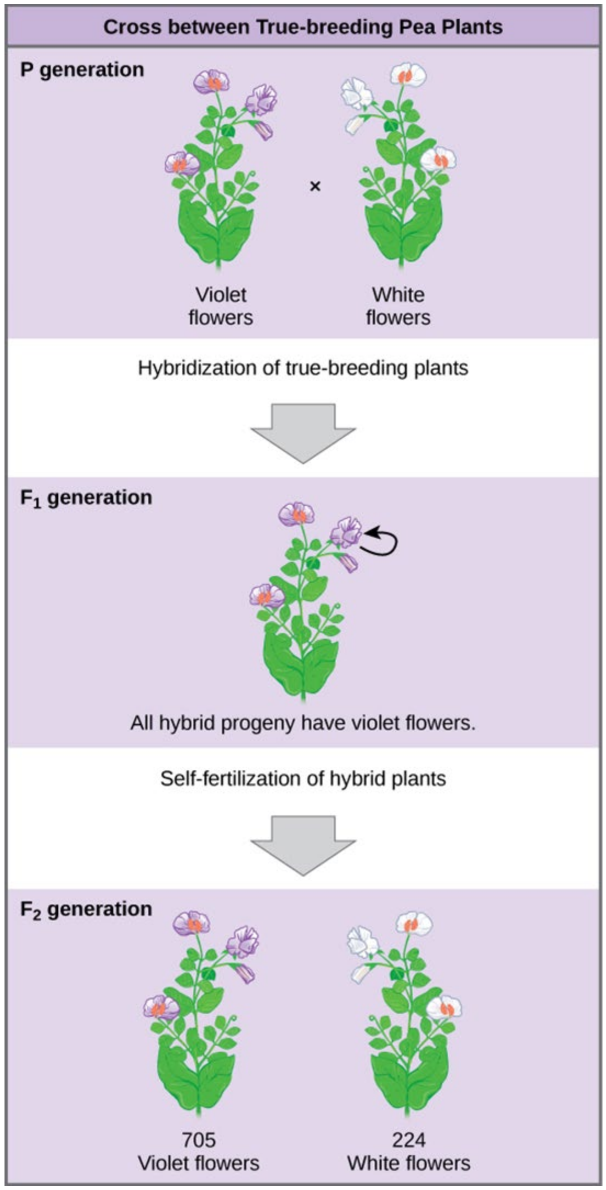


Figure 8.1.2**:** Mendel's process for performing crosses included examining flower color.

The seven characteristics that Mendel evaluated in his pea plants were each expressed as one of two versions, or traits. Mendel deduced from his results that each individual had two discrete copies of the characteristic that are passed individually to offspring. We now call those two copies genes, which are carried on chromosomes. The reason we have two copies of each gene is that we inherit one from each parent. Recall that in meiosis these chromosomes are separated out into haploid gametes. This separation, or segregation, of the homologous chromosomes means also that only one of the copies of the gene gets moved into a gamete. The offspring are formed when that gamete unites with one from another parent and the two copies of each gene (and chromosome) are restored.

For cases in which a single gene controls a single characteristic, a diploid organism has two genetic copies that may or may not encode the same version of that characteristic. For example, one individual may carry a gene that determines white flower color and a gene that determines violet flower color. Gene variants that arise by mutation and exist at the same relative locations on homologous chromosomes are called alleles. Mendel examined the inheritance of genes with just two allele forms, but it is common to encounter more than two alleles for any given gene in a natural population.

Phenotypes and Genotypes

Two alleles for a given gene in a diploid organism are expressed and interact to produce physical characteristics. The observable traits expressed by an organism are referred to as its phenotype. An organism's underlying genetic makeup, consisting of both the physically visible and the non-expressed alleles, is called its genotype. Mendel's hybridization experiments demonstrate the difference between phenotype and genotype. For example, the phenotypes that Mendel observed in his crosses between pea plants with differing traits are connected to the diploid genotypes of the plants in the P, F_1, and F_2 generations. We will use a second trait that Mendel investigated, seed color, as an example. Seed color is governed by a single gene with two alleles. The yellow-seed allele is dominant, and the green-seed allele is recessive. When true-breeding plants were cross-fertilized, in which one parent had yellow seeds and one had green seeds, all F_1hybrid offspring had yellow seeds. That is, the hybrid offspring were phenotypically identical to the true-breeding parent with yellow seeds. However, we know that the allele donated by the parent with green seeds was not simply lost because it reappeared in some of the F_2 offspring (Figure 8.2.1). Therefore, the F_1 plants must have been genotypically different from the parent with yellow seeds.

The P plants that Mendel used in his experiments were each homozygous for the trait he was studying. Diploid organisms that are homozygous for a gene have two identical alleles, one on each of their homologous chromosomes. The genotype is often written as *YY* or *yy*, for which each letter represents one of the two alleles in the genotype. The dominant allele is capitalized, and the recessive allele is lower case. The letter used for the gene (seed color in this case) is usually related to the dominant trait (yellow allele, in this case, or "*Y*"). Mendel's parental pea plants always bred true because both produced gametes carried the same allele. When P plants with contrasting traits were cross-fertilized, all the offspring were heterozygous for the contrasting trait, meaning their genotype had different alleles for the gene being examined. For example, the F_1 yellow plants that received a *Y* allele from their yellow parent and a *y* allele from their green parent had the genotype *Yy*.

Table 8.2.1***:*** Correspondence between Genotype and Phenotype for a Dominant-Recessive Characteristic.

	Homozygous	Heterozygous	Homozygous
Genotype	*YY*	*Yy*	*yy*
Phenotype	yellow	yellow	green

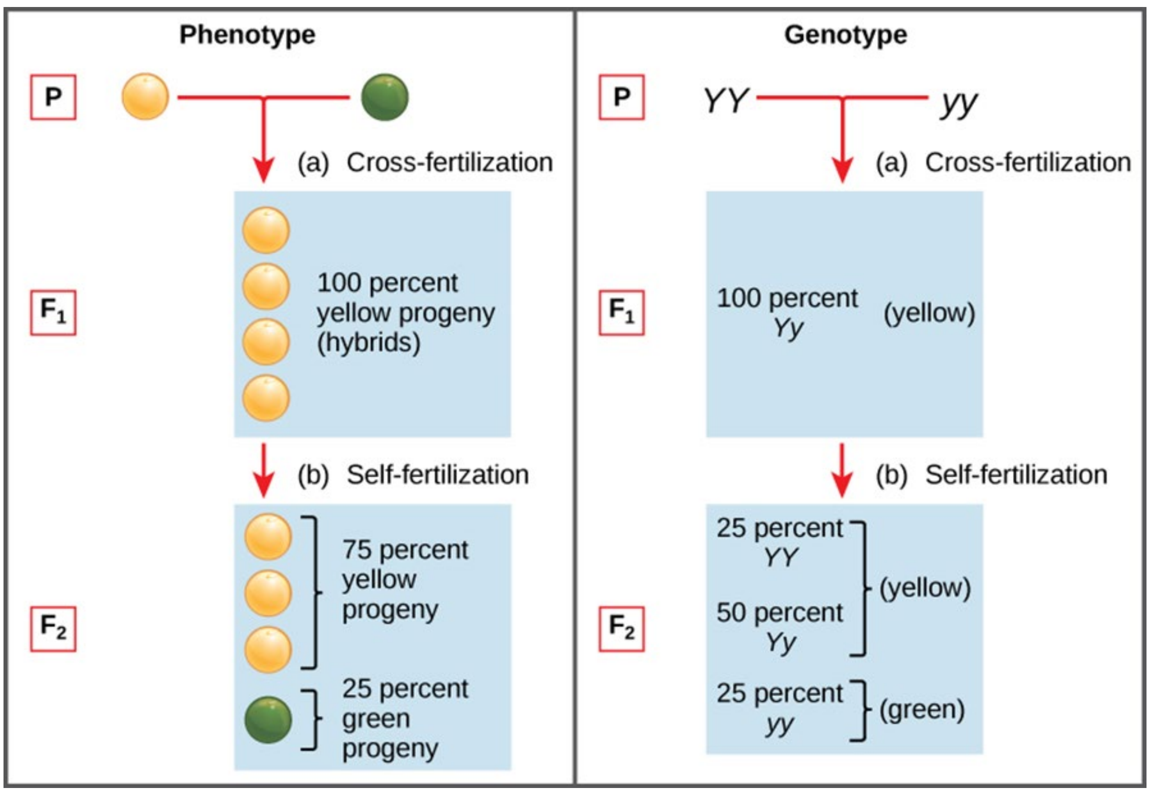


Figure 8.2.1**:** Phenotypes are physical expressions of traits that are transmitted by alleles. The phenotypic ratios are the ratios of visible characteristics. The genotypic ratios are the ratios of gene combinations in the offspring, and these are not always distinguishable in the phenotypes.

Law of Dominance

Our discussion of homozygous and heterozygous organisms brings us to why the F_1 heterozygous offspring were identical to one of the parents, rather than expressing both alleles. In all seven pea-plant characteristics, one of the two contrasting alleles was dominant, and the other was recessive. Mendel called the dominant allele the expressed unit factor; the recessive allele was referred to as the latent unit factor. We now know that these so-called unit factors are genes on homologous chromosomes. For a gene that is expressed in a dominant and recessive pattern, homozygous dominant and heterozygous organisms will look identical (that is, they will have different genotypes but the same phenotype), and the recessive allele will only be observed in homozygous recessive individuals (Table 8.2.1).

Mendel's law of dominance states that in a heterozygote, one trait will conceal the presence of another trait for the same characteristic. For example, when crossing true-breeding violet-flowered plants with true-breeding white-flowered plants, all the offspring were violet-flowered, even though they all had one allele for violet and one allele for white. Rather than both alleles contributing to a phenotype, the dominant allele will be expressed exclusively. The recessive allele will remain latent but will be transmitted to offspring in the same manner as that by which the dominant allele is transmitted. The recessive trait will only be expressed by offspring that have two copies of this allele (Figure 8.2.2), and these offspring will breed true when self-crossed.

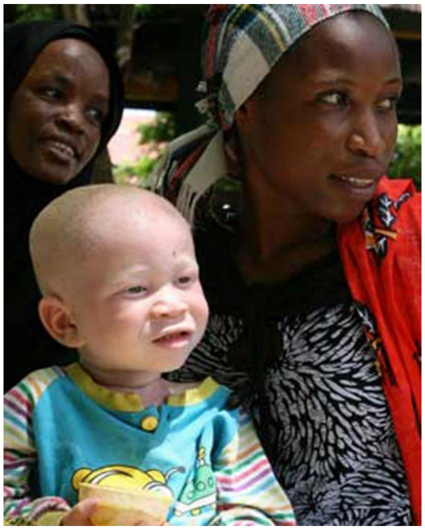


Figure 8.2.2**:** The allele for albinism, expressed here in humans, is recessive. Both of this child's parents carried the recessive allele.

Monohybrid Cross and Punnett Square

When fertilization occurs between two true-breeding parents that differ by only the characteristic being studied, the process is called a monohybrid cross, and the resulting offspring are called monohybrids. Mendel performed seven types of monohybrid crosses, each involving contrasting traits for distinctive characteristics. Out of these crosses, all the F_1 offspring had the phenotype of one parent, and the F_2 offspring had a 3:1 phenotypic ratio. Based on these results, Mendel postulated that each parent in the monohybrid cross contributed one of two paired unit factors to each offspring, and every possible combination of unit factors was equally likely.

To demonstrate this with a monohybrid cross, consider the case of true-breeding pea plants with yellow versus green seeds. The dominant seed color is yellow; therefore, the parental genotypes were *YY* for the plants with yellow seeds and *yy* for the plants with green seeds. A **Punnett square**, devised by the British geneticist Reginald Punnett, is useful for determining probabilities because it is drawn to predict all possible outcomes of all possible random fertilization events and their expected frequencies. Figure 8.2.5 shows a Punnett square for a cross between a plant with yellow peas and one with green peas. To prepare a Punnett square, all possible combinations of the parental alleles (the genotypes of the gametes) are listed along the top (for one parent) and side (for the other parent) of a grid. The combinations of egg and sperm gametes are then made in boxes in the table based on which alleles are combining. Each box then represents the diploid genotype of a zygote, or fertilized egg. Because each possibility is equally likely, genotypic ratios can be determined from a Punnett square. If the pattern of inheritance (dominant and recessive) is known, the phenotypic ratios can be inferred as well. For a monohybrid cross of two true-breeding parents, each parent contributes one type of allele. In this case, only one genotype is possible in the F_1 offspring. All offspring are *Yy* and have yellow seeds.

When the F_1 offspring are crossed with each other, each has an equal probability of contributing either a *Y* or a *y* to the F_2 offspring. The result is a 1 in 4 (25 %) probability of both parents contributing a *Y*, resulting in an offspring with a yellow phenotype; a 25 % probability of parent A contributing a *Y* and parent B a *y*, resulting in offspring with a yellow phenotype; a 25 % probability of parent A contributing a *y* and parent B a *Y*, also resulting in a yellow phenotype; and a 25 % probability of both parents contributing a *y*, resulting in a green phenotype. When counting all four possible outcomes, there is a 3 in 4 probability of offspring having the yellow phenotype and a 1 in 4 probability of offspring having the green phenotype. This explains why the results of Mendel's F_2 generation occurred in a 3:1 phenotypic ratio. Using large numbers of crosses, Mendel was able to calculate probabilities, found that they fit the model of inheritance, and use these to predict the outcomes of other crosses.

Law of Segregation

Observing that true-breeding pea plants with contrasting traits gave rise to F_1 generations that all expressed the dominant trait and F_2 generations that expressed the dominant and recessive traits in a 3:1 ratio, Mendel proposed the **law of segregation**. This law states that paired unit factors (genes) must segregate equally into gametes such that offspring have an equal likelihood of inheriting either factor. For the F_2 generation of a monohybrid cross, the following three possible combinations of genotypes result: homozygous dominant, heterozygous, or homozygous recessive. Because heterozygotes could arise from two different pathways (receiving one dominant and one recessive allele from either parent), and because heterozygotes and homozygous dominant individuals are phenotypically identical, the law supports Mendel's observed 3:1 phenotypic ratio. The equal segregation of alleles is the reason we can apply the Punnett square to accurately predict the offspring of parents with known genotypes. The physical basis of Mendel's law of segregation is the first division of meiosis in which the homologous chromosomes with their different versions of each gene are segregated into daughter nuclei. This process was not understood by the scientific community during Mendel's lifetime (Figure 8.2.3).

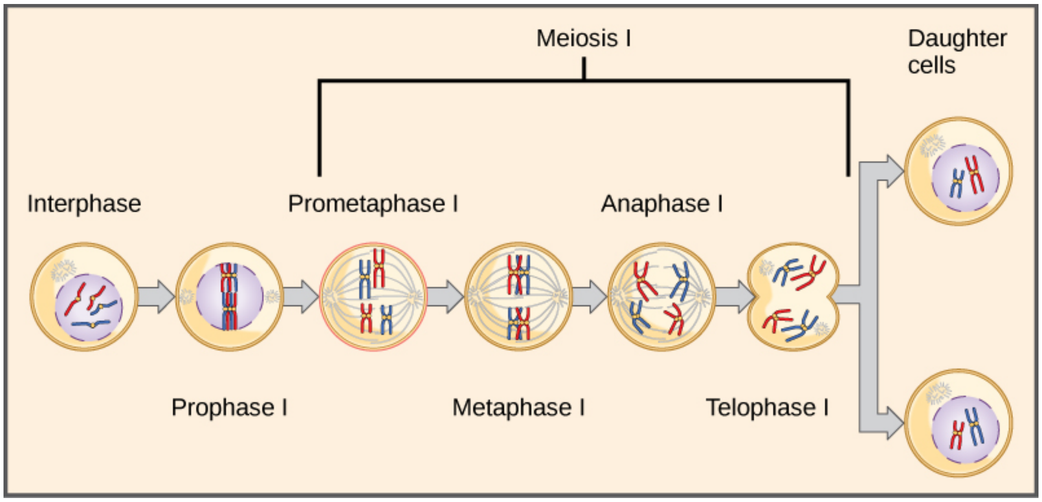


Figure 8.2.3**:** The first division in meiosis is shown.

Test Cross

Beyond predicting the offspring of a cross between known homozygous or heterozygous parents, Mendel also developed a way to determine whether an organism that expressed a dominant trait was a heterozygote or a homozygote. Called the test cross, this technique is still used by plant and animal breeders. In a test cross, the dominant-expressing organism is crossed with an organism that is homozygous recessive for the same characteristic. If the dominant-expressing organism is a homozygote, then all F_1 offspring will be heterozygotes expressing the dominant trait (Figure 8.2.4). Alternatively, if the dominant-expressing organism is a heterozygote, the F_1 offspring will exhibit a 1:1 ratio of heterozygotes and recessive homozygotes (Figure 8.2.4). The test cross further validates Mendel's postulate that pairs of unit factors segregate equally.

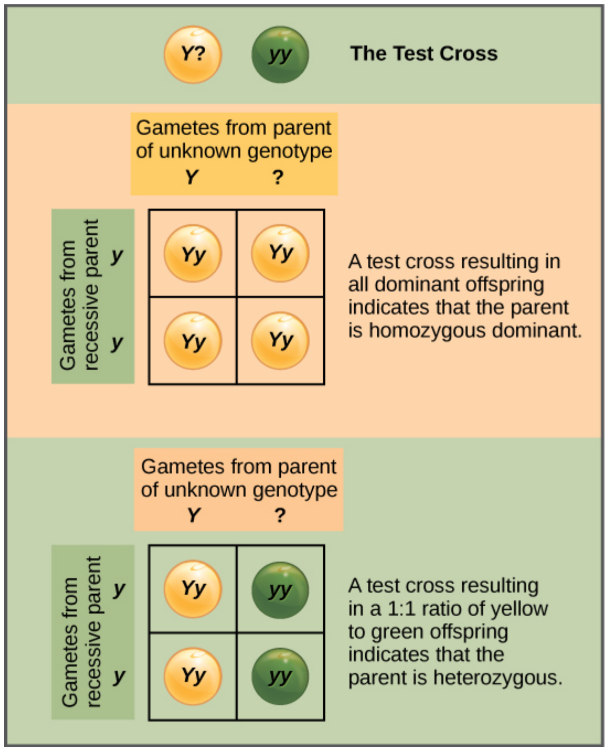


Figure 8.2.4: A test cross can be performed to determine whether an organism expressing a dominant trait is a homozygote or a heterozygote.

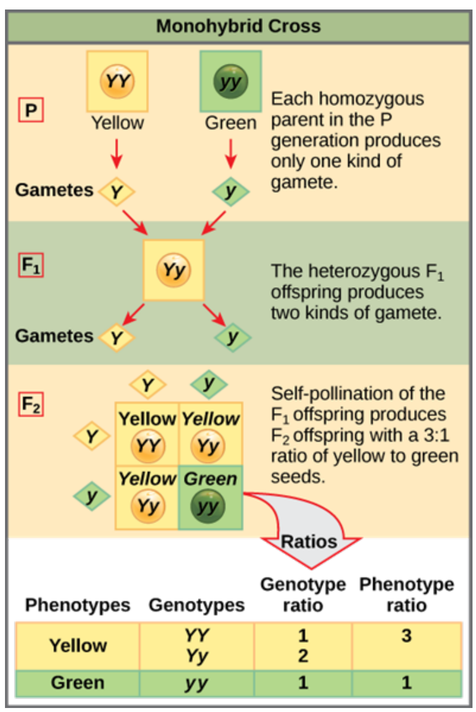


Figure 8.2.5: This Punnett square shows the cross between plants with yellow seeds and green seeds. The cross between the true-breeding P plants produces F_1 heterozygotes that can be

self-fertilized. The self-cross of the F_1 generation can be analyzed with a Punnett square to predict the genotypes of the F_2 generation. Given an inheritance pattern of dominant-recessive, the genotypic and phenotypic ratios can then be determined.

Law of Independent Assortment

Mendel's law of independent assortment states that genes do not influence each other regarding the sorting of alleles into gametes, and every possible combination of alleles for every gene is equally likely to occur. Independent assortment of genes can be illustrated by the dihybrid cross, a cross between two true-breeding parents that express different traits for two characteristics. Consider the characteristics of seed color and seed texture for two pea plants, one that has wrinkled, green seeds (*rryy*) and another that has round, yellow seeds (*RRYY*). Because each parent is homozygous, the law of segregation indicates that the gametes for the wrinkled–green plant all are *ry*, and the gametes for the round–yellow plant are all *RY*. Therefore, the F_1 generation of offspring all are *RrYy* (Figure 8.2.6).

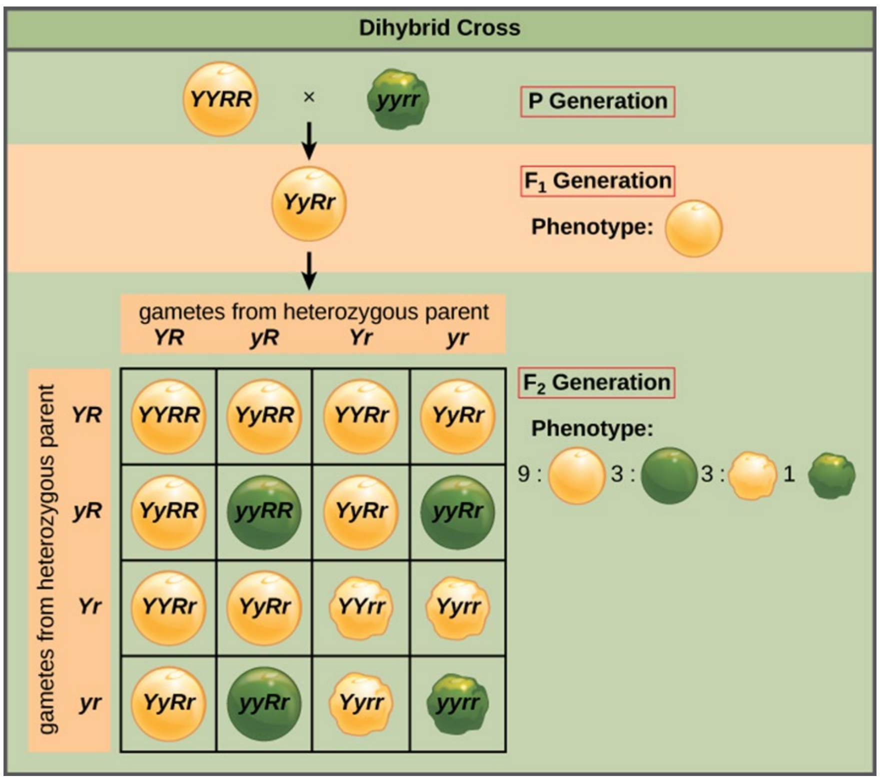


Figure 8.2.6: A dihybrid cross in pea plants involves the genes for seed color and texture. The P cross produces F_1 offspring that are all heterozygous for both characteristics. The resulting 9:3:3:1 F2 phenotypic ratio is obtained using a Punnett square.

The gametes produced by the F_1 individuals must have one allele from each of the two genes. For example, a gamete could get an *R* allele for the seed shape gene and either a *Y* or a *y* allele for the seed color gene. It cannot get both an *R* and an *r* allele; each gamete can have only one allele per gene. The law of independent assortment states that a gamete into which an *r* allele is sorted would be equally likely to contain either a *Y* or a *y* allele. Thus, there are four equally likely gametes that can be formed when the *RrYy* heterozygote is self-crossed, as follows: *RY*, *rY*, *Ry*, and *ry*. Arranging these gametes along the top and left of a 4 × 4 Punnett square (Figure 8.2.6) gives us 16 equally likely genotypic combinations. From these genotypes, we find a phenotypic ratio of 9 round–yellow:3 round–green:3 wrinkled–yellow:1 wrinkled–green (Figure 8.2.6). These are the offspring ratios we would expect, assuming we performed the crosses with a large enough sample size.

The physical basis for the law of independent assortment also lies in meiosis I, in which the different homologous pairs line up in random orientations. Each gamete can contain any combination of paternal and maternal chromosomes (and therefore the genes on them) because the orientation of tetrads on the metaphase plane is random (Figure 8.2.7).

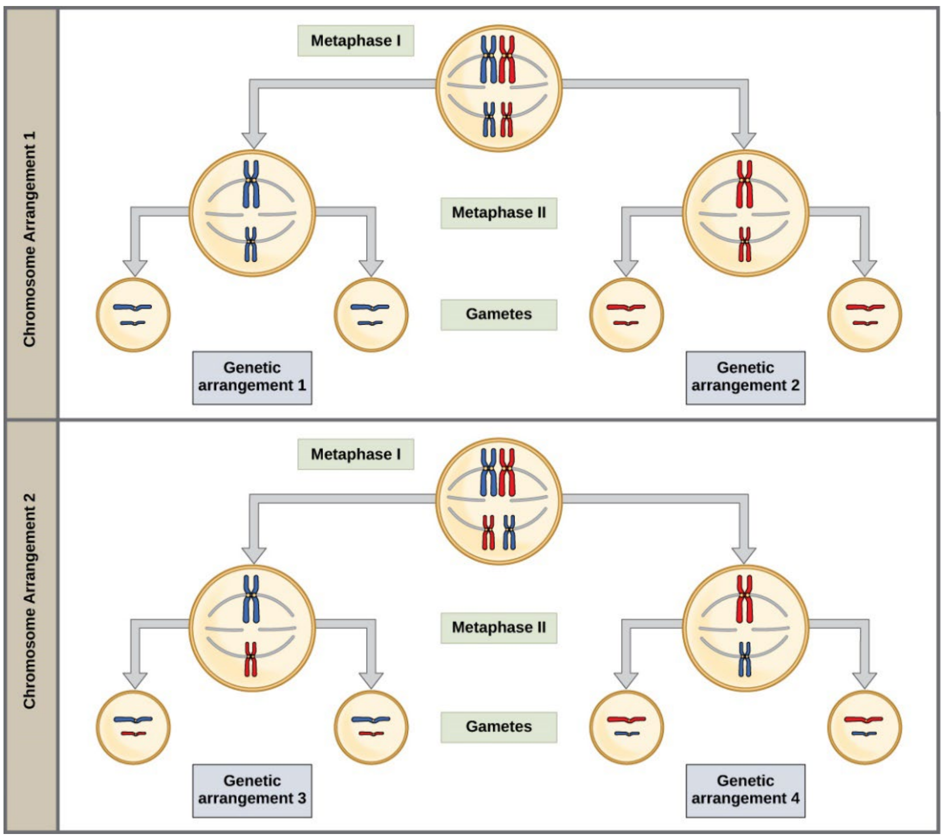


Figure 8.2.7**:** The random segregation into daughter nuclei that happens during the first division in meiosis can lead to a variety of possible genetic arrangements.

DNA

The building blocks of deoxyribonucleic acid, DNA, are nucleotides, which are made up of three parts: a deoxyribose (5-carbon sugar), a phosphate group, and a nitrogenous base (Figure 9.1.2). There are four types of nitrogenous bases in DNA. Adenine (A) and guanine (G) are double-ringed purines, and cytosine (C) and thymine (T) are smaller, single-ringed pyrimidines. The nucleotide is named according to the nitrogenous base it contains.

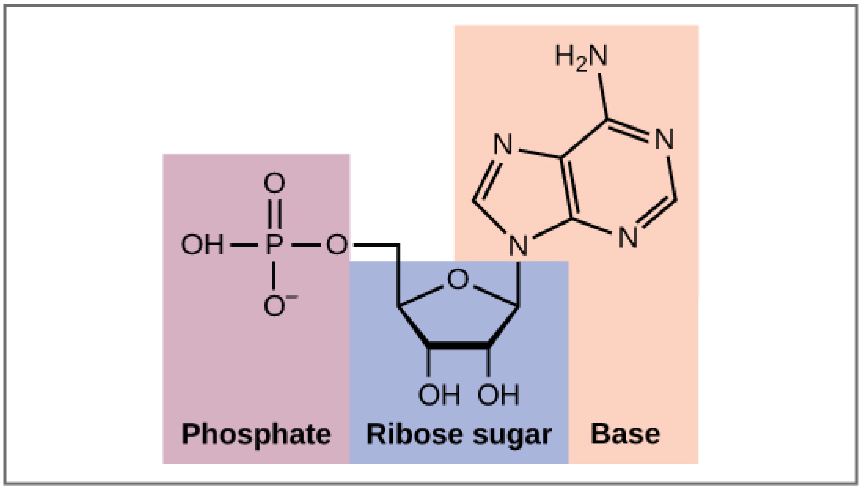


Figure 9.1.2**:** (a) Each DNA nucleotide is made up of a sugar, a phosphate group, and a base.

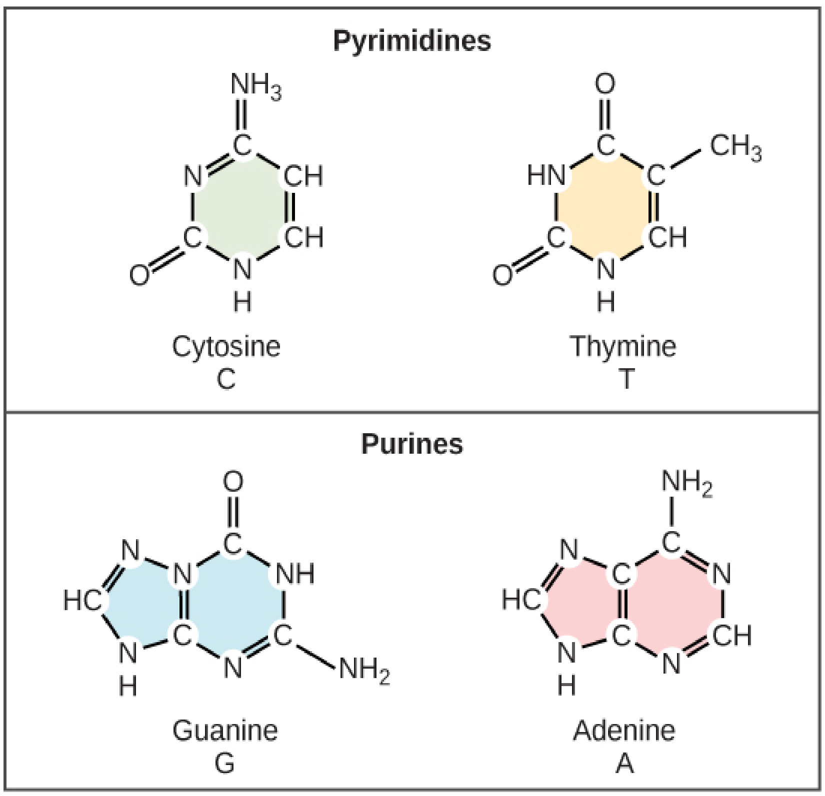


Figure 9.1.2: (b) Cytosine and thymine are pyrimidines. Guanine and adenine are purines.

The phosphate group of one nucleotide bonds covalently with the sugar molecule of the next nucleotide, and so on, forming a long polymer of nucleotide monomers. The sugar–phosphate groups line up in a “backbone” for each single strand of DNA, and the nucleotide bases stick out from this backbone. The carbon atoms of the five-carbon sugar are numbered clockwise from the oxygen as 1', 2', 3', 4', and 5' (1' is read as "one prime"). The phosphate group is attached to the 5' carbon of one nucleotide and the 3' carbon of the next nucleotide. In its natural state, each DNA molecule is composed of two single strands held together along their length with hydrogen bonds between the bases.

Watson and Crick proposed that the DNA is made up of two strands that are twisted around each other to form a right-handed helix, called a double helix. Base-pairing takes place between a purine and pyrimidine: namely, A pairs with T, and G pairs with C. In other words, adenine and thymine are complementary base pairs, and cytosine and guanine are also complementary base pairs. Because of their complementarity, there is as much adenine as thymine in a DNA molecule and as much guanine as cytosine. Adenine and thymine are connected by two hydrogen bonds, and cytosine and guanine are connected by three hydrogen bonds. The two strands are anti-parallel in nature; that is, one strand will have the 3' carbon of the sugar in the "upward" position, whereas the other strand will have the 5' carbon in the upward position. The diameter of the DNA double helix is uniform throughout because a purine (two rings) always pairs with a pyrimidine (one ring) and their combined lengths are always equal. (Figure 9.1.3).

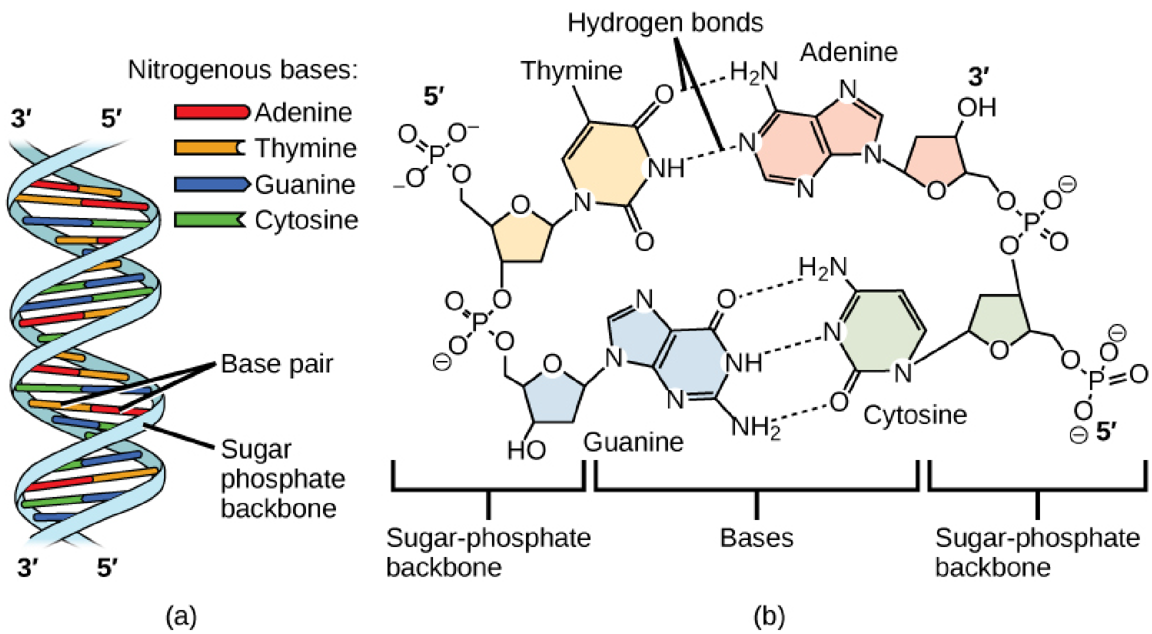


Figure 9.1.3**:** DNA (a) forms a double stranded helix, and (b) adenine pairs with thymine and cytosine pairs with guanine. (Credit: modification of work by Jerome Walker, Dennis Myts)

The Structure of RNA

There is a second nucleic acid in all cells called ribonucleic acid, or RNA. Like DNA, RNA is a polymer of nucleotides. Each of the nucleotides in RNA is made up of a nitrogenous base, a five-carbon sugar, and a phosphate group. In the case of RNA, the five-carbon sugar is ribose, not deoxyribose. Ribose has a hydroxyl group at the 2' carbon, unlike deoxyribose, which has only a hydrogen atom (Figure 9.1.4).

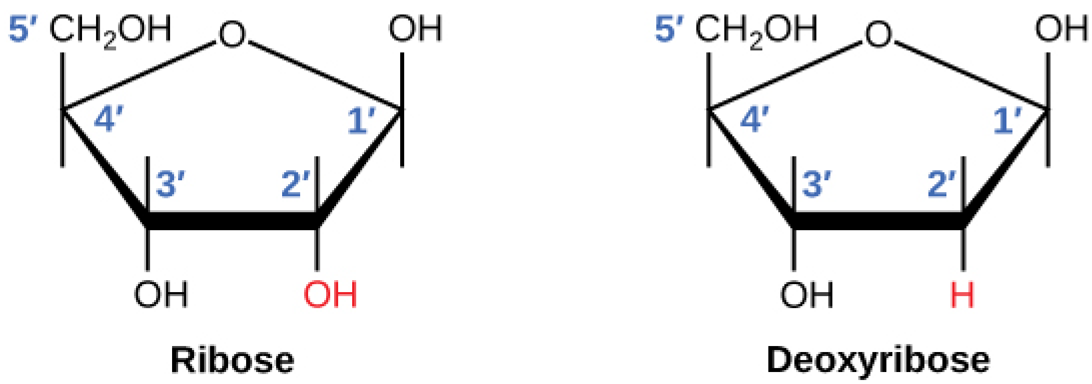


Figure 9.1.4**:** The difference between the ribose found in RNA and the deoxyribose found in DNA is that ribose has a hydroxyl group at the 2' carbon.

RNA nucleotides contain the nitrogenous bases adenine, cytosine, and guanine. However, they do not contain thymine, which is instead replaced by uracil, symbolized by a “U.” RNA exists as a single-stranded molecule rather than a double-stranded helix. Molecular biologists have named several kinds of RNA based on their function. These include messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA)—molecules that are involved in the production of proteins from the DNA code.

How DNA is Arranged in the Cell

DNA is a working molecule; it must be replicated when a cell is ready to divide, and it must be “read” to produce the molecules, such as proteins, to carry out the functions of the cell. For this reason, the DNA is protected and packaged in very specific ways. In addition, DNA molecules can be very long. Stretched end-to-end, the DNA molecules in a single human cell would come to a length of about 2 meters. Thus, the DNA for a cell must be packaged in a very ordered way to fit and function within a structure (the cell) that is not visible to the naked eye. The chromosomes of prokaryotes are much simpler than those of eukaryotes in many of their features (Figure 9.1.5). Most prokaryotes contain a single, circular chromosome that is found in an area in the cytoplasm called the nucleoid.

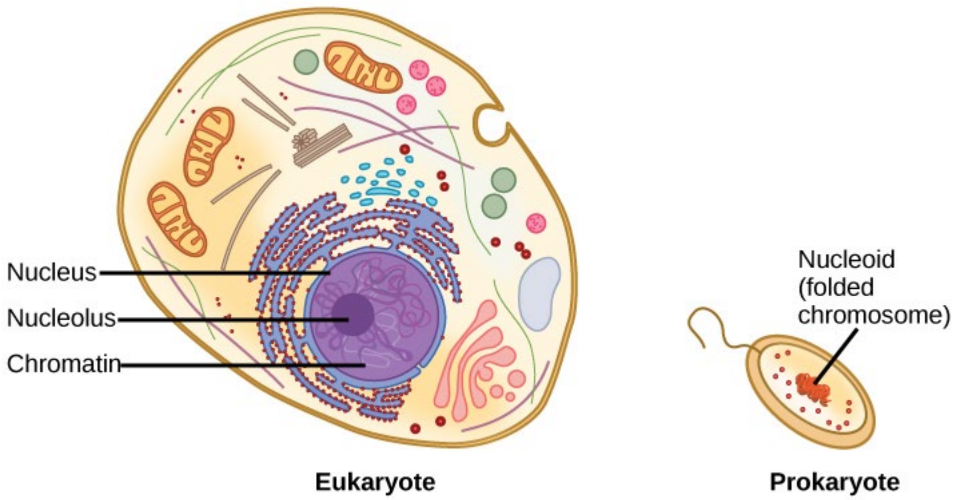


Figure 9.1.5**:** A eukaryote contains a well-defined nucleus, whereas in prokaryotes, the chromosome lies in the cytoplasm in an area called the nucleoid.

The size of the genome in one of the most well-studied prokaryotes, *Escherichia coli,* is 4.6 million base pairs, which would extend about 1.6 mm if stretched out. So how does this fit inside a small bacterial cell? The DNA is twisted beyond the double helix in what is known as supercoiling. Some proteins are known to be involved in the supercoiling; other proteins and enzymes help in maintaining the supercoiled structure.

Eukaryotes, whose chromosomes each consist of a linear DNA molecule, employ a different type of packing strategy to fit their DNA inside the nucleus (Figure 9.1.6). At the most basic level, DNA is wrapped around proteins known as histones to form structures called nucleosomes. The DNA is wrapped tightly around the histone core. This nucleosome is linked to the next one by a short strand of DNA that is free of histones. This is also known as the “beads on a string” structure; the nucleosomes are the “beads” and the short lengths of DNA between them are the “string.” The nucleosomes, with their DNA coiled around them, stack compactly onto each other to form a 30 nanometer (nm) wide fiber. This fiber is further coiled into a thicker and more compact structure. At the metaphase stage of mitosis, when the chromosomes are lined up in the center of the cell, the chromosomes are at their most compact. They are approximately 700 nm in width and are found in association with scaffold proteins.

In interphase, the phase of the cell cycle between mitoses at which the chromosomes are decondensed, eukaryotic chromosomes have two distinct regions that can be distinguished by staining. There is a tightly packaged region that stains darkly, and a less dense region. The darkly staining regions usually contain genes that are not active and are found in the regions of the centromere and telomeres. The lightly staining regions usually contain genes that are active, with DNA packaged around nucleosomes but not further compacted.

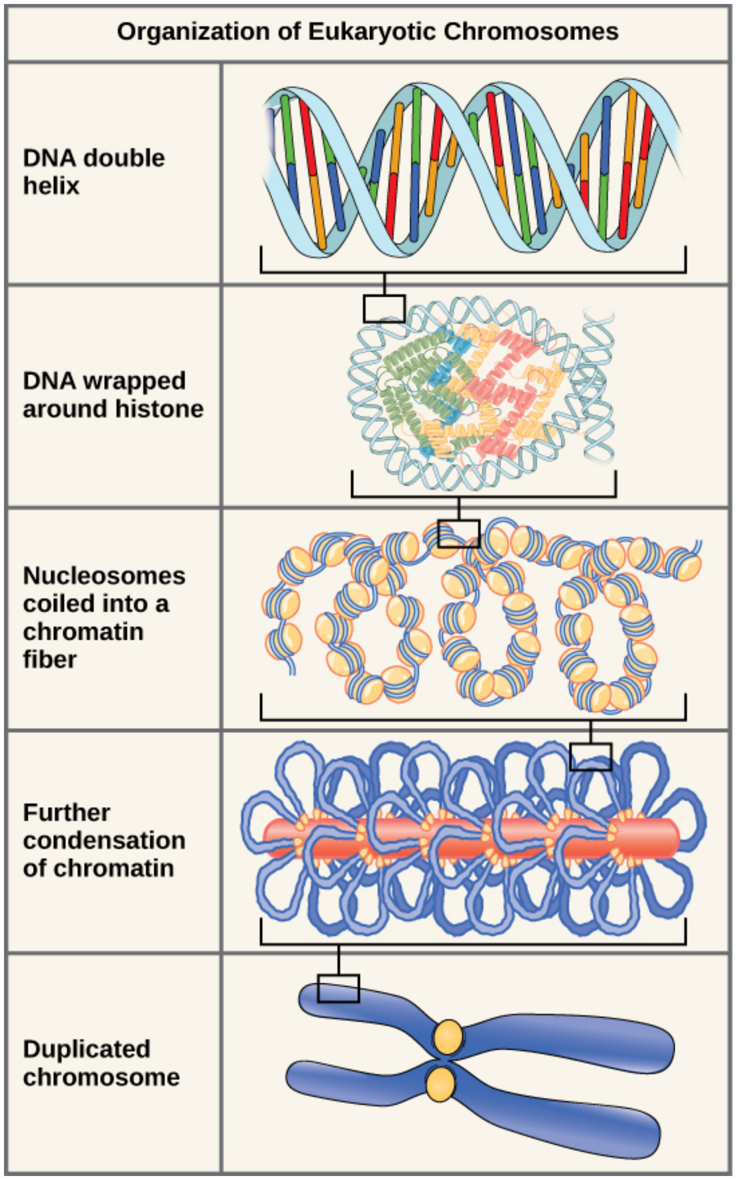


Figure 9.1.6**:** These figures illustrate the compaction of the eukaryotic chromosome.

Biotechnology

Biotechnology is the use of artificial methods to modify the genetic material of living organisms or cells to produce novel compounds or to perform new functions. Biotechnology has been used for improving livestock and crops since the beginning of agriculture through selective breeding. Since the discovery of the structure of DNA in 1953, and particularly since the development of tools and methods to manipulate DNA in the 1970s, biotechnology has become synonymous with the manipulation of organisms' DNA at the molecular level. The primary applications of this technology are in medicine (to produce vaccines and antibiotics) and in agriculture (for the genetic modification of crops). Biotechnology also has many industrial applications, such as fermentation, the treatment of oil spills, and the production of biofuels, as well as many household applications such as the use of enzymes in laundry detergent.

Manipulating Genetic Material

To accomplish the applications described above, biotechnologists must be able to extract, manipulate, and analyze nucleic acids.

Review of Nucleic Acid Structure

To understand the basic techniques used to work with nucleic acids, remember that nucleic acids are macromolecules made of nucleotides (a sugar, a phosphate, and a nitrogenous base). The phosphate groups on these molecules each have a net negative charge. A complete set of DNA molecules in the nucleus of eukaryotic organisms is called the genome. DNA has two complementary strands linked by hydrogen bonds between the paired bases.

Unlike DNA in eukaryotic cells, RNA molecules leave the nucleus. Messenger RNA (mRNA) is analyzed most frequently because it represents the protein-coding genes that are being expressed in the cell.

Isolation of Nucleic Acids

To study or manipulate nucleic acids, the DNA must first be extracted from cells. Various techniques are used to extract different types of DNA (Figure 10.1.1). Most nucleic acid extraction techniques involve steps to break open the cell, and then the use of enzymatic reactions to destroy all undesired macromolecules. Cells are broken open using a detergent solution containing buffering compounds. To prevent degradation and contamination, macromolecules such as proteins and RNA are inactivated using enzymes. The DNA is then brought out of solution using alcohol. The resulting DNA, because it is made up of long polymers, forms a gelatinous mass.

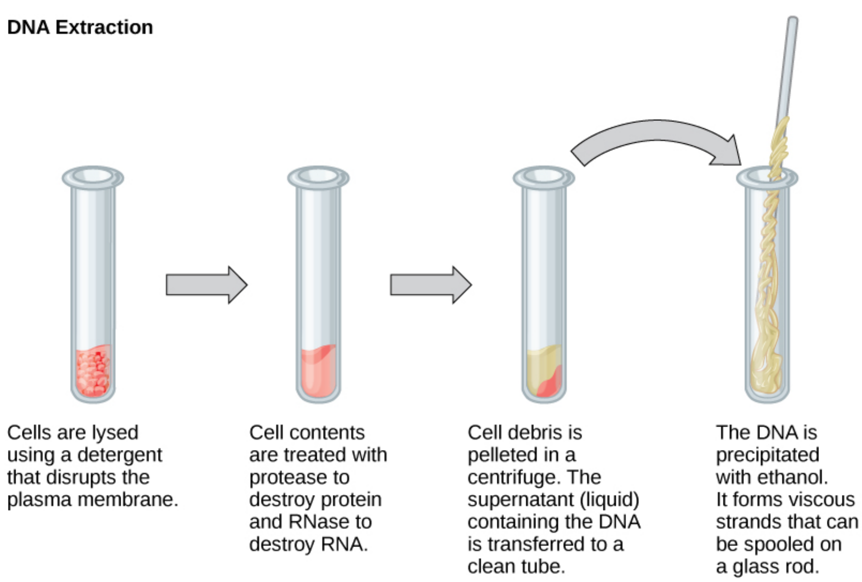


Figure 10.1.1**:** This diagram shows the basic method used for the extraction of DNA.

RNA is studied to understand gene expression patterns in cells. RNA is naturally very unstable because enzymes that break down RNA are commonly present in nature. Some are even secreted by our own skin and are difficult to inactivate. Like DNA extraction, RNA extraction involves the use of various buffers and enzymes to inactivate other macromolecules and preserve only the RNA.

Polymerase Chain Reaction

DNA analysis often requires focusing on one or more specific regions of the genome. It also frequently involves situations in which only one or a few copies of a DNA molecule are available for further analysis. These amounts are insufficient for most procedures. Polymerase chain reaction (PCR)is a technique used to rapidly increase the number of copies of specific regions of DNA for further analyses (Figure 10.1.3). PCR uses a special form of DNA polymerase, the enzyme that replicates DNA, and other short nucleotide sequences called primers that base pair to a specific portion of the DNA being replicated. PCR is used for many purposes in laboratories; for instance: 1) the identification of the owner of a DNA sample left at a crime scene, 2) paternity analysis, 3) the comparison of tiny amounts of ancient DNA with modern organisms, and 4) determining the sequence of nucleotides in a specific region.

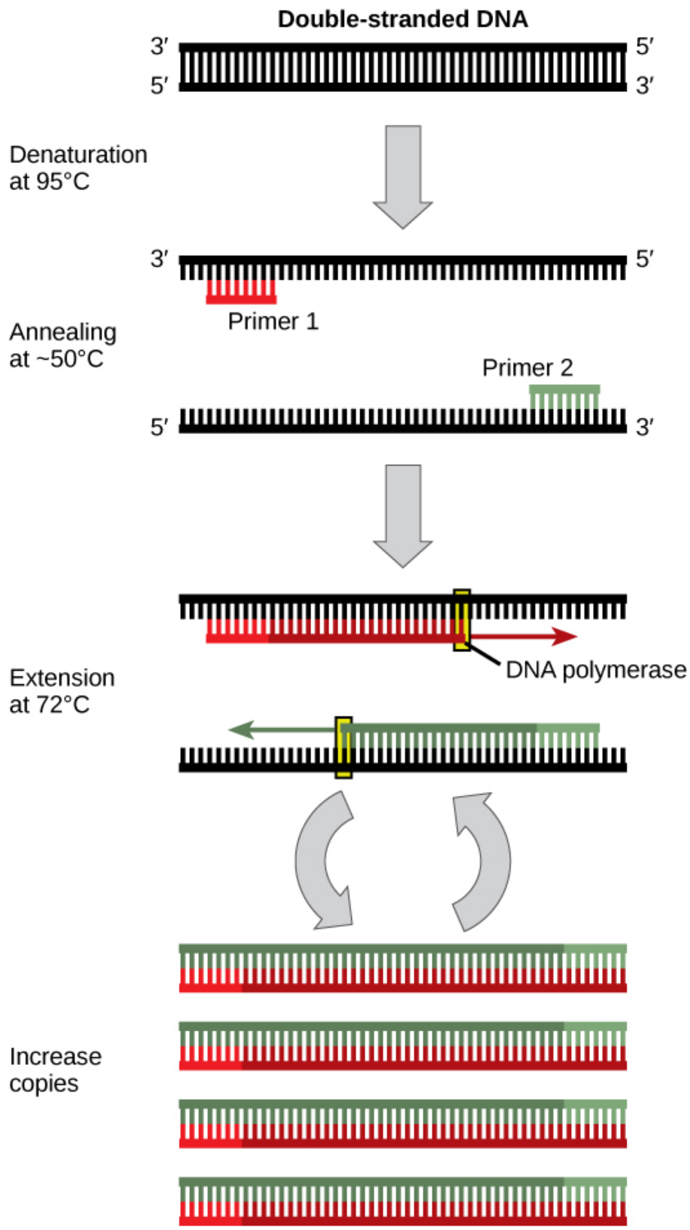


Figure 10.1.3**:** Polymerase chain reaction, or PCR, is used to produce many copies of a specific sequence of DNA using a special form of DNA polymerase.

Cloning

In general, cloning means the creation of a perfect replica. Typically, the word is used to describe the creation of a genetically identical copy. In biology, the re-creation of a whole organism is referred to as "reproductive cloning." Long before attempts were made to clone an entire organism, researchers learned how to copy short stretches of DNA—a process that is referred to as molecular cloning.

Molecular Cloning

Cloning allows for the creation of multiple copies of genes, expression of genes, and study of specific genes. To get the DNA fragment into a bacterial cell in a form that will be copied or expressed, the fragment is first inserted into a plasmid. A plasmid (also called a vector in this context) is a small circular DNA molecule that replicates independently of the chromosomal DNA in bacteria. In cloning, the plasmid molecules can be used to provide a "vehicle" in which to insert a desired DNA fragment. Modified plasmids are usually reintroduced into a bacterial host for replication. As the bacteria divide, they copy their own DNA (including the plasmids). The inserted DNA fragment is copied along with the rest of the bacterial DNA. In a bacterial cell, the fragment of DNA from the human genome (or another organism that is being studied) is referred to as foreign DNA to differentiate it from the DNA of the bacterium (the host DNA).

Plasmids occur naturally in bacterial populations (such as *Escherichia coli*) and have genes that can contribute favorable traits to the organism, such as antibiotic resistance. Plasmids have been highly engineered as vectors for molecular cloning and for the subsequent large-scale production of important molecules, such as insulin. A valuable characteristic of plasmid vectors is the ease with which a foreign DNA fragment can be introduced. These plasmid vectors contain many short DNA sequences that can be cut with different commonly available restriction enzymes. Restriction enzymes (also called restriction endonucleases) recognize specific DNA sequences and cut them in a predictable manner; they are naturally produced by bacteria as a defense mechanism against foreign DNA. Many restriction enzymes make staggered cuts in the two strands of DNA, such that the cut ends have a 2- to 4-nucleotide single-stranded overhang. The sequence that is recognized by the restriction enzyme is a four- to eight-nucleotide sequence that is a palindrome. Like with a word palindrome, this means the sequence reads the same forward and backward. In most cases, the sequence reads the same forward on one strand and backward on the complementary strand. When a staggered cut is made in a sequence like this, the overhangs are complementary (Figure 10.1.4).

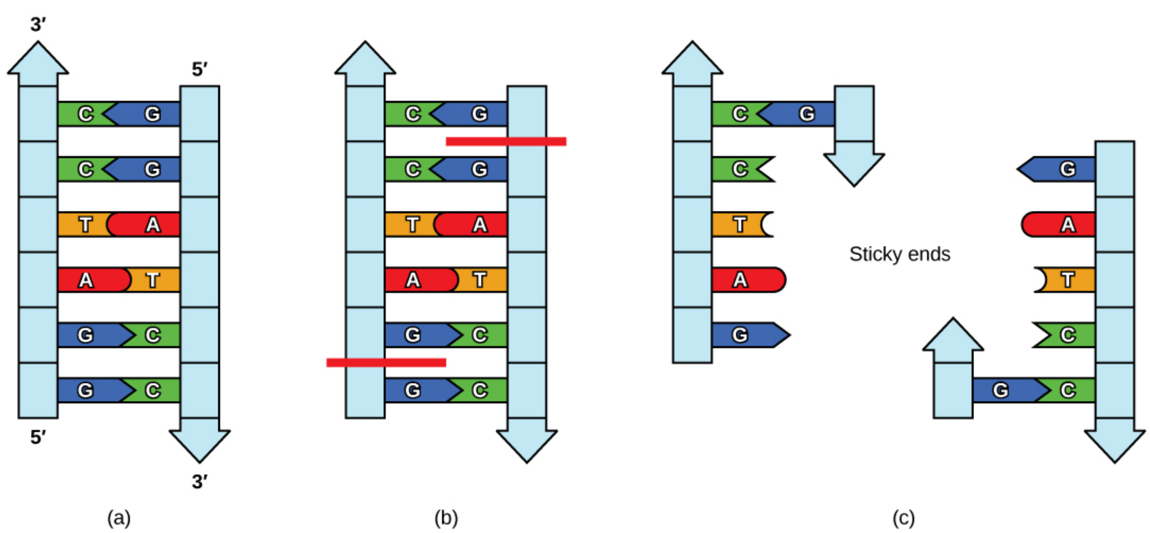


Figure 10.1.4**:** In this (a) six-nucleotide restriction enzyme recognition site, notice that the sequence of six nucleotides reads the same in the 5' to 3' direction on one strand as it does in the 5' to 3' direction on the complementary strand. This is known as a palindrome. (b) The restriction enzyme makes breaks in the DNA strands, and (c) the cut in the DNA results in "sticky ends." Another piece of DNA cut on either end by the same restriction enzyme could attach to these sticky ends and be inserted into the gap made by this cut.

Because these overhangs can come back together by hydrogen bonding with complementary overhangs on a piece of DNA cut with the same restriction enzyme, these are called "sticky ends." The process of forming hydrogen bonds between complementary sequences on single strands to form double-stranded DNA is called annealing. Addition of an enzyme called DNA ligase, which takes part in DNA replication in cells, permanently joins the DNA fragments when the sticky ends come together. In this way, any DNA fragment can be spliced between the two ends of a plasmid DNA that has been cut with the same restriction enzyme (Figure 10.1.5).

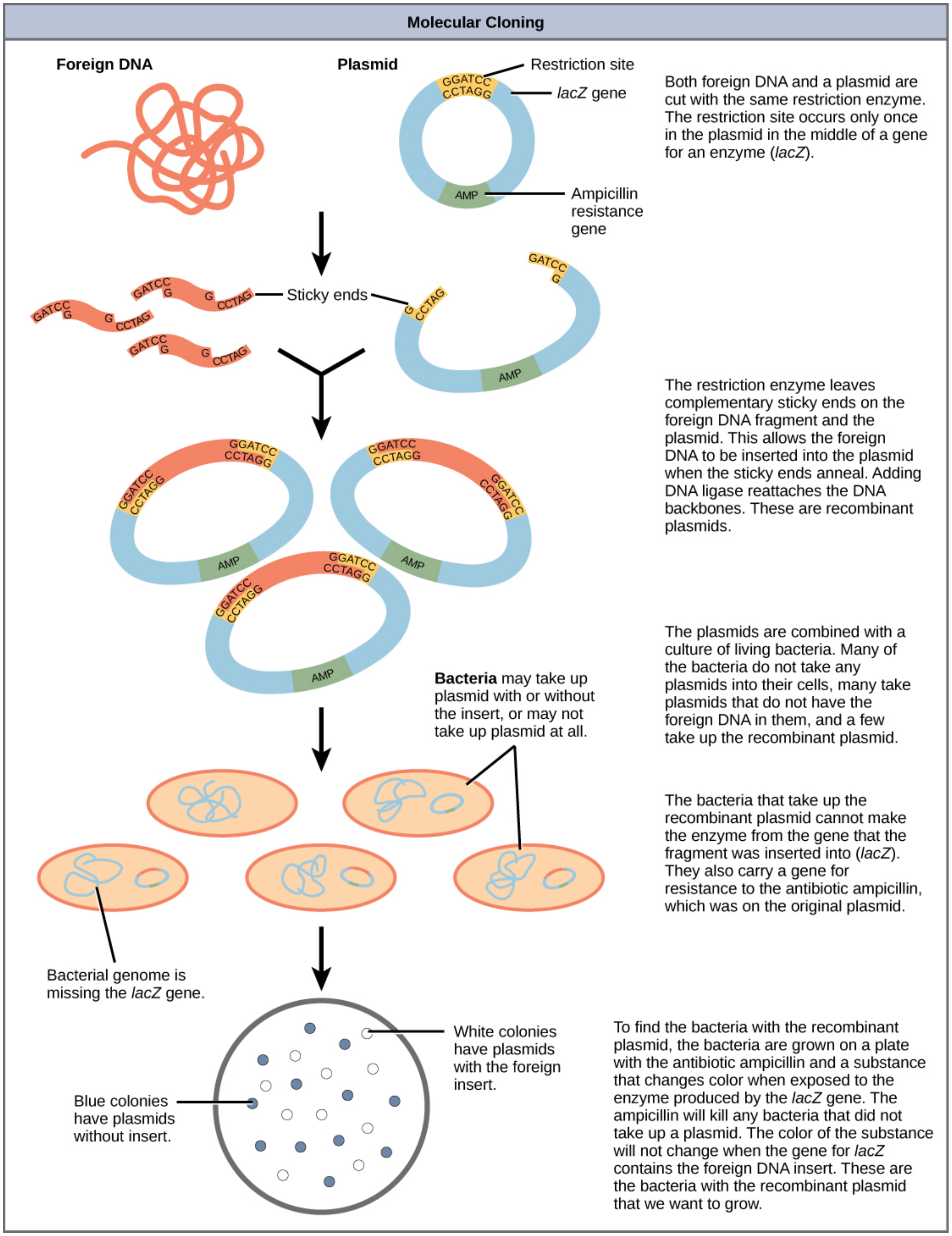


Figure 10.1.5**:** This diagram shows the steps involved in molecular cloning.

Plasmids with foreign DNA inserted into them are called recombinant DNA molecules because they contain new combinations of genetic material. Proteins that are produced from recombinant DNA molecules are called recombinant proteins. Not all recombinant plasmids can express genes. Plasmids may also be engineered to express proteins only when stimulated by certain environmental factors, so that scientists can control the expression of the recombinant proteins.

Reproductive Cloning

Reproductive cloning is a method used to make a clone or an identical copy of an entire multicellular organism. Most multicellular organisms undergo reproduction by sexual means, which involves the contribution of DNA from two individuals (parents), making it impossible to generate an identical copy or a clone of either parent. Recent advances in biotechnology have made it possible to reproductively clone mammals in the laboratory.

Natural sexual reproduction involves the union, during fertilization, of a sperm and an ovum. Each of these gametes is haploid, meaning they contain one set of chromosomes in their nuclei. The resulting cell, or zygote, is then diploid and contains two sets of chromosomes. This cell divides mitotically to produce a multicellular organism. However, the union of just any two cells cannot produce a viable zygote; there are components in the cytoplasm of the egg cell that are essential for the early development of the embryo during its first few cell divisions. Without these provisions, there would be no subsequent development. Therefore, to produce a new individual, both a diploid genetic complement and an egg cytoplasm are required. The approach to producing an artificially cloned individual is to take the egg cell of one individual and to remove the haploid nucleus. Then a diploid nucleus from a body cell of a second individual, the donor, is put into the egg cell. The egg is then stimulated to divide so that development proceeds. This sounds simple, but in fact it takes many attempts before each of the steps is completed successfully.

The first cloned agricultural animal was Dolly, a sheep who was born in 1996. The success rate of reproductive cloning at the time was very low. Dolly lived for six years and died of a lung tumor (Figure 10.1.6). There was speculation that because the cell DNA that gave rise to Dolly came from an older individual, the age of the DNA may have affected her life expectancy. Since Dolly, several species of animals (such as horses, bulls, and goats) have been successfully cloned.

There have been attempts at producing cloned human embryos as sources of embryonic stem cells. In the procedure, the DNA from an adult human is introduced into a human egg cell, which is then stimulated to divide. The technology is like the technology that was used to produce Dolly, but the embryo is never implanted into a surrogate mother. The cells produced are called embryonic stem cells because they have the capacity to develop into many kinds of cells, such as muscle or nerve cells. The stem cells could be used to research and provide therapeutic applications, such as replacing damaged tissues. The benefit of cloning in this instance is that the cells used to regenerate new tissues would be a perfect match to the donor of the original DNA. For example, a leukemia patient would not require a sibling with a tissue match for a bone-marrow transplant.

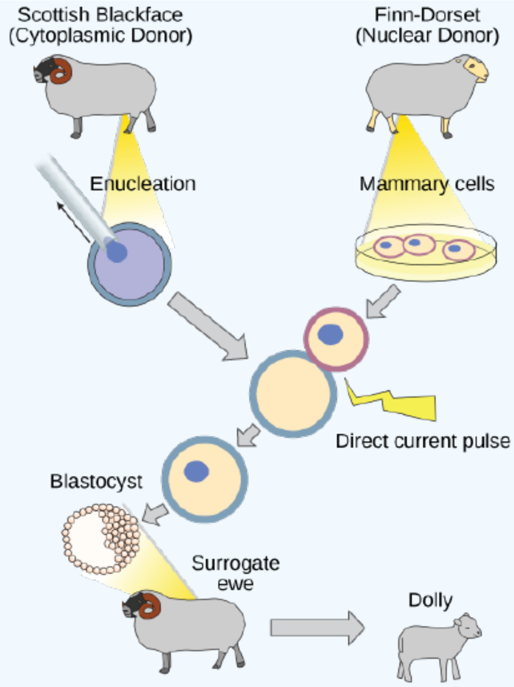


Figure 10.1.6**:** Dolly the sheep was the first agricultural animal to be cloned. To create Dolly, the nucleus was removed from a donor egg cell. The enucleated egg was placed next to the other cell, then they were shocked to fuse. They were shocked again to start division. The cells were allowed to divide for several days until an early embryonic stage was reached, before being implanted in a surrogate mother.

Genetic Engineering

Using recombinant DNA technology to modify an organism's DNA to achieve desirable traits is called genetic engineering. Addition of foreign DNA in the form of recombinant DNA vectors that are generated by molecular cloning is the most common method of genetic engineering. An organism that receives recombinant DNA is called a genetically modified organism (GMO). If the foreign DNA that is introduced comes from a different species, the host organism is called transgenic. Bacteria, plants, and animals have been genetically modified since the early 1970s for academic, medical, agricultural, and industrial purposes.

Human Body

Skeleton

Axial skeleton

The bones of the human body can be divided into two broad groups, the **axial skeleton,** and the **appendicular skeleton**. The axial skeleton comprises the bones found along the central axis traveling down the center of the body. The appendicular skeleton comprises the bones appended to the central axis.

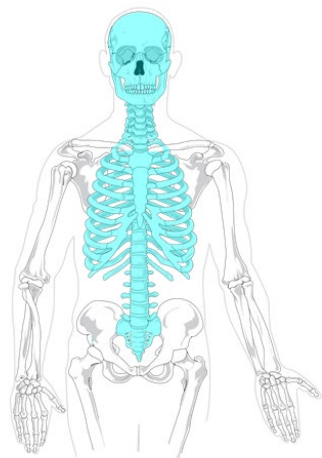


Figure 5.1.1: The axial skeleton highlighted in blue (Public Domain, LadyofHats Mariana Ruiz Villarreal, Wikimedia)

The axial skeleton consists of the bones of the **skull**, the bones of the **inner ear** (known as ossicles), the **hyoid bone** in the throat, and the bones of the **vertebral column**, including the **sacrum and coccyx** bones in the center of the pelvic girdle.

1) **The Bones of the Skull: There** is only one movable joint in the skull. That is the joint connecting the lower jaw, or mandible, to the rest of the skull. All the other bones in the skull are firmly attached to one another by **sutures**.

Sutures are rigid immovable connections holding bones tightly to one another. Some of the sutures in the skull take a few months-to-years after birth to completely form.

The brain is encased in the **cranium** of the skull. The bones that make up the cranium are called cranial **bones**. The remainder of the bones in the skull is facial **bones**.

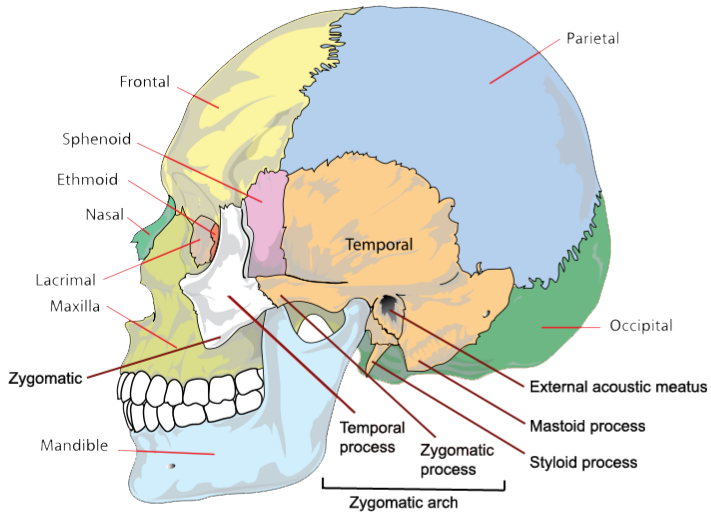


Figure 5.1.2: The bones of the skull, left lateral view. (Public Domain, LadyofHats Mariana Ruiz Villarreal, Wikimedia)

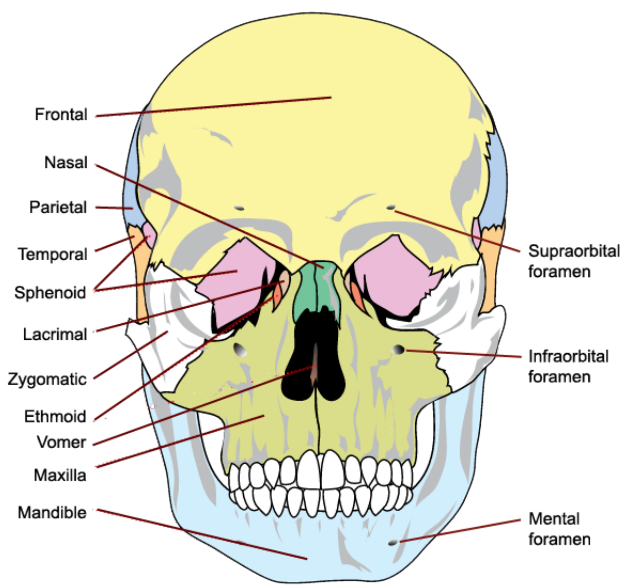


Figure 5.1.3: The bones of the skull, anterior view. (Public Domain, Wikimedia)

2) **The Hyoid Bone**: The hyoid bone in the neck is the only bone in the body that does not articulate directly with at least one other bone. It is U-shaped and is held in place by, and helps anchor, muscles that connect to the floor of the mouth and the tongue. It helps provide greater movement of the tongue and larynx, and so is crucial to human speech.

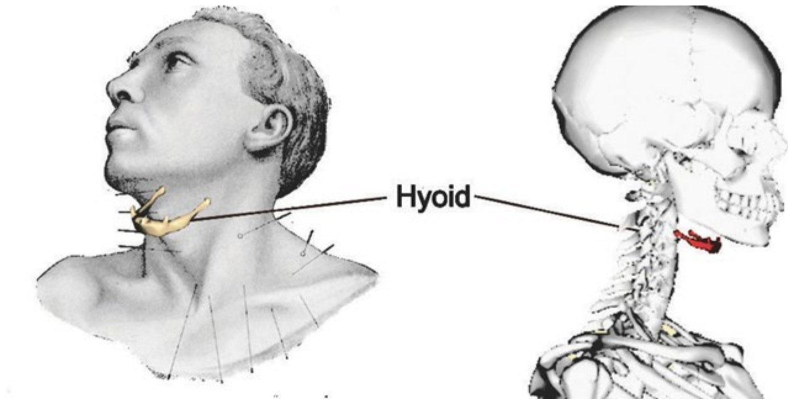


Figure 5.2.1: The hyoid bone. (CC-BY-SA, Was a bee, Wikimedia)

3) **The vertebral column** is more colloquially called the backbone or the spine. It consists of 24 **vertebrae** bones, and two bones from the axial section of the pelvic girdle, the **sacrum** and the **coccyx**.

The vertebrae are divided into three groups. There are **seven cervical vertebrae** (C1 through C7), **twelve thoracic vertebrae** (T1 through T12), and **five lumbar vertebrae** (L1 through L5).

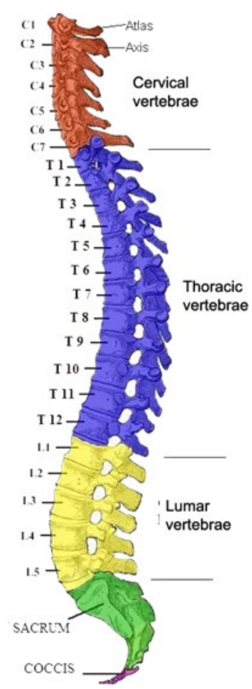


Figure 5.2.2: The bones of the vertebral column. (CC-BY-SA, Henry Grey, Henry Vandyke Carter, Wikimedia)

4) The **sacrum** is part of both the vertebral column and the pelvic girdle. It articulates with the intervertebral disc under the L5 vertebra above it, and with two coxal bones lateral to it.

The sacrum starts out as five vertebrae that fuse to form the one structure. This fusion is not complete until somewhere between the 18th and 30th year.

5) The **coccyx** is a vestigial tailbone. It is the evolutionary remnant of an ancestral species to humans that did have tails. It no longer serves as a functional tail, but some muscles, tendons, and ligaments do attach to it, making it useful. It forms from the fusion of usually three vertebrae, but a small proportion of the population have four or even five vertebrae in their coccyx.

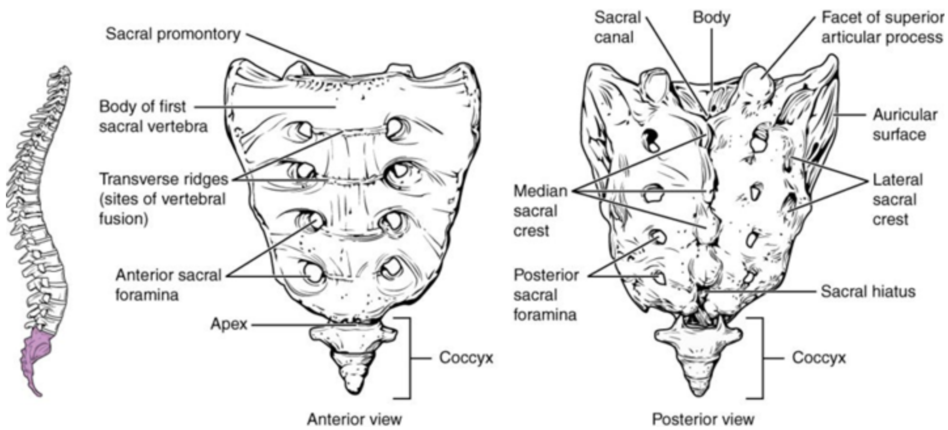


Figure 5.2.4: The sacrum and coccyx. (CC-BY-SA, OpenStax College, OpenStax)

6) **The Thoracic Cage – Ribs and Sternum**: The thoracic cage surrounds and protects the heart and lungs in the thoracic cavity. It consists of the ribs, the sternum, and the thoracic vertebrae, to which the ribs articulate.

There are twelve pairs of ribs. The number is the same in both males and females. Each pair articulates with a different thoracic vertebra on the posterior side of the body. The most superior rib is designated rib 1 and it articulates with the T1 thoracic vertebrae. The rib below is rib 2, and it connects to the T2 thoracic vertebra, and so on. Ten of the twelve ribs connect to strips of hyaline cartilage on the anterior side of the body. The cartilage strips are called **costal cartilage** ("costal" is the anatomical adjective that refers to the rib) and connect on their other end to the sternum.

On an individual rib, one end has various processes, facets, and bumps. This is the end that articulates with the vertebra. The other end is blunt and smooth. This is the end that connects to costal cartilage (unless it is a floating rib. See below.)

The **sternum** has three parts: 1) The **manubrium**, at the superior end of the sternum, and wider than the rest of the bone, provides articulation points for the clavicles and for the costal cartilage extending from rib 1. 2) The central, thin **body** provides articulation points for costal cartilage from ribs 2 through 7. 3) The **xiphoid process** which hangs down at the inferior end of the process ("xiphoid" is from the Greek for sword), starts out as cartilage, and does not typically ossify into bone until an individual is about 40 years old.

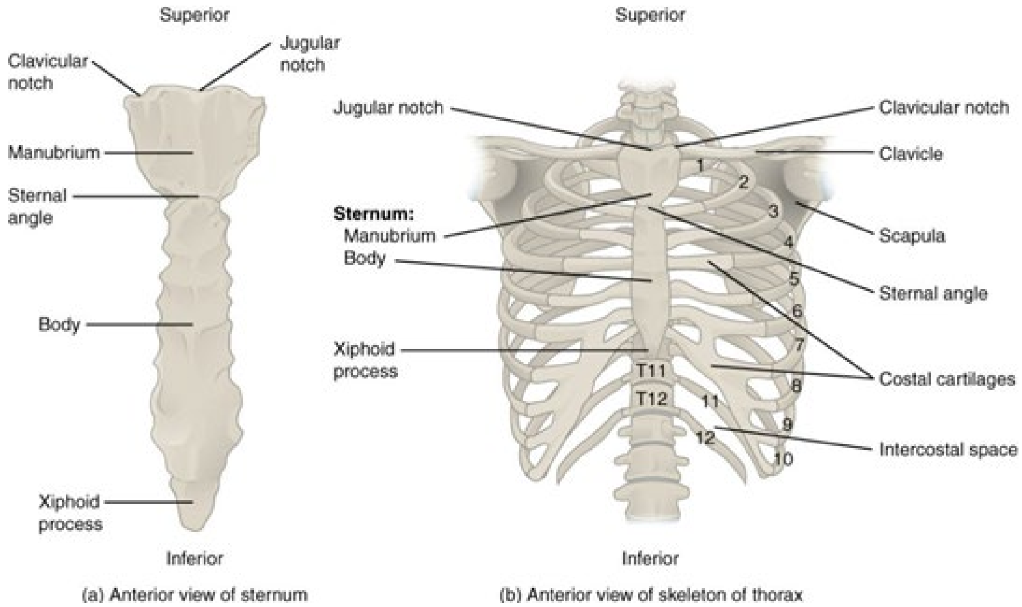
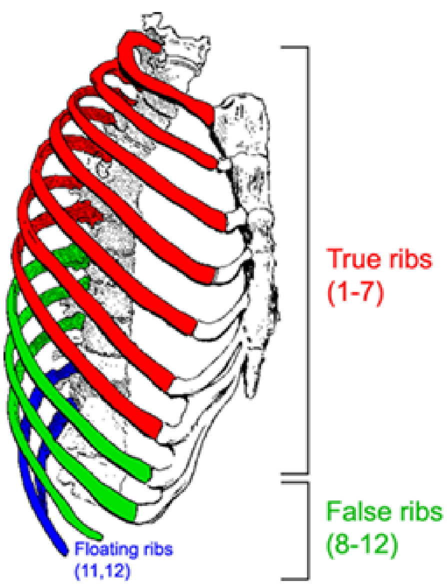


Figure 5.3.1: Ribs and sternum**.** ([CC-BY-SA](), OpenStax College, [OpenStax]())



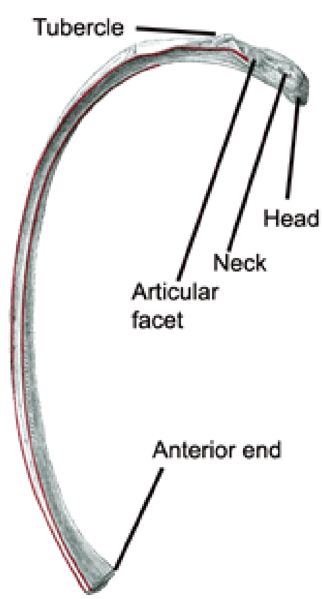


Figure 5.3.1: True, false, and floating ribs. (CC-BY-SA, Cristobal Carrasco., [Wikimedia]())

Figure 5.3.1: The parts of a rib. ([CC-BY-SA](), Henry Vandyke Carter, [Wikimedia]())

Appendicular skeleton

The appendicular skeleton is made up of the bones attached or appended to the axial skeleton. These are the bones of the limbs, hands, and feet, the bones of the pectoral (shoulder) girdles, and the coxal bones of the pelvic girdle.

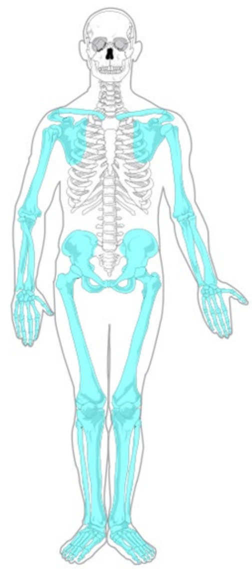


Figure 6.16.1: The appendicular skeleton highlighted in blue. LibreTexts

1)The pectoral girdle above each arm, consisting of the **scapula** (shoulder blade) and **clavicle** (collar bone.)

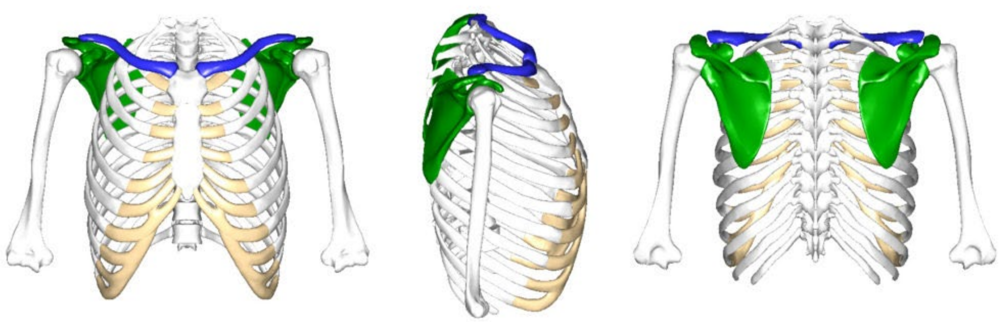


Figure 6.1.1: **The pectoral girdle. The scapulae are green, and the clavicles are blue.** (CC-BY-SA, Wikimedia, BodyParts3D/Anatomography) LibreTexts

1) **The upper limb** consists of the arm (the upper arm), the forearm (the lower arm), and the hand. The arm consists of a single bone, the humerus. The forearm consists of two bones, the ulna and radius. And the hand consists of 27 bones, which are grouped into phalanges, metacarpals, and carpals.

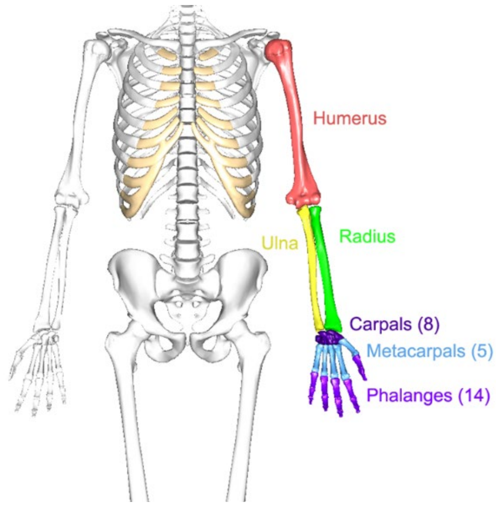


Figure 6.2.1: **The bones of the upper left limb.** (CC-BY-SA, BodyParts3D/Anatomography). LibreTexts

2) **The pelvis** is the bowl-shaped structure generated by the two coxal bones articulated with the sacrum and coccyx bones. On the anterior side of the pelvis, the pubis portions of the two coxal bones do not articulate with each other, but instead are joined with a small piece of cartilage called the **pubic symphysis** ("PYOO-bick SIM-fiss-is")

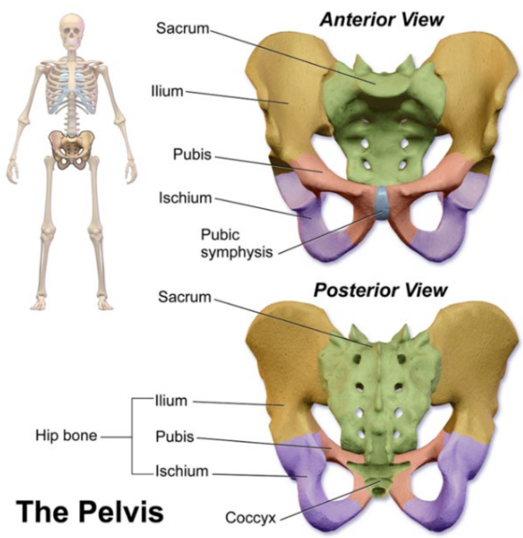


Figure 6.4.1: The bones of the pelvis. (Public Domain, BruceBlaus, Wikimedia). LibreTexts

The lower limb consists of the thigh (the upper leg), the leg (the lower leg), and the foot. The thigh consists of a single bone, the **femur**. The leg consists of two long bones, the **tibia** and **fibula**, and the sesamoid bone, the **patella**, that serves as the knee cap. The foot consists of 26 bones, which are grouped into the **tarsals**, **metatarsals**, and **phalanges**.

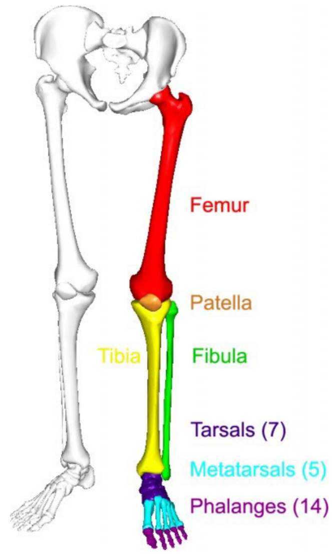


Figure 6.5.1: The bones of the lower left limb. ((CC-BY-SA, BodyParts3D/Anatomography). LibreTexts

The knee joint is the largest joint of the body. It consists of three articulations. The femoropatellar joint is found between the patella and the distal femur. The medial tibiofemoral joint and lateral tibiofemoral joint are located between the medial and lateral condyles of the femur and the medial and lateral condyles of the tibia. These articulations are enclosed within a single articular capsule. The knee functions as a **hinge joint**, allowing flexion and extension of the leg. This action is generated by both rolling and gliding motions of the femur on the tibia. In addition, some rotation of the leg is available when the knee is flexed, but not when extended. The knee is well constructed for weight bearing in its extended position, but is vulnerable to injuries associated with hyperextension, twisting, or blows to the medial or lateral side of the joint, particularly while weight bearing.

3) The **elbow joint** is a uniaxial **hinge joint** formed by the **humeroulnar joint**, the articulation between the trochlea of the humerus and the trochlear notch of the ulna. Also associated with the elbow are the humeroradial joint and the proximal radioulnar joint. All three of these joints are enclosed within a single articular capsule.

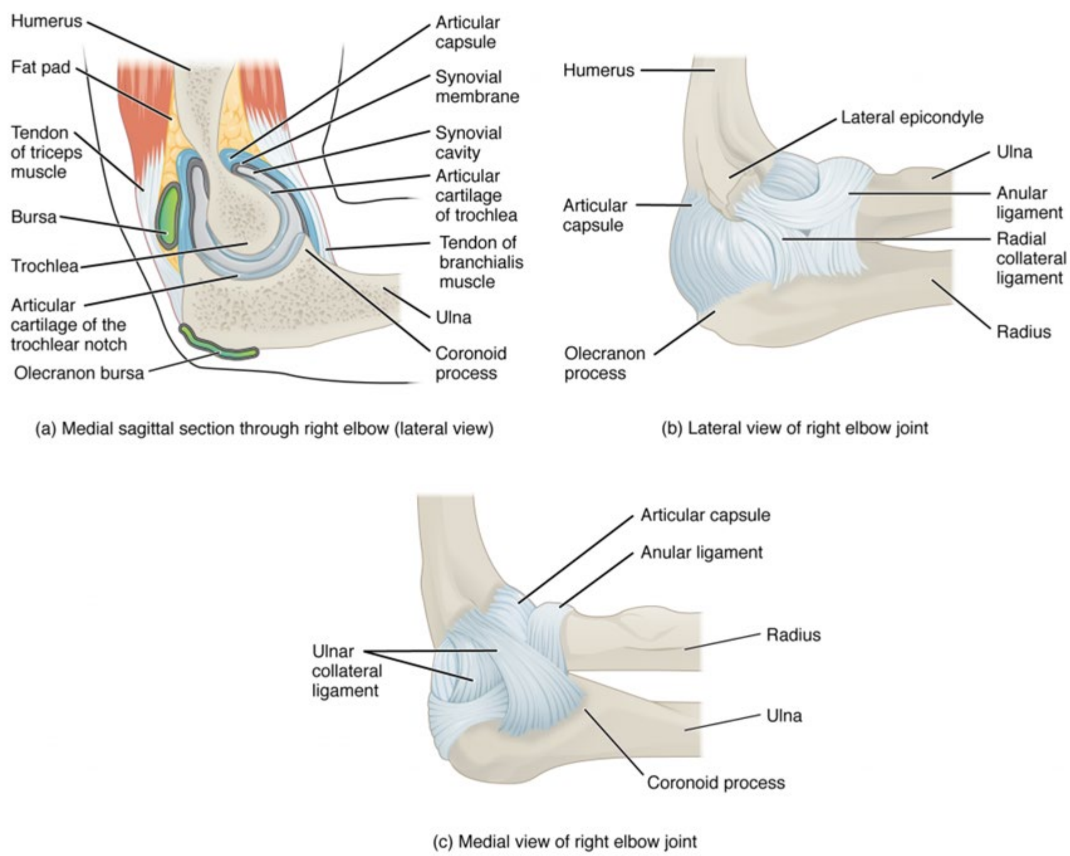


Figure 7.2.1: Elbow Joint. (a) The elbow is a hinge joint that allows only for flexion and extension of the forearm. (b) It is supported by the ulnar and radial collateral ligaments. (c) The annular ligament supports the head of the radius at the proximal radioulnar joint, the pivot joint that allows for rotation of the radius. (CC-BY-SA, Open Oregon)

4) **The shoulder joint** is called the glenohumeral joint. This is a **ball-and-socket joint** formed by the articulation between the head of the humerus and the glenoid cavity of the scapula (Figure 7.3). This joint has the largest range of motion of any joint in the body. However, this freedom of movement is due to the lack of structural support and thus the enhanced mobility is offset by a loss of stability.

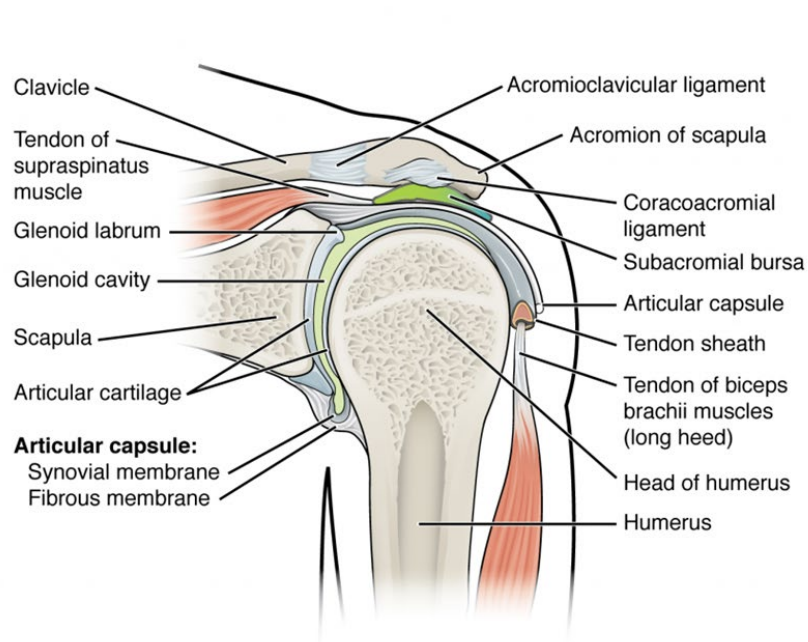


Figure 7.3.1: Glenohumeral Joint The glenohumeral (shoulder) joint is a ball-and-socket joint that provides the widest range of motions. It has a loose articular capsule and is supported by ligaments and the rotator cuff muscles. (CC-BY-SA, Open Oregon)

Muscles

Three different kinds of muscles are found in vertebrate animals.

- **Heart muscle**, also called cardiac muscle, makes up the wall of the heart.
- **Smooth muscle** is found in the walls of all the hollow organs of the body (except the heart). Its contraction reduces the size of these structures. Thus it
  - regulates the flow of blood in the arteries
  - moves your breakfast along through your gastrointestinal tract
  - expels urine from your urinary bladder
  - sends babies out into the world from the uterus
  - regulates the flow of air through the lungs

  The contraction of smooth muscle is generally not under voluntary control.
- **Skeletal muscle**, as its name implies, is the muscle attached to the skeleton. It is also called striated muscle. The contraction of skeletal muscle is under voluntary control.

Skeletal muscle is found attached to bones. It consists of long multinucleate fibers. The fibers run the entire length of the muscle they come from and so are usually too long to have their ends visible when viewed under the microscope. The fibers are relatively wide and very long, but unbranched. Fibers are not individual cells but are formed from the fusion of thousands of precursor cells. Therefore, they are so long and why individual fibers are multinucleate (a single fiber has many nuclei). The nuclei are usually up against the edge of the fiber. There are striations in skeletal muscle. These are alternating dark and light bands perpendicular to the edge of the fiber that are present all along the fiber.

1) Figure 8.1.1 lists the muscles of the head and neck. A single **platysma** muscle is only shown in the lateral view of the head muscles. There are two platysma muscles, one on each side of the neck. Each is a broad sheet of muscle that covers most of the anterior neck on that side of the body. The other anterior neck muscles are below them, and most models have the platysma muscles cut away to show the deeper muscles. The platysma muscles help pull down the lower jaw (mandible.)

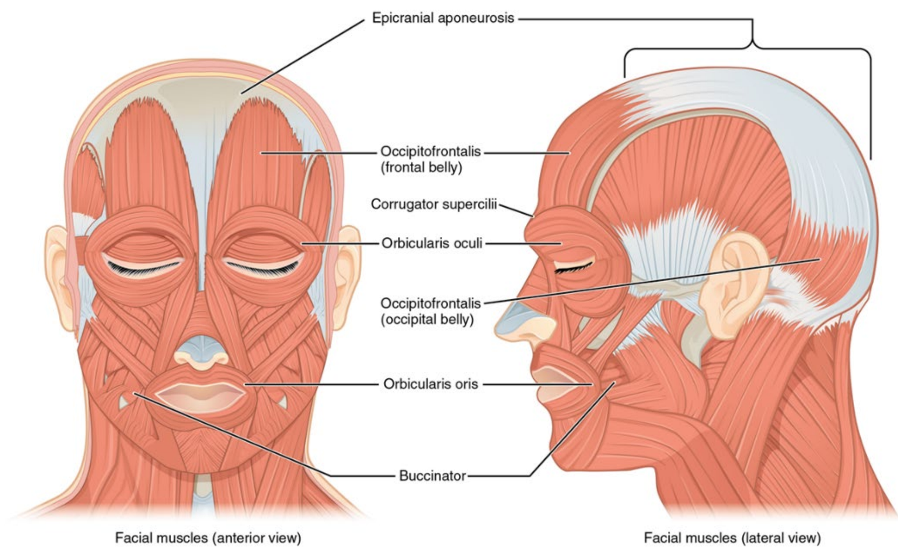


Figure 8.1.1: The muscles of the head. (CC-BY-4.0 OpenStax, Human Anatomy)

2) The Muscles of the Trunk

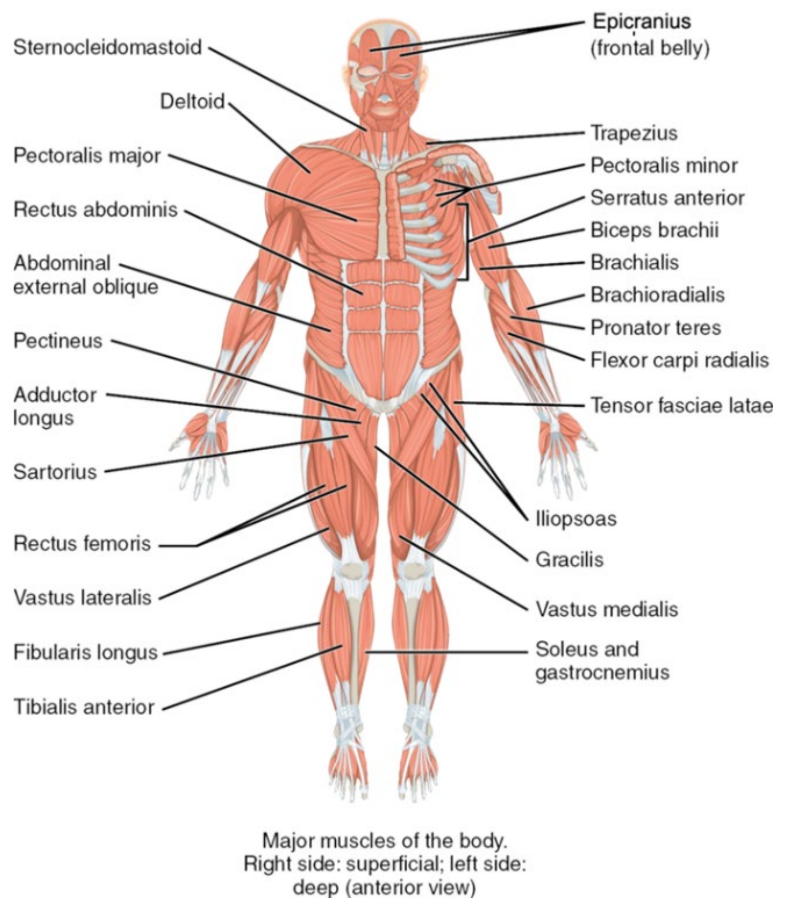


Figure 8.2.1: The major muscles of the body, anterior view. Anatomical right shows superficial muscles. Anatomical left shows deep muscles. (CC-BY-4.0, OpenStax, Human Anatomy)

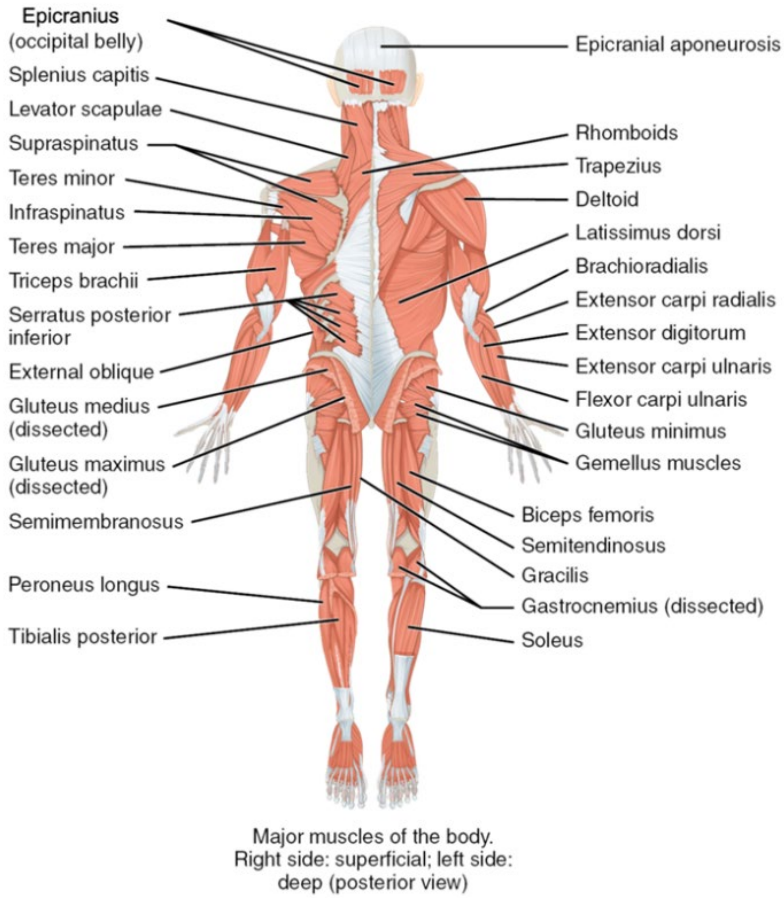


Figure 8.2.2: The major muscles of the body, posterior view. Anatomical right shows superficial muscles. Anatomical left shows deep muscles. (CC-BY-4.0, OpenStax, Human Anatomy)

The Central Nervous System (Brain)

The brain and the spinal cord are the central nervous system, and they represent the main organs of the nervous system. The spinal cord is a single structure, whereas the adult brain is described in terms of four major regions: the cerebrum, the diencephalon, the brain stem, and the cerebellum. A person's conscious experiences are based on neural activity in the brain. The regulation of homeostasis is governed by a specialized region in the brain. The coordination of reflexes depends on the integration of sensory and motor pathways in the spinal cord.

The cerebrum

The iconic gray mantle of the human brain, which appears to make up most of the mass of the brain, is the **cerebrum** (**Figure 11.1**). The wrinkled portion is the **cerebral cortex**, and the rest of the structure is beneath that outer covering. There is a large separation between the two sides of the cerebrum called the **longitudinal fissure**. It separates the cerebrum into two distinct halves, a right and left **cerebral hemisphere**. Deep within the cerebrum, the white matter of the **corpus callosum** provides the major pathway for communication between the two hemispheres of the cerebral cortex.

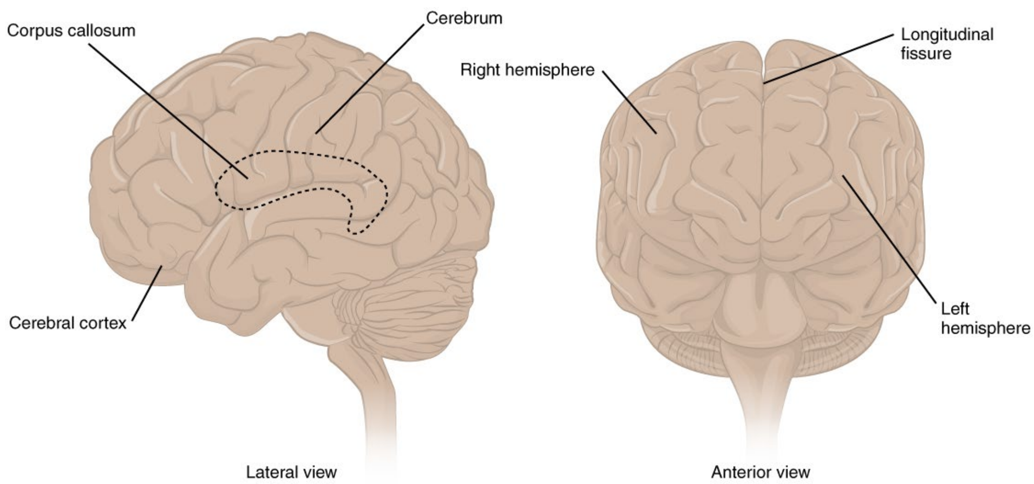


Figure 11.1.1: The cerebrum is a large component of the CNS in humans, and the most obvious aspect of it is the folded surface called the cerebral cortex. (CC-BY-4.0 OpenStax, Human Anatomy)

Cerebral Cortex

The cerebrum is covered by a continuous layer of gray matter that wraps around either side of the forebrain—the cerebral cortex. This thin, extensive region of wrinkled gray matter is responsible for the higher functions of the nervous system. A **gyrus** (plural = gyri) is the ridge of one of those wrinkles, and a **sulcus** (plural = sulci) is the groove between two gyri. The pattern of these folds of tissue indicates specific regions of the cerebral cortex.

The folding of the cortex maximizes the amount of gray matter in the cranial cavity. During embryonic development, as the telencephalon expands within the skull, the brain goes through a regular course of growth that results in everyone's brain having a similar pattern of folds. The surface of the brain can be mapped based on the locations of large gyri and sulci. Using these landmarks, the cortex can be separated into four major regions, or lobes (**Figure 11.1.2**). The **lateral sulcus** that separates the **temporal lobe** from the other regions is one such landmark. Superior to the lateral sulcus are the **parietal lobe** and **frontal lobe**, which are separated from each other by the **central sulcus**. The posterior region of the cortex is the **occipital lobe**, which has no obvious anatomical border between it and the parietal or temporal lobes on the lateral surface of the brain. From the medial surface, an obvious landmark separating the parietal and occipital lobes is called the **parieto- occipital sulcus**.

The fact that there is no obvious anatomical border between these lobes is consistent with the functions of these regions being interrelated.

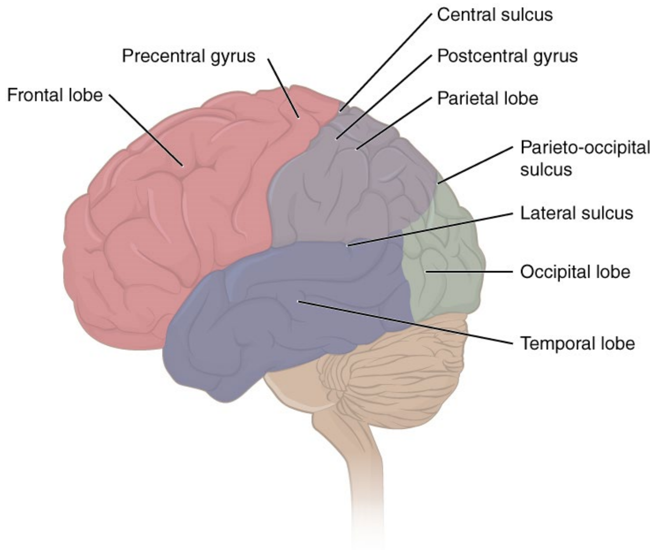


Figure 11.1.2: The cerebral cortex is divided into four lobes. Extensive folding increases the surface area available for cerebral functions. (CC-BY-4.0 OpenStax, Human Anatomy)

The diencephalon

Diencephalon is the one region of the adult brain that retains its name from embryologic development. The etymology of the word diencephalon translates to "through brain." It is the connection between the cerebrum and the rest of the nervous system, with one exception. The rest of the brain, the spinal cord, and the PNS all send information to the cerebrum through diencephalon. Output from the cerebrum passes through diencephalon. The single exception is the system associated with olfaction, or the sense of smell, which connects directly with the cerebrum. In the earliest vertebrate species, the cerebrum was not much more than olfactory bulbs that received peripheral information about the chemical environment (to call it smell in these organisms is imprecise because they lived in the ocean).

The diencephalon is deep beneath the cerebrum and constitutes the walls of the third ventricle. Diencephalon can be described as any region of the brain with "thalamus" in its name. The two major regions of diencephalon are the thalamus itself and the hypothalamus. There are other structures, such as the epithalamus, which contains the pineal gland, or the subthalamus, which includes the subthalamic nucleus that is part of the basal nuclei.

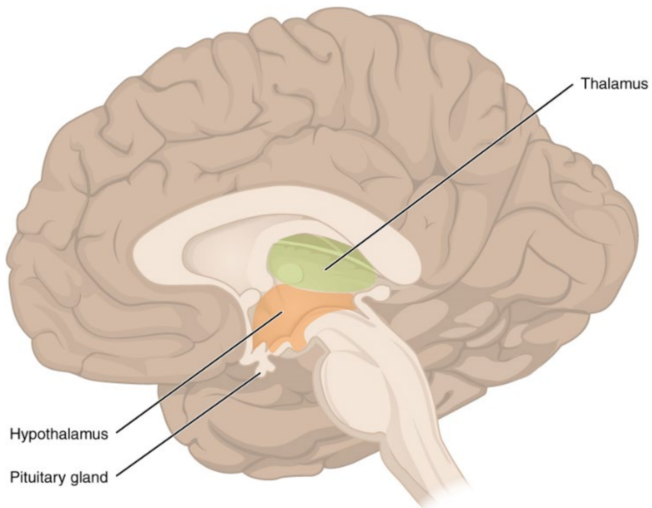


Figure 11.2.1: Diencephalon (CC-BY-4.0 OpenStax, Human Anatomy)

The brain stem

The midbrain and hindbrain (composed of the pons and the medulla) are collectively referred to as the brain stem (**Figure** 11.3.1). The structure emerges from the ventral surface of the forebrain as a tapering cone that connects the brain to the spinal cord. Attached to the brain stem, but considered a separate region of the adult brain, is the cerebellum. The midbrain coordinates sensory representations of the visual, auditory, and somatosensory perceptual spaces. The pons is the main connection with the cerebellum. The pons and the medulla regulate several crucial functions, including the cardiovascular and respiratory systems and rates.

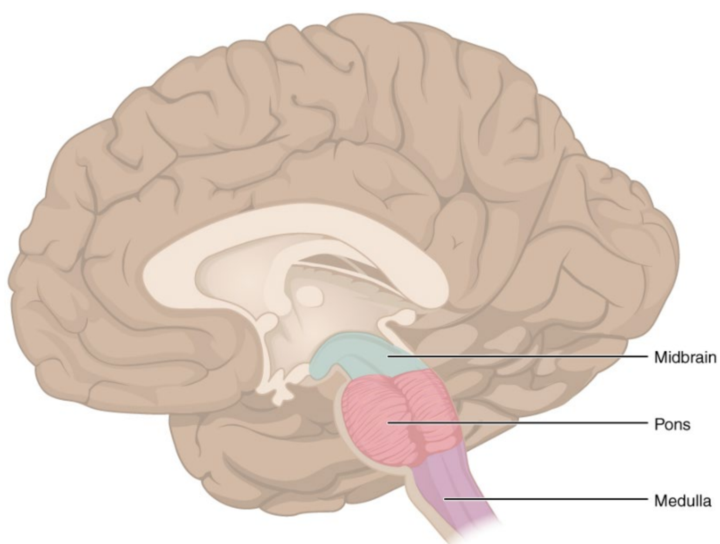
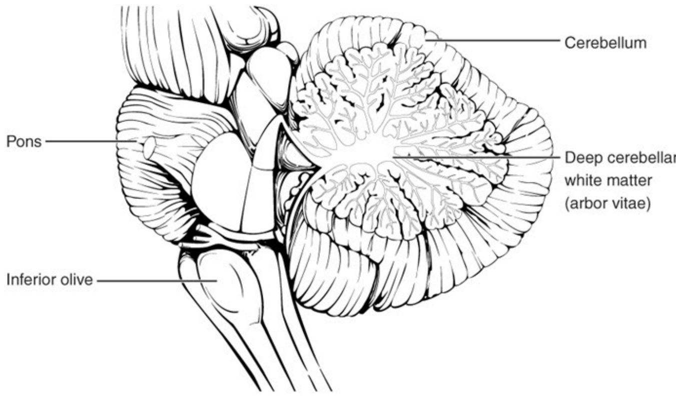


Figure 11.3.1: Brian Stem (CC-BY-4.0 OpenStax, Human Anatomy)

The cerebellum

The **cerebellum**, as the name suggests, is the “little brain.” The cerebellum is largely responsible for comparing information from the cerebrum with sensory feedback from the periphery through the spinal cord. It accounts for approximately 10 percent of the mass of the brain.



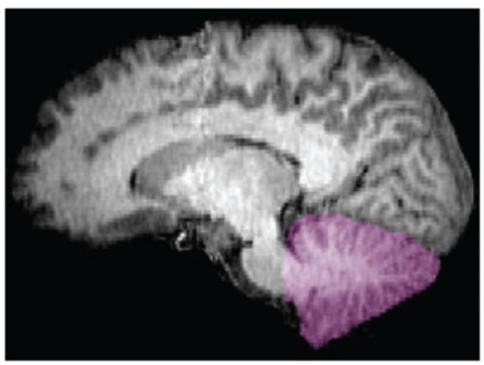


Figure 11.4.1: The cerebellum is situated on the posterior surface of the brain stem. Descending input from the cerebellum enters through the large white matter structure of the pons. Ascending input from the periphery and spinal cord enters through the fibers of the inferior olive. Output goes to the midbrain, which sends a descending signal to the spinal cord. (CC-BY-4.0, OpenStax, Human Anatomy)

The Endocrine System

The endocrine system consists of cells, tissues, and organs that secrete hormones as a primary or secondary function. The primary function of the **endocrine glands** is to secrete their hormones directly into the surrounding fluid. The interstitial fluid and the blood vessels then transport the hormones throughout the body. The endocrine system includes the pituitary, thyroid, parathyroid, adrenal, and pineal glands (Figure 14.1.1). Some of these glands have both endocrine and non-endocrine functions. For example, the pancreas contains cells that function in digestion as well as cells that secrete the hormones insulin and glucagon, which regulate blood glucose levels. The hypothalamus, thymus, heart, kidneys, stomach, small intestine, liver, skin, female ovaries, and male testes are other organs that contain cells with endocrine function. Moreover, adipose tissue has long been known to produce hormones, and recent research has revealed that even bone tissue has endocrine functions.

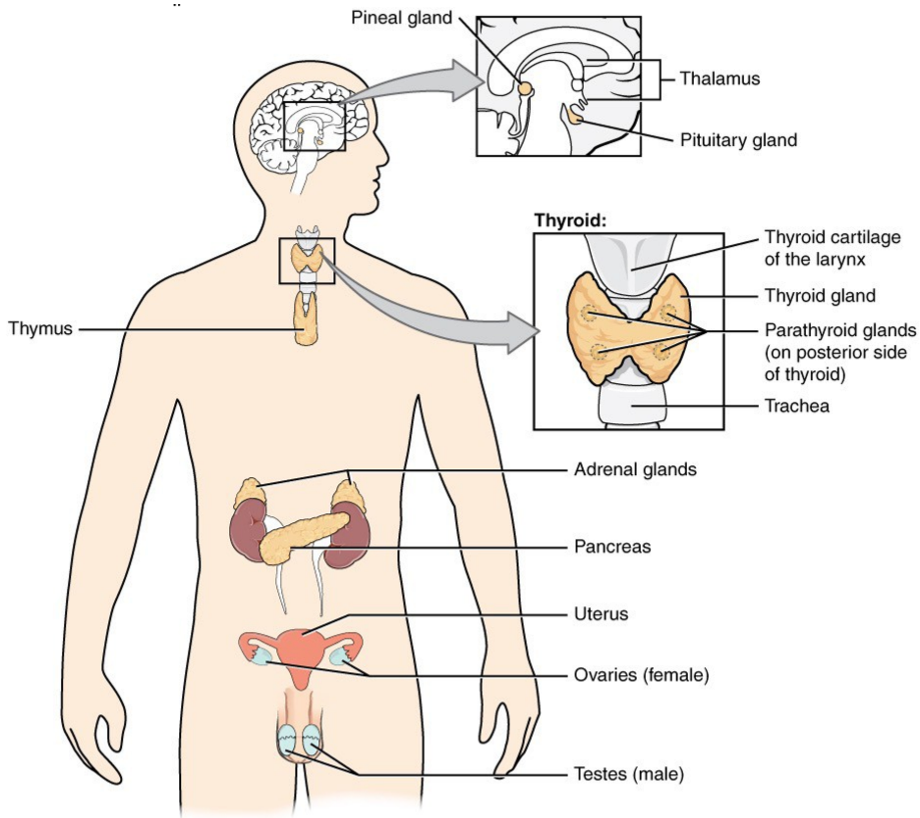
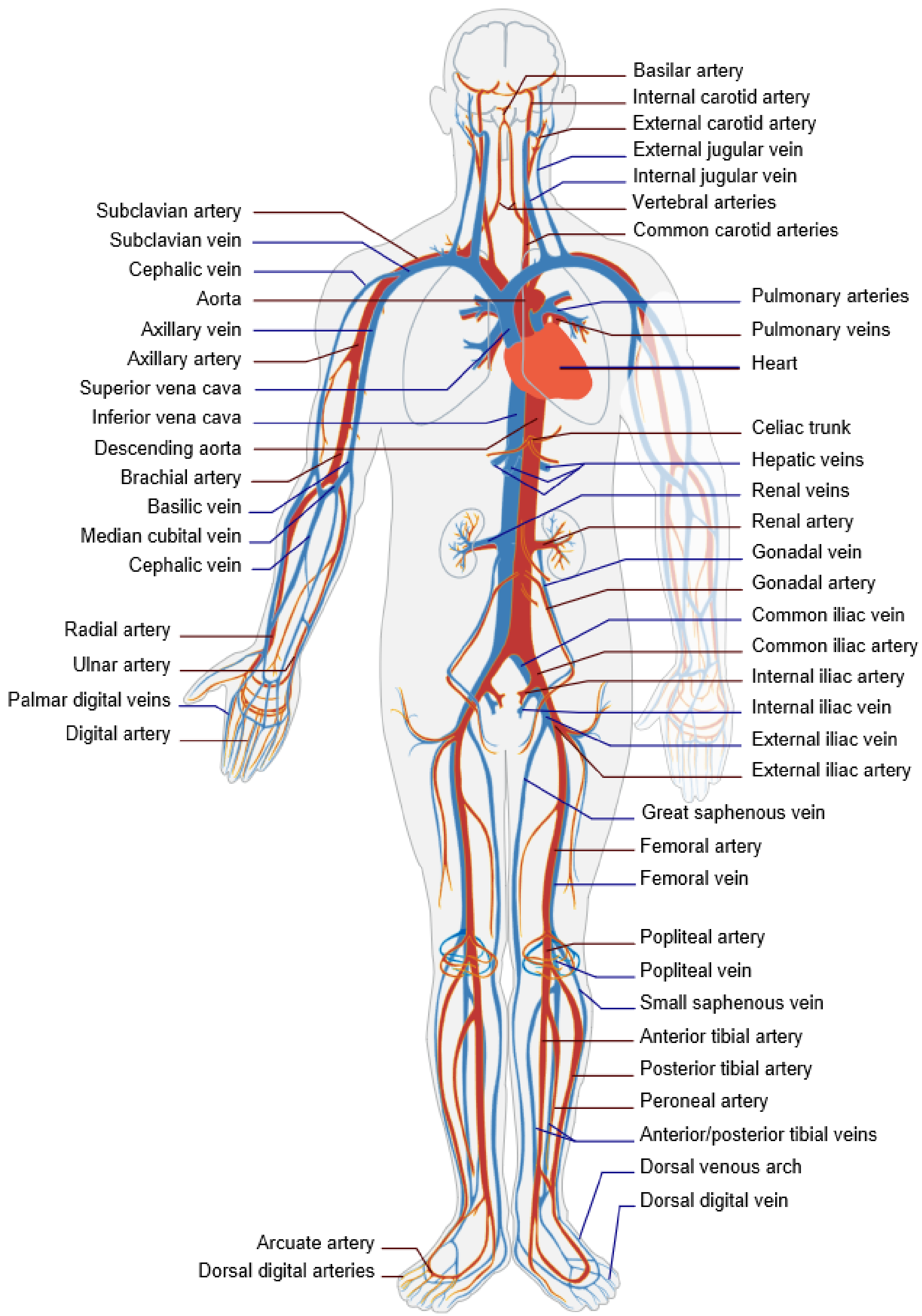


Figure 14.1.1: **Endocrine System** Endocrine glands and cells are located throughout the body and play an important role in homeostasis

The ductless endocrine glands are not to be confused with the body's **exocrine system**, whose glands release their secretions through ducts. Examples of exocrine glands include the sebaceous and sweat glands of the skin. As just noted, the pancreas also has an exocrine function: most of its cells secrete pancreatic juice through the pancreatic and accessory ducts to the lumen of the small intestine

The Circulatory System

The circulatory system is an organ system that permits blood to circulate and transport nutrients (such as amino acids and electrolytes), oxygen, carbon dioxide, hormones, and blood cells to and from the cells in the body to provide nourishment and help in fighting diseases, stabilize temperature and pH, and maintain homeostasis.



Simplified diagram of the human Circulatory system in anterior view. (Public Domain; LadyofHats)

Main Features of the Human Circulatory System

- A liquid, blood, to transport nutrients, wastes, oxygen and carbon dioxide, and hormones.

- Two pumps (in a single heart): one to pump deoxygenated blood to the lungs and the other to pump oxygen**ated** blood to all the other organs and tissues of the body
- A system of **blood vessels** to distribute blood throughout the body
- Specialized **organs for exchange** of materials between the blood and the external environment; for example, organs like the lungs and intestine that add materials to the blood and organs like the lungs and kidneys that remove materials from the blood and deposit them back in the external environment

The Heart and Pulmonary System

The heart is located roughly in the center of the chest cavity. It is covered by a protective membrane, the **pericardium**.

- Deoxygenated blood from the body enters the **right atrium**.
- It flows through the **tricuspid valve** into the **right ventricle**. The term tricuspid refers to the three flaps of tissue that make up the valve.
- Contraction of the ventricle then closes the tricuspid valve and forces open the pulmonary valve.
- Blood flows into the **pulmonary artery**.
- This branches immediately, carrying blood to the right and left **lungs**.
- Here the blood gives up carbon dioxide and takes on a fresh supply of oxygen.
- The capillary beds of the lungs are drained by venules that are the tributaries of the **pulmonary veins**.
- Four pulmonary veins, two draining each lung, carry oxygenated blood to the **left atrium** of the heart.

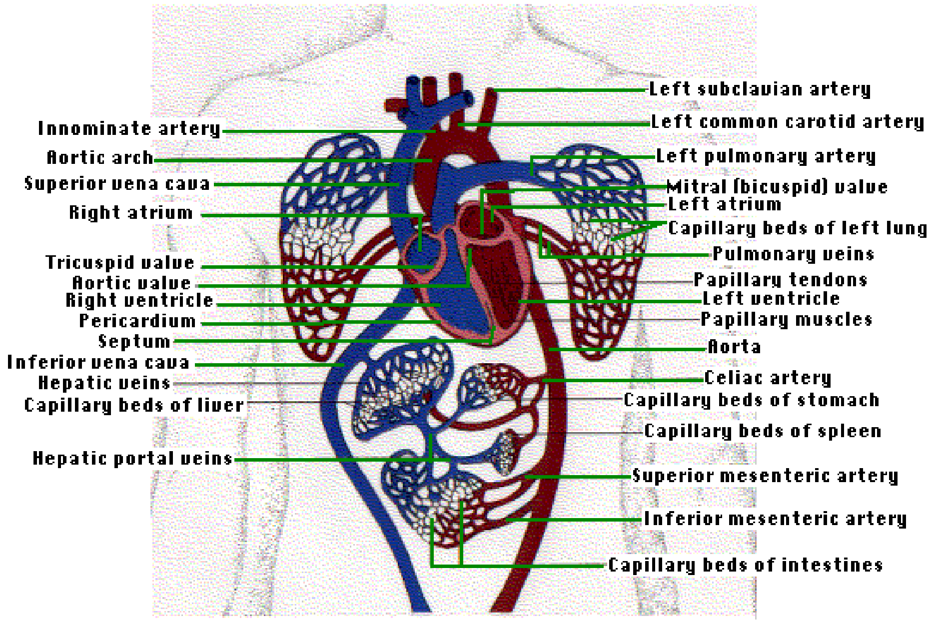


Figure 15.3.1.1 Human heart

The above figure shows the human heart, with a schematic view of the pathway of blood through the lungs and internal organs. Oxygenated blood is shown in red; deoxygenated blood in blue. Note that the blood draining the stomach, spleen, and intestines passes through the liver before it is returned to the heart. Here surplus or harmful materials picked up from those organs can be removed before the blood returns to general circulation.

The Coronary System

From the **left atrium**,

- Blood flows through the **mitral valve** (also known as the bicuspid valve) into the **left ventricle**.
- Contraction of the ventricle closes the mitral valve and opens the **aortic valve** at the entrance to the **aorta**.
- The first branches from the aorta occur just beyond the aortic valve still within the heart.
- Two openings lead to the right and left **coronary arteries**, which supply blood to the heart itself. Although the coronary arteries arise within the heart, they pass directly out to the surface of the heart and extend down across it. They supply blood to the network of capillaries that penetrate every portion of the heart.
- The capillaries drain into two **coronary veins** that empty into the **right atrium**.

The Systemic Circulation

The remainder of the system is known as systemic circulation. The graphic shows the major arteries (in bright red) and veins (dark red) of the system. Blood from the aorta passes into a branching system of arteries that leads to all parts of the body. It then flows into a system of capillaries where its exchange functions take place.

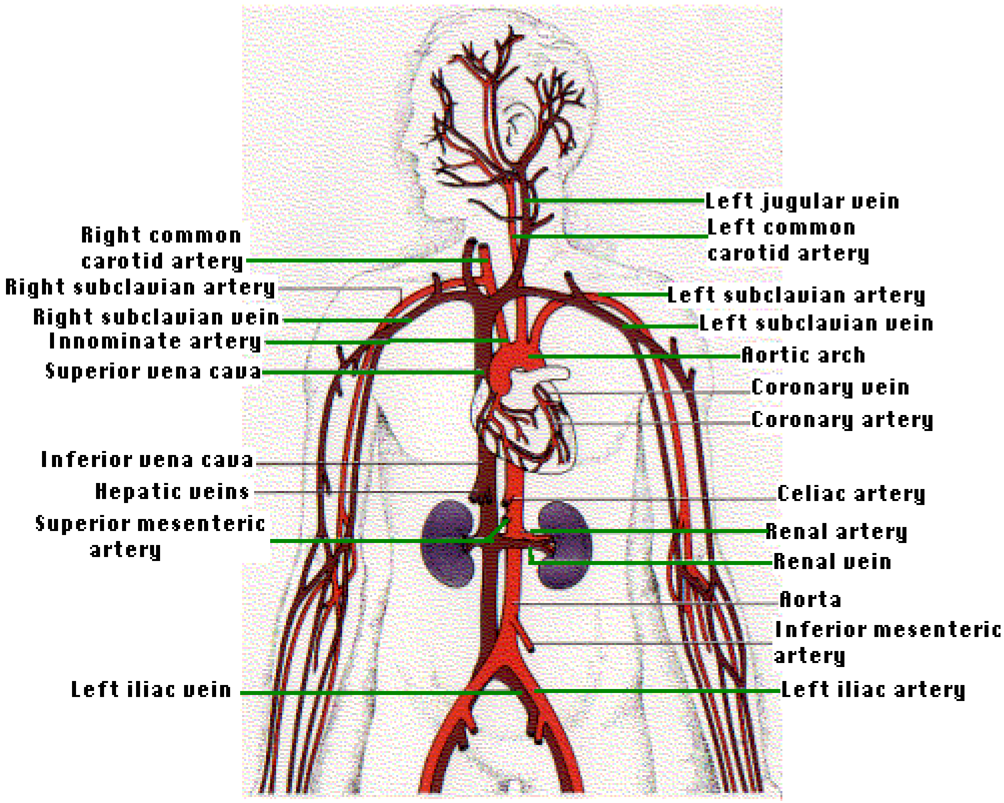


Figure 15.3.1.2 Human circulation system

Blood from the capillaries flows into venules which are drained by veins.

- Veins draining the upper portion of the body lead to the **superior vena cava**.
- Veins draining the lower part of the body lead to the **inferior vena cava**.
- Both empty into the right atrium.

The Role of Blood in the Body

Hemoglobin is responsible for distributing oxygen, and to a lesser extent, carbon dioxide, throughout the circulatory systems of humans, vertebrates, and many invertebrates. The blood is more than the proteins, though. Blood is a term used to describe the liquid that moves through the vessels and includes plasma (the liquid portion, which contains water, proteins, salts, lipids, and glucose) and the cells (red and white cells) and cell fragments called platelets.

Blood plasma is the dominant component of blood and contains water, proteins, electrolytes, lipids, and glucose. The cells are responsible for carrying the gases (red cells) and immune the response (white). The platelets are responsible for blood clotting. Interstitial fluid that surrounds cells is separate from the blood, but in hemolymph, they are combined. In humans, cellular components make up approximately 45 percent of the blood and the liquid plasma 55 percent. Blood is 20 percent of a person's extracellular fluid and eight percent of weight.

Blood, like the human blood illustrated in Figure 40.2.1, is important for regulation of the body's systems and homeostasis. Blood helps maintain homeostasis by stabilizing pH, temperature, osmotic pressure, and by eliminating excess heat. Blood supports growth by distributing nutrients and hormones, and by removing waste. Blood plays a protective role by transporting clotting factors and platelets to prevent blood loss and transporting disease-fighting agents (white blood cells) to sites of infection.

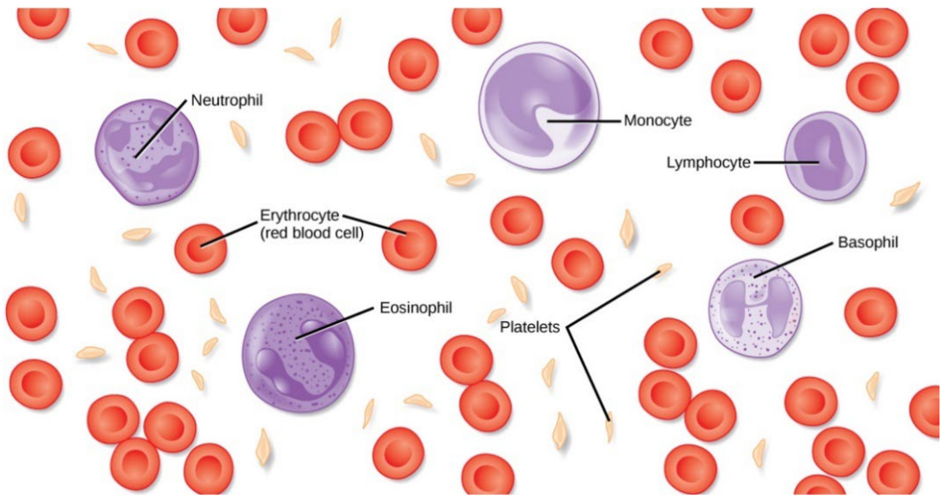


Figure 40.2.1: The cells and cellular components of human blood are shown. Red blood cells deliver oxygen to the cells and remove carbon dioxide. White blood cells—including neutrophils, monocytes, lymphocytes, eosinophils, and basophiles—are involved in the immune response. Platelets form clots that prevent blood loss after injury.

Red Blood Cells

Red blood cells, or erythrocytes (erythro- = "red"; -cyte = "cell"), are specialized cells that circulate through the body delivering oxygen to cells; they are formed from stem cells in the bone marrow. In mammals, red blood cells are small biconcave cells that at maturity do not contain a nucleus or mitochondria and are only 7–8 µm in size. In birds and non-avian reptiles, a nucleus is still maintained in red blood cells.

The small size and large surface area of red blood cells allows for rapid diffusion of oxygen and carbon dioxide across the plasma membrane. In the lungs, carbon dioxide is released, and oxygen is taken in by the blood. In the tissues, oxygen is released from the blood and carbon dioxide is bound for transport back to the lungs. Studies have found that hemoglobin also binds nitrous oxide (N_2O). N_2O is a vasodilator that relaxes the blood vessels and capillaries and may help with gas exchange and the passage of red blood cells through narrow vessels. Nitroglycerin, a heart medication for angina and heart attacks, is converted to N_2O to help relax the blood vessels and increase oxygen flow through the body.

A characteristic of red blood cells is their glycolipid and glycoprotein coating; these are lipids and proteins that have carbohydrate molecules attached. In humans, the surface glycoproteins and glycolipids on red blood cells vary between individuals, producing the different blood types, such as A, B, and O. Red blood cells have an average life span of 120 days, at which time they are broken down and recycled in the liver and spleen by phagocytic macrophages, a type of white blood cell.

White Blood Cells

White blood cells, also called leukocytes (leuko = white), make up approximately one percent of the volume of the cells in blood. The role of white blood cells is very different than that of red blood cells: they are primarily involved in the immune response to identify and target pathogens, such as invading bacteria, viruses, and other foreign organisms. White blood cells are formed continually; some only live for hours or days, but some live for years.

The morphology of white blood cells differs significantly from red blood cells. They have nuclei and do not contain hemoglobin. The different types of white blood cells are identified by their microscopic appearance after histologic staining, and each has a different specialized function. The two main groups, both illustrated in Figure 40.2.3 are the granulocytes, which include the neutrophils, eosinophils, and basophils, and the agranulocytes, which include the monocytes and lymphocytes.

Figure 40.2.3: (a) Granulocytes—including neutrophils, eosinophils and basophils—are characterized by a lobed nucleus and granular inclusions in the cytoplasm. Granulocytes are typically first-responders during injury or infection. (b) Agranulocytes include lymphocytes and monocytes. Lymphocytes, including B and T cells, are responsible for adaptive immune response. Monocytes differentiate into macrophages and dendritic cells, which in turn respond to infection or injury.

Granulocytes contain granules in their cytoplasm; the agranulocytes are so named because of the lack of granules in their cytoplasm. Some leukocytes become macrophages that either stay at the same site or move through the blood stream and gather at sites of infection or inflammation where they are attracted by chemical signals from foreign particles and damaged cells. Lymphocytes are the primary cells of the immune system and include B cells, T cells, and natural killer cells. B cells destroy bacteria and inactivate their toxins. They also produce antibodies. T cells attack viruses, fungi, some bacteria, transplanted cells, and cancer cells. T cells attack viruses by releasing toxins that kill the viruses. Natural killer cells attack a variety of infectious microbes and certain tumor cells.

One reason that HIV poses significant management challenges is because the virus directly targets T cells by gaining entry through a receptor. Once inside the cell, HIV then multiplies using the T cell's own genetic machinery. After the HIV virus replicates, it is transmitted directly from the infected T cell to macrophages. The presence of HIV can remain unrecognized for an extensive period before full disease symptoms develop.

Platelets and Coagulation Factors

Blood must clot to heal wounds and prevent excess blood loss. Small cell fragments called platelets (thrombocytes) are attracted to the wound site where they adhere by extending many projections and releasing their contents.

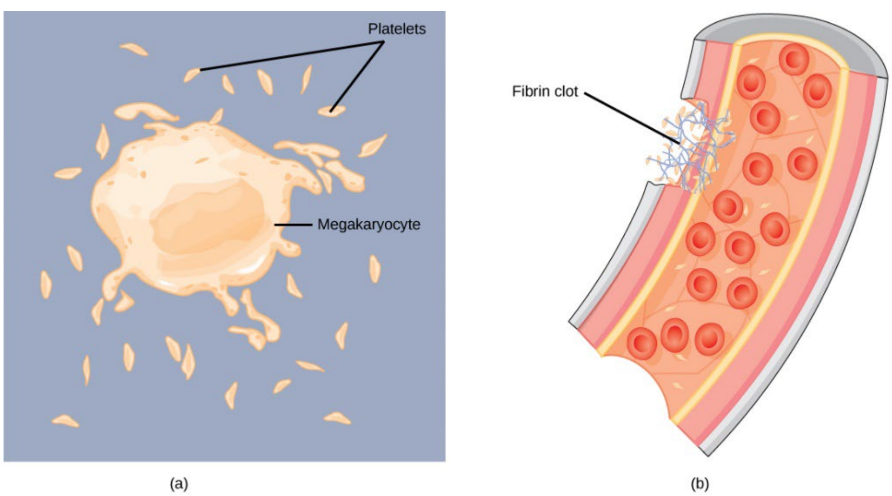


Figure 40.2.4: (a) Platelets are formed from large cells called megakaryocytes. The megakaryocyte breaks up into thousands of fragments that become platelets. (b) Platelets are required for clotting the blood. The platelets collect at a wound site in conjunction with other clotting factors, such as fibrinogen, to form a fibrin clot that prevents blood loss and allows the wound to heal.

Plasma and Serum

The liquid component of blood is called plasma, and it is separated by spinning or centrifuging the blood at high rotations (3000 rpm or higher). The blood cells and platelets are separated by centrifugal forces to the bottom of a specimen tube. The upper liquid layer, plasma, consists of 90 percent water along with various substances required for maintaining the body's pH, osmotic load, and for protecting the body. Plasma also contains coagulation factors and antibodies.

The plasma component of blood without coagulation factors is called the serum. Serum is like interstitial fluid in which the correct composition of key ions acting as electrolytes is essential for normal functioning of muscles and nerves. Other components in the serum include proteins that assist with maintaining pH and osmotic balance while giving viscosity to the blood. The serum also contains antibodies, specialized proteins that are important for defense against viruses and bacteria. Lipids, including cholesterol, are also transported in the serum, along with various other substances including nutrients, hormones, metabolic waste, plus external substances, such as, drugs, viruses, and bacteria.

Human serum albumin is the most abundant protein in human blood plasma and is synthesized in the liver. Albumin, which constitutes about half of the blood serum protein, transports hormones and fatty acids, buffers pH, and maintains osmotic pressures. Immunoglobulin is a protein antibody produced in the mucosal lining and plays an important role in antibody mediated immunity.

The Respiratory System

Humans, when they are not exerting themselves, breathe approximately 15 times per minute on average. This equates to about 900 breaths an hour or 21,600 breaths per day. With every inhalation, air fills the lungs, and with every exhalation, it rushes back out. That air is doing more than just inflating and deflating the lungs in the chest cavity. The air contains oxygen that crosses the lung tissue, enters the bloodstream, and travels to organs and tissues. There, oxygen is exchanged for carbon dioxide, which is a cellular waste material. Carbon dioxide exits the cells, enters the bloodstream, travels back to the lungs, and is expired out of the body during exhalation.

The end of the trachea divides into two bronchi that enter the right and left lung. Air enters the lungs through the primary bronchi. The primary bronchus divide, creating smaller and smaller diameter bronchi until the passages are under 1 mm in diameter when they are called bronchioles as they split and spread through the lung. Like the trachea, the bronchus and bronchioles are made of cartilage and smooth muscle. Bronchi are innervated by nerves of both the parasympathetic and sympathetic nervous systems that control muscle contraction (parasympathetic) or relaxation (sympathetic) in the bronchi and bronchioles, depending on the nervous system's cues. The final bronchioles are the respiratory bronchioles. Alveolar ducts are attached to the end of each respiratory bronchiole. At the end of each duct are alveolar sacs, each containing 20 to 30 alveoli. Gas exchange occurs only in the alveoli. The alveoli are thin-walled and look like tiny bubbles within the sacs. The alveoli are in direct contact with capillaries of the circulatory system. Such intimate contact ensures that oxygen will diffuse from the alveoli into the blood. In addition, carbon dioxide will diffuse from the blood into the alveoli to be exhaled. The anatomical arrangement of capillaries and alveoli emphasizes the structural and functional relationship of the respiratory and circulatory systems. Estimates for the surface area of alveoli in the lungs vary around 100 m^2. This large area is about half a tennis court. This large surface area, combined with the thin-walled nature of the alveolar cells, allows gases to easily diffuse across the cells.

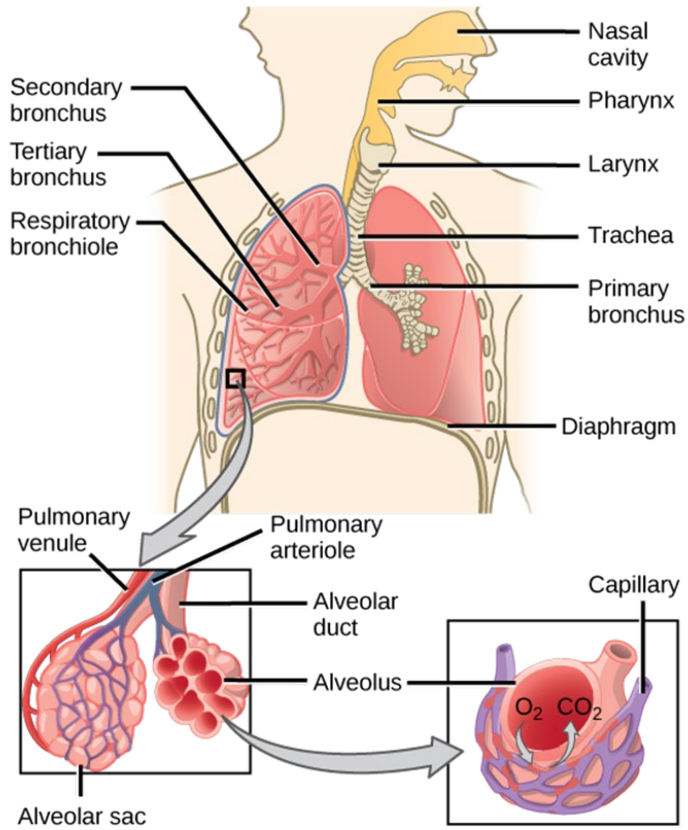


Figure 16.3.1**:** Air enters the respiratory system through the nasal cavity, and then passes through the pharynx and the trachea into the lungs. (Credit: modification of work by NCI)

The Digestive System

All living organisms need nutrients to survive. While plants can obtain nutrients from their roots and the energy molecules required for cellular function through the process of photosynthesis, animals obtain their nutrients by the consumption of other organisms. At the cellular level, the biological molecules necessary for animal function are amino acids, lipid molecules, nucleotides, and simple sugars. However, the food consumed consists of protein, fat, and complex carbohydrates. Animals must convert these macromolecules into the simple molecules required for maintaining cellular function. The conversion of the food consumed to the nutrients required is a multistep process involving digestion and absorption. During digestion, food particles are broken down into smaller components, which are later absorbed by the body. This happens by both physical means, such as chewing, and by chemical means.

One of the challenges in human nutrition is maintaining a balance between food intake, storage, and energy expenditure. Taking in more food energy than is used in activity leads to storage of the excess in the form of fat deposits. The rise in obesity and the resulting diseases like type 2 diabetes makes understanding the role of diet and nutrition in maintaining good health more important.

The process of digestion begins in the mouth with the intake of food (Figure 16.2.1). The teeth play an important role in masticating (chewing) or physically breaking food into smaller particles. The enzymes present in saliva also begin to chemically break down food. The food is then swallowed and enters the esophagus—a long tube that connects the mouth to the stomach. Using peristalsis, or wave-like smooth-muscle contractions, the muscles of the esophagus push the food toward the stomach. The stomach contents are extremely acidic, with a pH between 1.5 and 2.5. This acidity kills microorganisms, breaks down food tissues, and activates digestive enzymes. Further breakdown of food takes place in the small intestine where bile produced by the liver, and enzymes produced by the small intestine and the pancreas, continue the process of digestion. The smaller molecules are absorbed into the blood stream through the epithelial cells lining the walls of the small intestine. The waste material travels on to the large intestine where water is absorbed, and the drier waste material is compacted into feces; it is stored until it is excreted through the anus.

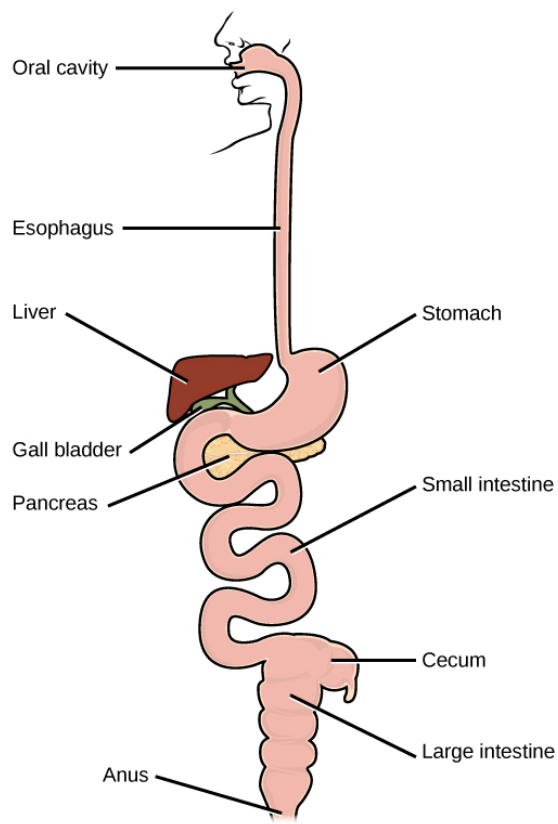


Figure 16.2.1**:** The components of the human digestive system are shown.

Oral Cavity

The chemical process of digestion begins during chewing as food mixes with saliva, produced by the salivary glands (Figure 16.2.2). Saliva contains mucus that moistens food and buffers the pH of the food. Saliva also contains lysozyme, which has antibacterial action. It also contains an enzyme called salivary amylase that begins the process of converting starches in the food into a disaccharide called maltose. Another enzyme called lipase is produced by cells in the tongue to break down fats. The chewing and wetting action provided by the teeth and saliva prepare the food into a mass called the bolus for swallowing. The tongue helps in swallowing—moving the bolus from the mouth into the pharynx. The pharynx opens to two passageways: the esophagus and the trachea. The esophagus leads to the stomach and the trachea leads to the lungs. The epiglottis is a flap of tissue that covers the tracheal opening during swallowing to prevent food from entering the lungs.

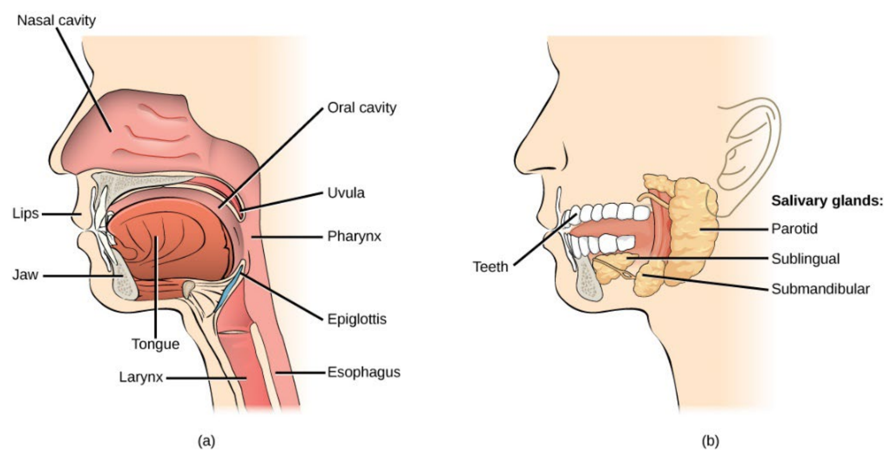


Figure 16.2.2**:** (a) Digestion of food begins in the mouth. (b) Food is masticated by teeth and moistened by saliva secreted from the salivary glands. Enzymes in the saliva begin to digest starches and fats. With the help of the tongue, the resulting bolus is moved into the esophagus by swallowing. (Credit: modification of work by Mariana Ruiz Villareal)

Esophagus

The esophagus is a tubular organ that connects the mouth to the stomach. The chewed and softened food passes through the esophagus after being swallowed. The smooth muscles of the esophagus undergo peristalsis that pushes the food toward the stomach. The peristaltic wave is unidirectional—it moves food from the mouth to the stomach, and reverse movement is not possible, except in the case of the vomit reflex. The peristaltic movement of the esophagus is an involuntary reflex; it takes place in response to the act of swallowing.

Ring-like muscles called sphincters form valves in the digestive system. The gastro-esophageal sphincter (or cardiac sphincter) is located at the stomach end of the esophagus. In response to swallowing and the pressure exerted by the bolus of food, this sphincter opens, and the bolus enters the stomach. When there is no swallowing action, this sphincter is shut and prevents the contents of the stomach from traveling up the esophagus. Acid reflux or "heartburn" occurs when the acidic digestive juices escape into the esophagus.

Stomach

A large part of protein digestion occurs in the stomach (Figure 16.2.4). The stomach is a saclike organ that secretes gastric digestive juices.

Protein digestion is carried out by an enzyme called pepsin in the stomach chamber. The highly acidic environment kills many microorganisms in the food and combined with the action of the enzyme pepsin, results in the catabolism of protein in the food. Chemical digestion is facilitated by the churning action of the stomach caused by contraction and relaxation of smooth muscles. The partially digested food and gastric juice mixture is called chyme. Gastric emptying occurs within two to six hours after a meal. Only a small amount of chyme is released into the small intestine at a time. The movement of chyme from the stomach into the small intestine is regulated by hormones, stomach distension and muscular reflexes that influence the pyloric sphincter.

The stomach lining is unaffected by pepsin and acidity because pepsin is released in an inactive form and the stomach has a thick mucus lining that protects the underlying tissue.

Small Intestine

Chyme moves from the stomach to the small intestine. The small intestine is the organ where the digestion of protein, fats, and carbohydrates is completed. The small intestine is a long tube-like organ with a highly folded surface containing finger-like projections called the villi. The top surface of each villus has many microscopic projections called microvilli. The epithelial cells of these structures absorb nutrients from the digested food and release them to the bloodstream on the other side. The villi and microvilli, with their many folds, increase the surface area of the small intestine and increase absorption efficiency of the nutrients.

The human small intestine is over 6 m (19.6 ft) long and is divided into three parts: the duodenum, the jejunum and the ileum. The duodenum is separated from the stomach by the pyloric sphincter. The chyme is mixed with pancreatic juices, an alkaline solution rich in bicarbonate that neutralizes the acidity of chyme from the stomach. Pancreatic juices contain several digestive enzymes that break down starches, disaccharides, proteins, and fats. Bile is produced in the liver and stored and concentrated in the gallbladder; it enters the duodenum through the bile duct. Bile contains bile salts, which make lipids accessible to the water-soluble enzymes. The monosaccharides, amino acids, bile salts, vitamins, and other nutrients are absorbed by the cells of the intestinal lining.

The undigested food is sent to the colon from the ileum via peristaltic movements. The ileum ends and the large intestine begins at the ileocecal valve. The vermiform, "worm-like," appendix is located at the ileocecal valve. The appendix of humans has a minor role in immunity.

Large Intestine

The large intestine reabsorbs the water from indigestible food material and processes the waste material (Figure 16.2.3). The human large intestine is much smaller in length compared to the small intestine but larger in diameter. It has three parts: the cecum, the colon, and the rectum. The cecum joins the ileum to the colon and is the receiving pouch for waste matter. The colon is home to many bacteria or "intestinal flora" that aid in the digestive processes. The colon has four regions, the ascending colon, the transverse colon, the descending colon and the sigmoid colon. The main functions of the colon are to extract the water and mineral salts from undigested food, and to store waste material.

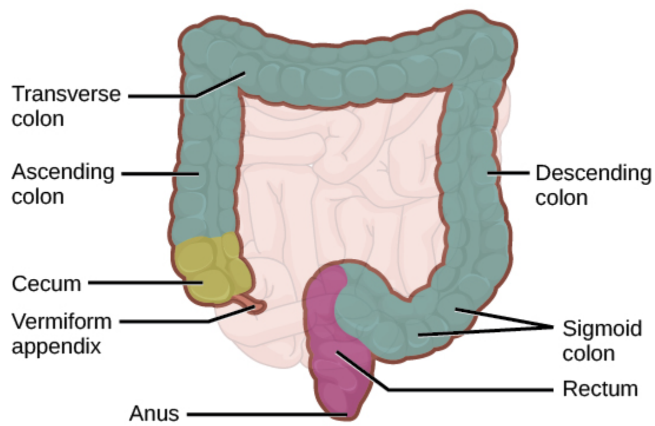


Figure 16.2.3**:** The large intestine reabsorbs water from undigested food and stores waste until it is eliminated. (Credit: modification of work by Mariana Ruiz Villareal)

The rectum (Figure 16.2.3) stores feces until defecation. The feces are propelled using peristaltic movements during elimination. The anus is an opening at the far-end of the digestive tract and is the exit point for the waste material. Two sphincters regulate the exit of feces, the inner sphincter is involuntary, and the outer sphincter is voluntary.

Accessory Organs

The organs discussed above are the organs of the digestive tract through which food passes. Accessory organs add secretions and enzymes that break down food into nutrients. Accessory organs include the salivary glands, the liver, the pancreas, and the gall bladder. The secretions of the liver, pancreas, and gallbladder are regulated by hormones in response to food consumption.

The liver is the largest internal organ in humans, and it plays an important role in digestion of fats and detoxifying blood. The liver produces bile, a digestive juice that is required for the breakdown of fats in the duodenum. The liver also processes the absorbed vitamins and fatty acids and synthesizes many plasma proteins. The gallbladder is a small organ that aids the liver by storing bile and concentrating bile salts.

The pancreas secretes bicarbonate that neutralizes acidic chyme and a variety of enzymes for the digestion of protein and carbohydrates.

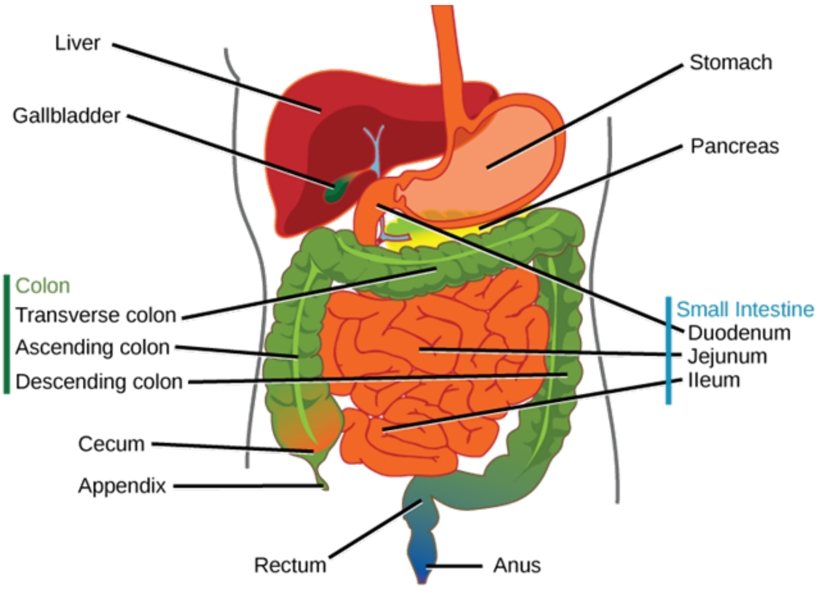


Figure 16.2.4**:** The stomach has an extremely acidic environment where most of the protein gets digested. (Credit: modification of work by Mariana Ruiz Villareal)

The Reproductive System

The **reproductive system** is the human organ system responsible for the production and fertilization of gametes (sperm or eggs) and carrying of a fetus. Both sexes' **gonads** produce gametes. A **gamete** is a haploid cell that combines with another haploid gamete during fertilization, forming a single diploid cell called a zygote. Besides producing gametes, the gonads also produce sex hormones. **Sex hormones** are endocrine hormones that control the development of sex organs before birth, sexual maturation at puberty, and reproduction once sexual maturation has occurred. Other reproductive system organs have various functions, such as maturing gametes, delivering gametes to the site of fertilization, and providing an environment for the development and growth of offspring.

Sex Differences in the Reproductive System

The reproductive system is the only human organ system that is significantly different between males and females. Embryonic structures that will develop into the reproductive system start out the same in males and females, but by birth, the reproductive systems have differentiated. How does this happen?

Sex Differentiation

Starting around the seventh week after conception in genetically male (XY) embryos, a gene called SRY on the Y chromosome (Figure 22.2.2) initiates the production of multiple proteins.

These proteins cause undifferentiated gonadal tissue to develop into testes. Testes secrete hormones — including testosterone — that trigger other changes in the developing offspring (now called a fetus), causing it to develop a complete male reproductive system. Without a Y chromosome, an embryo will develop ovaries, that will produce estrogen. Estrogen, in turn, will lead to the formation of the other organs of a female reproductive system.

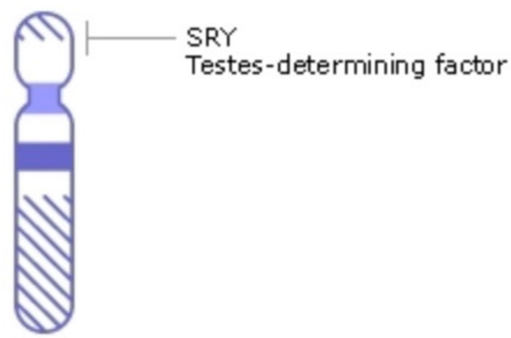


Figure 22.2.2: The SRY gene on the short arm of the Y chromosome causes the undifferentiated gonads of an embryo to develop into testes. Otherwise, the gonads develop into ovaries.

Homologous Structures

Undifferentiated embryonic tissues develop into different structures in male and female fetuses. Structures that arise from the same tissues in males and females are called **homologous structures**. The testes and ovaries, for example, are homologous structures that develop from the undifferentiated gonads of the embryo. Likewise, the penis and clitoris are homologous structures that develop from the same embryonic tissues.

Sex Hormones and Maturation

Male and female reproductive systems are different at birth, but they are immature and incapable of producing gametes or sex hormones. Maturation of the reproductive system occurs during puberty when hormones from the hypothalamus and pituitary gland stimulate the testes or ovaries to start producing sex hormones again. The main sex hormones are **testosterone** and **estrogen**. Sex hormones, in turn, lead to the growth and maturation of the reproductive organs, rapid body growth, and the development of **secondary sex characteristics**, such as body and facial hair and breasts.

Role of Sex Hormones in Transgender Treatment

Feminizing or masculinizing hormone therapy is the administration of exogenous endocrine agents to induce changes in physical appearance. Since hormone therapy is inexpensive relative to surgery and highly effective in the development of secondary sex characteristics (e.g., facial and body hair in female-to-male [FTM] individuals or breast tissue in male-to-females [MTFs]), hormone therapy is often the first, and sometimes only, medical gender affirmation intervention accessed by transgender individuals looking to develop masculine or feminine characteristics consistent with their gender identity. In some cases, hormone therapy may be required before surgical interventions can be conducted. Trans-females are prescribed estrogen and anti-testosterone medication, such as cyproterone acetate and spironolactone. Trans-men are prescribed testosterone.

Male Reproductive System

The main structures of the male reproductive system are external to the body and illustrated in Figure 22.2.3. The two testes (singular, testis) hang between the thighs in a sack of skin called the scrotum. The testes produce both sperm and testosterone. Resting atop each testis is a coiled structure called the epididymis (plural, epididymes). The function of the epididymes is to mature and store sperm. The penis is a tubular organ that contains the urethra and can stiffen during sexual arousal. Sperm passes out of the body through the urethra during a sexual climax (orgasm). This release of sperm is called ejaculation.

In addition to these organs, there are several ducts and glands that are internal to the body. The ducts, which include the vas deferens (also called the ductus deferens), transport sperm from the epididymis to the urethra. The glands, which include the prostate gland and seminal vesicles, produce fluids that become part of semen. Semen is the fluid that carries sperm through the urethra and out of the body. It contains substances that control pH and provide sperm with nutrients for energy.

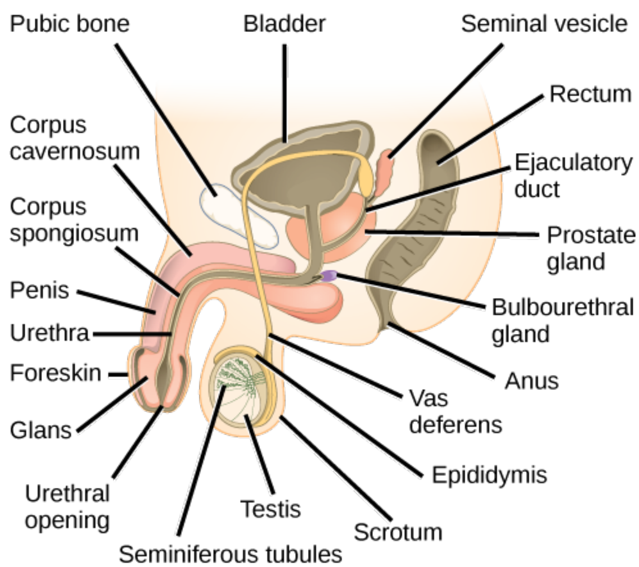


Figure 22.2.3: The main organs of the male reproductive system focus on the seminiferous tubules, testis, scrotum, epididymis, vas deferens, urethra, penis, and the glands that produce semen.

Female Reproductive System

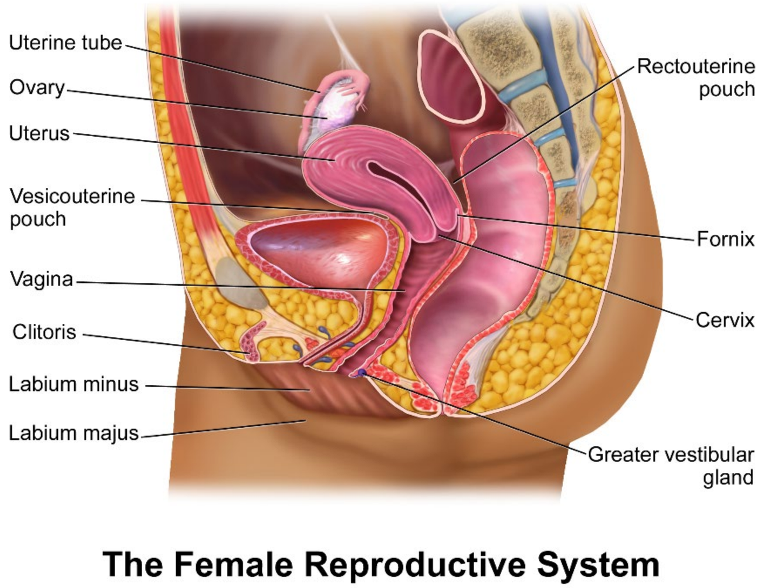


Figure 22.2.4: The main organs of the female reproductive system lie within the abdominal cavity: ovaries, uterine tube, uterus, cervix, and vagina.

The main structures of the female reproductive system are internal to the body and shown in Figure 22.2.4. They include the paired ovaries, which are small, oval structures that produce eggs and secrete estrogen. The two Fallopian tubes (aka uterine tubes) start near the ovaries and end at the uterus. Their function is to transport eggs from the ovaries to the uterus. If an egg is fertilized, it usually occurs while it is traveling through a Fallopian tube. The uterus is a pear-shaped muscular organ that functions to carry a fetus until birth. It can expand greatly to accommodate a growing fetus, and its muscular walls can contract forcefully during labor to push the baby into the vagina. The vagina is a tubular tract connecting the uterus to the outside of the body. The vagina is where sperm is usually deposited during sexual intercourse and ejaculation. The vagina is also called the birth canal because a baby travels through the vagina to leave the body during birth.

The external structures of the female reproductive system are referred to collectively as the vulva. They include the clitoris, which is homologous to the male penis. They also include two pairs of labia (singular, labium), which surround and protect the openings of the urethra and vagina.

Urinary System

The actual human **urinary system**, also known as the renal system, is shown in Figure 19.3.2. The system consists of the kidneys, ureters, bladder, and urethra, which is the only structure not visible in the sculpture above. The main function of the urinary system is to eliminate the waste products of metabolism from the body by forming and excreting **urine.** Between 1 and 2 liters of urine are normally produced every day in a healthy individual.

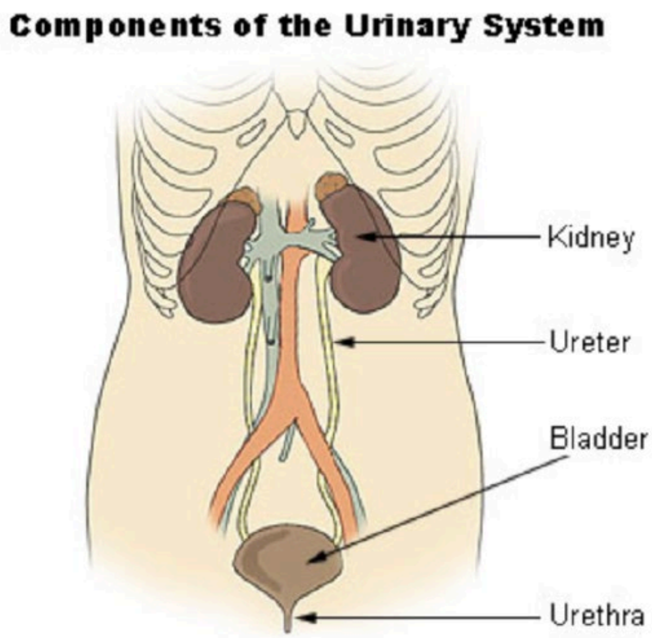


Figure 19.3.2: The components of the urinary system include the two kidneys which lead to two tubes called ureters which lead to a holding structure called the bladder which leads to a tube called the urethra.

Organs of the Urinary System

The urinary system is all about urine. It includes organs that form urine and those that transport, store, or excrete urine.

1) **Kidneys**

Urine is formed by the kidneys, which filter many substances out of blood, allow the blood to reabsorb needed materials, and use the remaining materials to form urine. The human body normally has two paired kidneys, although it is possible to get by quite well with just one kidney.

2) **Ureters, Bladder, Urethra**

After urine forms in the kidneys, it is transported through the ureters (one per kidney) to the sac-like bladder, which stores the urine until urination. During urination, the urine is released from the bladder and transported by the urethra to be excreted outside the body through the external urethral opening.

Functions of the Urinary System

Waste products removed from the body with the formation and elimination of urine include many water-soluble metabolic products. The main waste products are urea, a by-product of protein catabolism, and uric acid, a by-product of nucleic acid catabolism. Excess water and mineral ions are also eliminated in urine.

Besides the elimination of waste products such as these, the urinary system has several other vital functions. These include:

- maintaining homeostasis of mineral ions in extracellular fluid. These ions are either excreted in urine or returned to the blood as needed to maintain the proper balance.

- regulating the acid-base balance in the body. For example, when pH is too low (blood is too acidic), the kidneys excrete less bicarbonate (which is basic) in the urine. When pH is too high (blood is too basic), the opposite occurs, and more bicarbonate is excreted in the urine.

- controlling the volume of extracellular fluids, including the blood, which helps maintain blood pressure. The kidneys control fluid volume and blood pressure by excreting salt and water in urine.

Control of the Urinary System

The formation of urine must be closely regulated to maintain body-wide homeostasis. Several endocrine hormones help control this function of the urinary system, including antidiuretic hormone, parathyroid hormone, and aldosterone.

- Antidiuretic hormone, also called vasopressin, is secreted by the hypothalamus. One of its main roles is conserving body water. It is released when the body is dehydrated and causes the kidneys to excrete less water in urine.

- Parathyroid hormone is secreted by the parathyroid glands. It works to regulate the balance of mineral ions in the body through its effects on several organs, including the kidneys. Parathyroid hormone stimulates the kidneys to excrete less calcium and more phosphorus in the urine.

- Aldosterone is secreted by the cortex of the adrenal glands, which rest atop the kidneys, as shown in Figure 19.3.3. It plays a central role in regulating blood pressure through its effects on the kidneys. It causes the kidneys to excrete less sodium and water in urine.

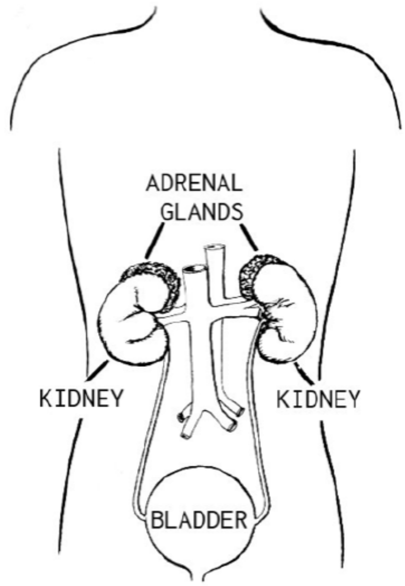


Figure 19.3.3: The adrenal glands are located on top of the kidneys. They secrete aldosterone into the bloodstream, which carries it to the kidneys.

Once urine forms, it is excreted from the body in the process of urination. This process is controlled by both the autonomic and the somatic nervous systems. As the bladder fills with urine, it causes the autonomic nervous system to signal a muscle in the bladder wall to contract and the sphincter between the bladder and urethra to relax and open. This forces urine out of the bladder and through the urethra. Another sphincter at the distal end of the urethra is under voluntary control. When it relaxes under the influence of the somatic nervous system, it allows urine to leave the body through the external urethral opening.

Homeostasis

Each body system contributes to the homeostasis of other systems and of the entire organism. No system of the body works in isolation, and the well-being of the person depends upon the well-being of all the interacting body systems. A disruption within one system has consequences for several other body systems. Most of these organ systems are controlled by **hormones** secreted from the pituitary gland. The table below summarizes how various body systems work together to maintain homeostasis.

Main examples of homeostasis in mammals are as follows:

- The regulation of the amounts of water and minerals in the body. This is known as **osmoregulation.** This happens primarily in the kidneys.
- The removal of metabolic waste. This is known as **excretion.** This is done by the excretory organs such as the kidneys and lungs.
- The regulation of the body temperature. This is mainly done by the skin.

- The regulation of blood glucose levels. This is mainly done by the liver and the insulin and glucagon secreted by the pancreas.

Types of Homeostatic Regulation in the Body

	Homeostatic Processes	**Hormones and Other Messengers**	**Tissues, Organs, and Organ Systems Involved**
Osmoregulation (also called excretion)	Excess water, salts, and urea expelled from the body.	Antidiuretic hormone (ADH), aldosterone, angiotensin II, and carbon dioxide	Kidneys, urinary bladder, ureters, urethra (urinary system), pituitary gland (endocrine system), and lungs (respiratory system).
Thermoregulation	Sweating, shivering, dilation/constriction of blood vessels at the skin surface, insulation by adipose tissue, and breakdown of adipose tissue to produce heat.	Nerve impulses	Skeletal muscle (muscular system), nerves (nervous system), blood vessels (cardiovascular system), skin and adipose tissue (integumentary system), and hypothalamus (endocrine system).
Chemical Regulation (including glucoregulation)	Release of insulin and glucagon into the blood in response to rising and falling blood glucose levels, respectively. Increase in breathing rate in response to increased carbon dioxide levels in the	Insulin, glucagon, cortisol, carbon dioxide, nerve impulses, and erythropoietin (EPO).	Pancreas (endocrine system), liver (digestive system), adrenal glands (endocrine system), lungs (respiratory system), brain (nervous system), and

	blood, release of carbon dioxide into exhaled air from the lungs, and secretion of erythropoietin by kidneys to stimulate formation of red blood cells.		kidneys (urinary system).

Animals

Skeleton

A skeletal system is necessary to support the body, protect internal organs, and allow for the movement of an organism. There are three different skeleton designs that fulfill these functions: hydrostatic skeleton, exoskeleton, and endoskeleton.

A. Hydrostatic Skeleton

A hydrostatic skeleton is a skeleton formed by a fluid-filled compartment within the body, called the coelom. The organs of the coelom are supported by the aqueous fluid, which also resists external compression. This compartment is under hydrostatic pressure because of the fluid and supports the other organs of the organism. This type of skeletal system is found in soft-bodied animals such as sea anemones, earthworms, Cnidaria, and other invertebrates (Figure 38.1.1).

Figure 38.1.1: The skeleton of the red-knobbed sea star (*Protoreaster linckii*) is an example of a hydrostatic skeleton. (Credit: "Amada44"/Wikimedia Commons)

Movement in a hydrostatic skeleton is provided by muscles that surround the coelom. The muscles in a hydrostatic skeleton contract to change the shape of the coelom; the pressure of the fluid in the coelom produces movement. For example, earthworms move by waves of muscular contractions of the skeletal muscle of the body wall hydrostatic skeleton, called peristalsis, which alternately shorten and lengthen the body. Lengthening the body extends the anterior end of the organism. Most organisms have a mechanism to fix themselves in the substrate. Shortening the muscles then draws the posterior portion of the body forward. Although a hydrostatic skeleton is well-suited to invertebrate organisms such as earthworms and some aquatic organisms, it is not an efficient skeleton for terrestrial animals.

B. Exoskeleton

An exoskeleton is an external skeleton that consists of a hard encasement on the surface of an organism. For example, the shells of crabs and insects are exoskeletons (Figure 38.1.2). This skeleton type provides defense against predators, supports the body, and allows for movement through the contraction of attached muscles. As with vertebrates, muscles must cross a joint inside the exoskeleton. Shortening of the muscle changes the relationship of the two segments of the exoskeleton. Arthropods such as crabs and lobsters have exoskeletons that consist of 30–50 percent chitin, a polysaccharide derivative of glucose that is a strong but flexible material. Chitin is secreted by epidermal cells. The exoskeleton is further strengthened by the addition of calcium carbonate in organisms such as the lobster. Because the exoskeleton is acellular, arthropods must periodically shed their exoskeletons because the exoskeleton does not grow as the organism grows.

Figure 38.1.2: Muscles attached to the exoskeleton of the Halloween crab (*Gecarcinus quadratus*) allow it to move.

C. Endoskeleton

An endoskeleton is a skeleton that consists of hard, mineralized structures located within the soft tissue of organisms. An example of a primitive endoskeletal structure is the spicules of sponges. The bones of vertebrates are composed of tissues, whereas sponges have no true tissues (Figure 38.1.1). Endoskeletons provide support for the body, protect internal organs, and allow for movement through contraction of muscles attached to the skeleton.

Figure 38.1.3: The skeletons of humans and horses are examples of endoskeletons. (Credit: Ross Murphy)

Invertebrates

Invertebrates, or invertebrata, are animals that do not contain bony structures, such as the cranium and vertebrae. The simplest of all the invertebrates are the Parazoans, which include only the phylum Porifera: the sponges (Figure 28.1.1). Parazoans do not display tissue-level organization, although they do have specialized cells that perform specific functions. Sponge larvae can swim; however, adults are non-motile and spend their life attached to a substratum. Since water is vital to sponges for excretion, feeding, and gas exchange, their body structure facilitates the movement of water through the sponge. Structures such as canals, chambers, and cavities enable water to move through the sponge to nearly all body cells.

Figure 28.1.1: Sponges are members of the Phylum Porifera, which contains the simplest invertebrates. (Credit: Andrew Turner)

Morphology of Sponges

The morphology of the simplest sponges takes the shape of a cylinder with a large central cavity, the spongocoel, occupying the inside of the cylinder. Water can enter the spongocoel from numerous pores in the body wall. Water entering the spongocoel is extruded via a large common opening called the osculum. However, sponges exhibit a range of diversity in body forms, including variations in the size of the spongocoel, the number of osculi, and where the cells that filter food from the water are located.

While sponges (excluding the hexactinellids) do not exhibit tissue-layer organization, they do have different cell types that perform distinct functions. Pinacocytes, which are epithelial-like cells, form the outermost layer of sponges and enclose a jelly-like substance called mesohyl. Mesohyl is an extracellular matrix consisting of a collagen-like gel with suspended cells that perform various functions. The gel-like consistency of mesohyl acts like an endoskeleton and maintains the tubular morphology of sponges. In addition to the osculum, sponges have multiple pores called ostia on their bodies that allow water to enter the sponge. In some sponges, ostia are formed by porocytes, single tube-shaped cells that act as valves to regulate the flow of water into the spongocoel. In other sponges, ostia are formed by folds in the body wall of the sponge.

Choanocytes (“collar cells”) are present at various locations, depending on the type of sponge, but they always line the inner portions of some space through which water flows (the spongocoel in simple sponges, canals within the body wall in more complex sponges, and chambers scattered throughout the body in the most complex sponges). Whereas pinacocytes line the outside of the sponge, choanocytes tend to line certain inner portions of the sponge body that surround the mesohyl. The structure of a choanocyte is critical to its function, which is to generate a water current through the sponge and to trap and ingest food particles by phagocytosis. Note the similarity in appearance between the sponge choanocyte and choanoflagellates (Protista). This similarity suggests that sponges and choanoflagellates are closely related and share a recent common ancestry. The cell body is embedded in mesohyl and contains all organelles required for normal cell function but protruding into the “open space” inside of the sponge is a mesh-like collar composed of microvilli with a single flagellum in the center of the column. The cumulative effect of the flagella from all choanocytes aids the movement of water through the sponge: drawing water into the sponge through the numerous ostia, into the spaces lined by choanocytes, and eventually out through the osculum (or osculi). In the meantime, food particles, including waterborne bacteria and algae, are trapped by the sieve-like collar of the choanocytes, slide down into the body of the cell, are ingested by phagocytosis, and become encased in a food vacuole. Lastly, choanocytes will differentiate into sperm for sexual reproduction, where they will become dislodged from the mesohyl and leave the sponge with expelled water through the osculum.

The second crucial cells in sponges are called amoebocytes (or archaeocytes), named for the fact that they move throughout the mesohyl in an amoeba-like fashion. Amoebocytes have a variety of functions: delivering nutrients from choanocytes to other cells within the sponge, giving rise to eggs for sexual reproduction (which remain in the mesohyl), delivering phagocytized sperm from choanocytes to eggs, and differentiating into more-specific cell types. Some of these more-specific cell types include collencytes and lophocytes, which produce the collagen-like protein to maintain the mesohyl, sclerocytes, which produce spicules in some sponges, and spongocytes, which produce the protein spongin in most sponges. These cells produce collagen to maintain the consistency of the mesohyl. The different cell types in sponges are shown in Figure 28.1.2.

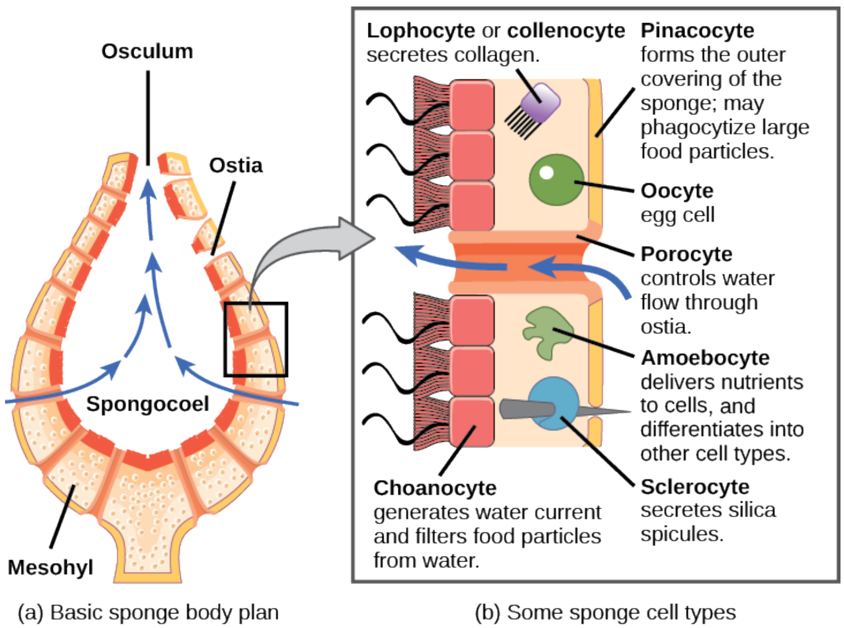


Figure 28.1.2: The sponge's (a) basic body plan and (b) some of the specialized cell types found in sponges are shown.

The presence and composition of spicules/spongin are the differentiating characteristics of the three classes of sponges (Figure 28.1.3): Class Calcarea contains calcium carbonate spicules and no spongin; class Hexactinellida contains six-rayed siliceous spicules and no spongin; and class Demospongia contains spongin and may or may not have spicules (if present, those spicules are siliceous). Spicules are most conspicuously present in class Hexactinellida, the order consisting of glass sponges. Some of the spicules may attain giant proportions (in relation to the typical size range of glass sponges of 3 to 10 mm) as seen in *Monorhaphis chuni*, which grows up to 3 m long.

Figure 28.1.3: (a) *Clathrina clathrus* belongs to class Calcarea, (b) *Staurocalyptus* spp. (common name: yellow Picasso sponge) belongs to class Hexactinellida, and (c) *Acarnus erithacus* belongs to class Demospongia. (Credit a: modification of work by Parent Géry; credit b: modification of work by Monterey Bay Aquarium Research Institute, NOAA; credit c: modification of work by Sanctuary Integrated Monitoring Network, Monterey Bay National Marine Sanctuary, NOAA)

Digestion

Sponges lack complex digestive, respiratory, circulatory, reproductive, and nervous systems. Their food is trapped when water passes through the ostia and out through the osculum. Bacteria smaller than 0.5 microns in size are trapped by choanocytes, which are the principal cells engaged in nutrition, and are ingested by phagocytosis. Particles that are larger than the ostia may be phagocytized by pinacocytes. In some sponges, amoebocytes transport food from cells that have ingested food particles to those that do not. For this type of digestion, in which food particles are digested within individual cells, the sponge draws water through diffusion. The limit of this type of digestion is that food particles must be smaller than individual cells.

All other major body functions in the sponge (gas exchange, circulation, excretion) are performed by diffusion between the cells that line the openings within the sponge and the water that is passing through those openings. All cell types within the sponge obtain oxygen from water through diffusion. Likewise, carbon dioxide is released into seawater by diffusion. In addition, nitrogenous waste produced as a byproduct of protein metabolism is excreted via diffusion by individual cells into the water as it passes through the sponge.

Reproduction

Sponges reproduce by sexual as well as asexual methods. The typical means of asexual reproduction is either fragmentation (where a piece of the sponge breaks off, settles on a new substrate, and develops into a new individual) or budding (a genetically identical outgrowth grows from the parent and eventually detaches or remains attached to form a colony).

Sexual reproduction in sponges occurs when gametes are generated. Sponges are monoecious (hermaphroditic), which means that one individual can produce both gametes (eggs and sperm) simultaneously. In some sponges, production of gametes may occur throughout the year, whereas other sponges may show sexual cycles depending upon water temperature. Sponges may also become sequentially hermaphroditic, producing oocytes first and spermatozoa later.

Vertebrates

Vertebrates are members of the kingdom Animalia and the phylum Chordata (Figure 29.1.1).

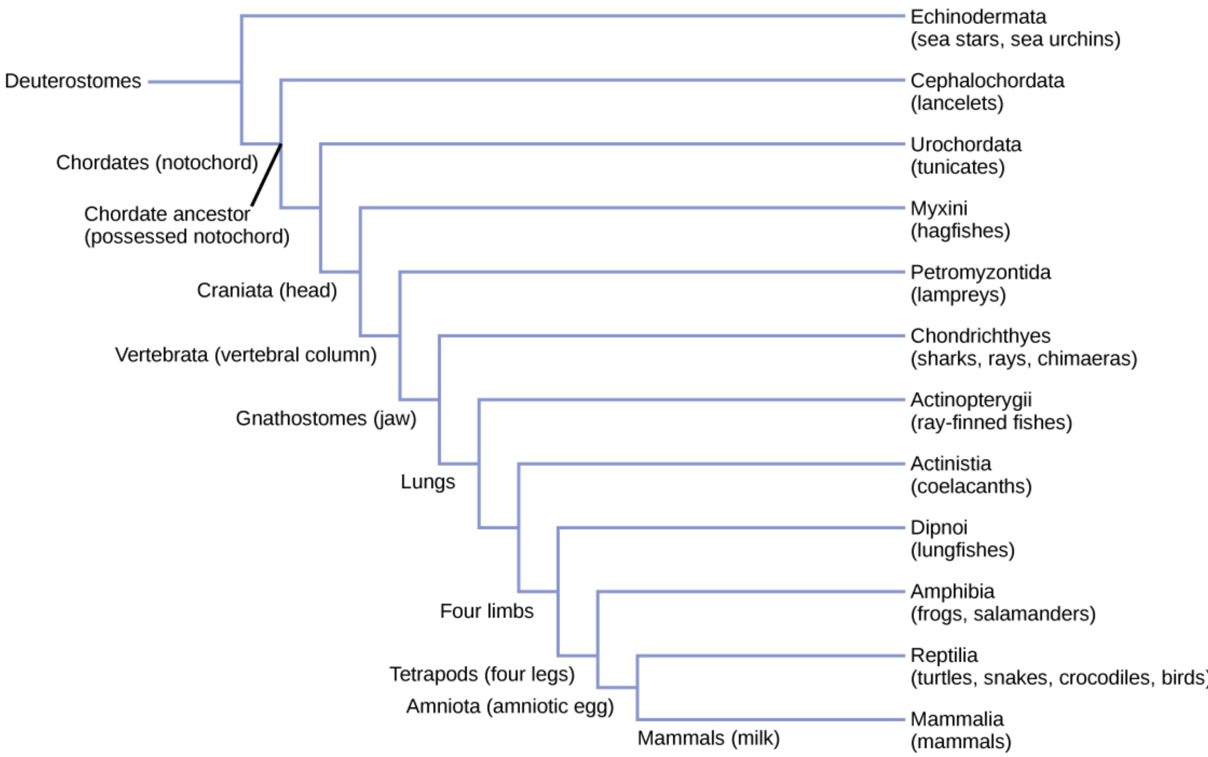


Figure 29.1.1: All chordates are deuterostomes possessing a notochord

Characteristics of Chordata

Animals in the phylum Chordata share four key features that appear at some stage during their development: a notochord, a dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail (Figure 29.1.2). In some groups, some of these are present only during embryonic development.

The chordates are named for the notochord, which is a flexible, rod-shaped structure that is found in the embryonic stage of all chordates and in the adult stage of some chordate species. It is located between the digestive tube and the nerve cord and provides skeletal support through the length of the body. In some chordates, the notochord acts as the primary axial support of the body throughout the animal’s lifetime. In vertebrates, the notochord is present during embryonic development, at which time it induces the development of the neural tube and serves as a support for the developing embryonic body. The notochord, however, is not found in the postnatal stage of vertebrates; at this point, it has been replaced by the vertebral column (that is, the spine).

Fish

Modern fish include an estimated 31,000 species. Fish were the earliest vertebrates, with jawless species being the earliest and jawed species evolving later. They are active feeders, rather than sessile, suspension feeders. Jawless fish—the hagfish and lampreys—have a distinct cranium and complex sense organs including eyes, distinguishing them from the invertebrate chordates.

1) **Jawless Fish**

Jawless fish are craniates that represent an ancient vertebrate lineage that arose over one half-billion years ago. In the past, hagfish and lampreys were classified together as agnathans. Today, hagfish and lampreys are recognized as separate clades, primarily because lampreys are true vertebrates, whereas hagfish are not. A defining feature is the lack of paired lateral appendages (fins). Some of the earliest jawless fish were the ostracoderms (which translates to “shell-skin”). Ostracoderms were vertebrate fish encased in bony armor, unlike present-day jawless fish, which lack bone in their scales.

2) **Myxini: Hagfish**

The clade Myxini includes at least 20 species of hagfish. Hagfish are eel-like scavengers that live on the ocean floor and feed on dead invertebrates, other fish, and marine mammals (Figure 29.2.1). Hagfish are entirely marine and are found in oceans around the world, except for the polar regions. A unique feature of these animals is the slime glands beneath the skin that release mucus through surface pores. This mucus allows the hagfish to escape from the grip of predators. Hagfish can also twist their bodies in a knot to feed and sometimes eat carcasses from the inside out.

Figure 29.2.1: Pacific hagfish are scavengers that live on the ocean floor. (Credit: Linda Snook, NOAA/CBNMS)

The skeleton of a hagfish is composed of cartilage, which includes a cartilaginous notochord that runs the length of the body. This notochord provides support to the hagfish's body. Hagfish do not replace the notochord with a vertebral column during development, as do true vertebrates.

3) Petromyzontidae: Lampreys

The clade Petromyzontidae includes approximately 35–40 or more species of lampreys. Lampreys are like hagfish in size and shape; however, lampreys possess some vertebral elements. Lampreys lack paired appendages and bone, as do hagfish. As adults, lampreys are characterized by a toothed, funnel-like sucking mouth. Many species have a parasitic stage of their life cycle during which they are ectoparasites of fish (Figure 29.2.2).

Figure 29.2.2: These parasitic sea lampreys attach to their lake trout host by suction and use their rough tongues to rasp away flesh in order to feed on the trout's blood. (Credit: USGS)

Lampreys live primarily in coastal and fresh waters, and have a worldwide distribution, except for in the tropics and polar regions. Some species are marine, but all species spawn in fresh water. Eggs are fertilized externally, and the larvae distinctly differ from the adult form, spending 3 to 15 years as suspension feeders. Lampreys possess a notochord as adults; however, this notochord is surrounded by a cartilaginous structure called an arcualia, which may resemble an evolutionarily early form of the vertebral column.

4) Gnathostomes: Jawed Fish

Gnathostomes or "jaw-mouths" are vertebrates that possess jaws. One of the most significant developments in early vertebrate evolution was the development of the jaw, which is a hinged structure attached to the cranium that allows an animal to grasp and tear its food. The evolution of jaws allowed early gnathostomes to exploit food resources that were unavailable to jawless fish.

Early gnathostomes also possessed two sets of paired fins, allowing the fish to maneuver accurately. Pectoral fins are typically located on the anterior body, and pelvic fins on the posterior. Evolution of the jaw and paired fins permitted gnathostomes to expand from the sedentary suspension feeding of jawless fish to become mobile predators.

Figure 29.2.3: *Dunkleosteous* was an enormous placoderm from the Devonian period, 380–360 million years ago. It measured up to 10 meters in length and weighed up to 3.6 tons. (Credit: Nobu Tamura)

5) Chondrichthyes: Cartilaginous Fish

The clade Chondrichthyes is diverse, consisting of sharks (Figure 29.2.4), rays, and skates, together with sawfish and a few dozen species of fish called *chimaeras*, or "ghost" sharks." Chondrichthyes are jawed fish that possess paired fins and a skeleton made of cartilage. Parts of shark skeleton are strengthened by granules of calcium carbonate, but this is not the same as bone.

Most cartilaginous fish live in marine habitats, with a few species living in fresh water for a part or all their lives. Most sharks are carnivores that feed on live prey, either swallowing it whole or using their jaws and teeth to tear it into smaller pieces. Shark teeth likely evolved from the jagged scales that cover their skin, called placoid scales. Some species of sharks and rays are suspension feeders that feed on plankton.

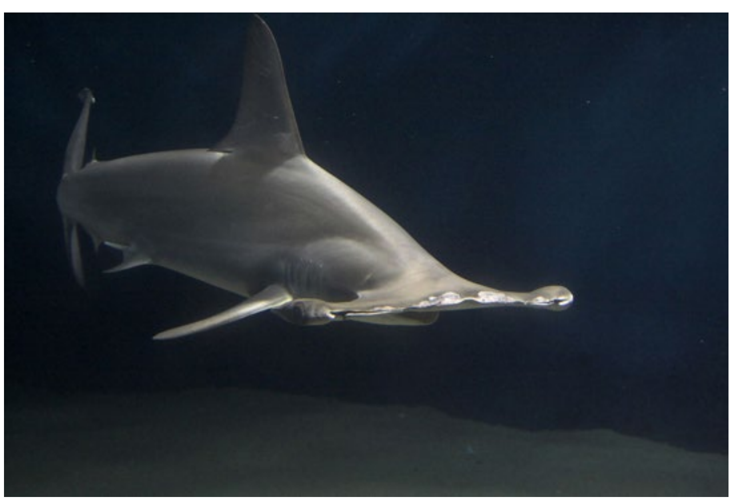


Figure 29.2.4: Hammerhead sharks tend to school during the day and hunt prey at night. (Credit: Masashi Sugawara)

Sharks have well-developed sense organs that aid them in locating prey, including a keen sense of smell and electroreception, with the latter perhaps the most sensitive of any animal. Organs called ampullae of Lorenzini allow sharks to detect the electromagnetic fields that are produced by all living things, including their prey. Electroreception has only been observed in aquatic or amphibious animals. Sharks, together with most fish and aquatic and larval amphibians, also have a sense organ called the lateral line, which is used to detect movement and vibration in the surrounding water and is often considered homologous to “hearing” in terrestrial vertebrates. The lateral line is visible as a darker stripe that runs along the length of a fish’s body.

Sharks reproduce sexually, and eggs are fertilized internally. Most species are ovoviviparous: The fertilized egg is retained in the oviduct of the mother’s body and the embryo is nourished by the egg yolk. The eggs hatch in the uterus, and young are born alive and fully functional. Some species of sharks are oviparous: They lay eggs that hatch outside of the mother’s body. Embryos are protected by a shark egg case or “mermaid’s purse” (Figure 29.2.5) that has the consistency of leather. The shark egg case has tentacles that snag in seaweed and give the newborn shark cover. A few species of sharks are viviparous: The young develop within the mother’s body, and she gives live birth.

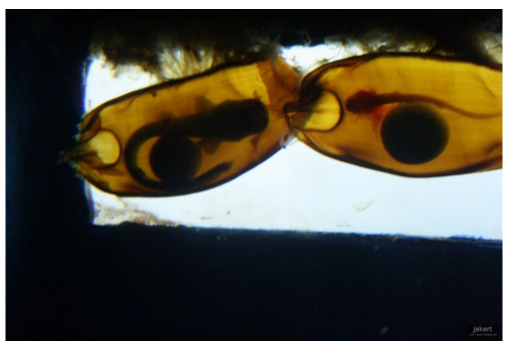


Figure 29.2.5: Shark embryos are clearly visible through these transparent egg cases. The round structure is the yolk that nourishes the growing embryo. (Credit: Jek Bacarisas)

Rays and skates comprise more than 500 species and are closely related to sharks. They can be distinguished from sharks by their flattened bodies, pectoral fins that are enlarged and fused to the head, and gill slits on their ventral surface (Figure 29.2.6). Like sharks, rays and skates have a cartilaginous skeleton. Most species are marine and live on the sea floor, with nearly a worldwide distribution.

Figure 29.2.6: This stingray blends into the sandy bottom of the ocean floor. (Credit: "Sailn1"/Flickr)

6) Osteichthyes: Bony Fish

Members of the clade Osteichthyes, also called bony fish, are characterized by a bony skeleton. Most present-day fish belong to this group, which consists of approximately 30,000 species, making it the largest class of vertebrates in existence today.

Nearly all bony fish have an ossified skeleton with specialized bone cells (osteocytes) that produce and maintain a calcium phosphate matrix. This characteristic has only reversed in a few groups of Osteichthyes, such as sturgeons and paddlefish, which have primarily cartilaginous skeletons. The skin of bony fish is often covered by overlapping scales, and glands in the skin secrete mucus that reduces drag when swimming and aids the fish in osmoregulation. Like sharks, bony fish have a lateral line system that detects vibrations in water.

All bony fish use gills to breathe. Water is drawn over gills that are in chambers covered and ventilated by a protective, muscular flap called the operculum. Many bony fish also have a swim bladder, a gas-filled organ that helps to control the buoyancy of the fish.

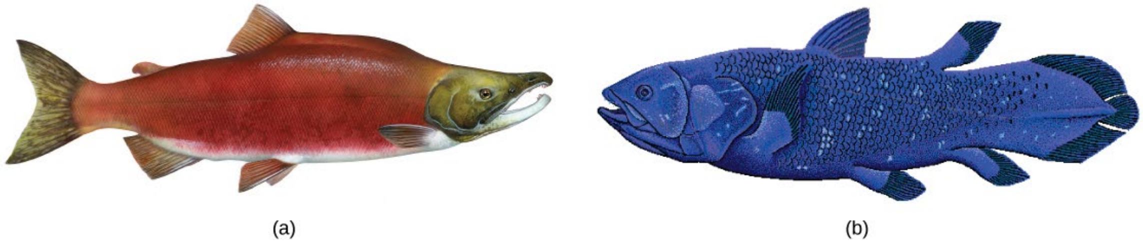


Figure 29.2.7: The (a) sockeye salmon and (b) coelacanth are both bony fish of the Osteichthyes clade. The coelacanth, sometimes called a lobe-finned fish, was thought to have gone extinct in

the Late Cretaceous period, 100 million years ago, until one was discovered in 1938 near the Comoros Islands between Africa and Madagascar. (Credit a: modification of work by Timothy Knepp, USFWS; credit b: modification of work by Robbie Cada).

Amphibians

Amphibians are vertebrate tetrapods. Amphibia includes frogs, salamanders, and caecilians. The term amphibian loosely translates from the Greek as “dual life,” which is a reference to the metamorphosis that many frogs and salamanders undergo and their mixture of aquatic and terrestrial environments in their life cycle. Amphibians evolved during the Devonian period and were the earliest terrestrial tetrapods.

As tetrapods, most amphibians are characterized by four well-developed limbs. Some species of salamanders and all caecilians are functionally limbless; their limbs are vestigial. An important characteristic of extant amphibians is a moist, permeable skin that is achieved via mucus glands that keep the skin moist; thus, exchange of oxygen and carbon dioxide with the environment can take place through it (cutaneous respiration). Additional characteristics of amphibians include pedicellate teeth—teeth in which the root and crown are calcified, separated by a zone of noncalcified tissue—and a papilla amphibiorum and papilla basilaris, structures of the inner ear that are sensitive to frequencies below and above 10,00 hertz, respectively. Amphibians also have an auricular operculum, which is an extra bone in the ear that transmits sounds to the inner ear. All extant adult amphibians are carnivorous, and some terrestrial amphibians have a sticky tongue that is used to capture prey.

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Figure 29.3.2: Most salamanders have legs and a tail, but respiration varies among species. (Credit: Valentina Storti)

Figure 29.3.3: The Australian green tree frog is a nocturnal predator that lives in the canopies of trees near a water source.

Amniotes

The amniotes —reptiles, birds, and mammals—are distinguished from amphibians by their terrestrially adapted egg, which is protected by amniotic membranes. The evolution of amniotic membranes meant that the embryos of amniotes were provided with their own aquatic environment, which led to less dependence on water for development and thus allowed the amniotes to branch out into drier environments. This was a significant development that distinguished them from amphibians, which were restricted to moist environments due to their shell-less eggs. Although the shells of various amniotic species vary significantly, they all allow retention of water. The shells of bird eggs are composed of calcium carbonate and are hard, but fragile. The shells of reptile eggs are leathery and require a moist environment. Most mammals do not lay eggs (except for monotremes). Instead, the embryo grows within the mother's body; however, even with this internal gestation, amniotic membranes are still present.

Characteristics of Amniotes

The amniotic egg is the key characteristic of amniotes. In amniotes that lay eggs, the shell of the egg provides protection for the developing embryo while being permeable enough to allow for the exchange of carbon dioxide and oxygen. The albumin, or egg white, provides the embryo with water and protein, whereas the fattier egg yolk is the energy supply for the embryo, as is the case with the eggs of many other animals, such as amphibians. However, the eggs of amniotes contain three additional extra-embryonic membranes: the chorion, amnion, and allantois (Figure 29.4.1). Extra-embryonic membranes are membranes present in amniotic eggs that are not a part of the body of the developing embryo. While the inner amniotic membrane surrounds the embryo itself, the chorion surrounds the embryo and yolk sac. The chorion facilitates the exchange of oxygen and carbon dioxide between the embryo and the egg's external environment. The amnion protects the embryo from mechanical shock and supports hydration. Allantois stores nitrogenous waste produced by the embryo and facilitates respiration. In mammals, membranes that are homologous to the extra-embryonic membranes in eggs are present in the placenta.

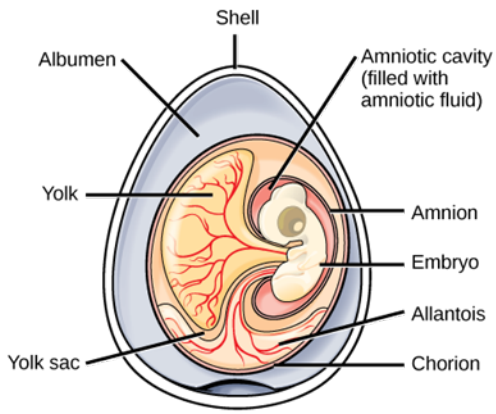


Figure 29.4.1: The key features of an amniotic egg are shown.

Reptiles

Reptiles are tetrapods. Limbless reptiles—snakes and other squamates—have vestigial limbs and, like caecilians, are classified as tetrapods because they are descended from four-limbed ancestors. Reptiles lay eggs enclosed in shells on land. Even aquatic reptiles return to the land to lay eggs. They usually reproduce sexually with internal fertilization. Some species display ovoviviparity, with the eggs remaining in the mother's body until they are ready to hatch. Other species are viviparous, with the offspring born alive.

One of the key adaptations that permitted reptiles to live on land was the development of their scaly skin, containing the protein keratin and waxy lipids, which reduced water loss from the skin. This occlusive skin means that reptiles cannot use their skin for respiration, like amphibians, and thus all breathe with lungs.

Reptiles are ectotherms, animals whose main source of body heat comes from the environment. This contrasts with endotherms, which use heat produced by metabolism to regulate body temperature. In addition to being ectothermic, reptiles are categorized as poikilotherms, or animals whose body temperatures vary rather than remain stable. Reptiles have behavioral adaptations to help regulate body temperature, such as basking in sunny places to warm up and finding shady spots or going underground to cool down. The advantage of ectothermy is that metabolic energy from food is not required to heat the body; therefore, reptiles can survive on about 10 percent of the calories required by a similarly sized endotherm. In cold weather, some reptiles such as the garter snake brumate. Brumation is like hibernation in that the animal becomes less active and can go for long periods without eating but differs from hibernation in that brumating reptiles are not asleep or living off fat reserves. Rather, their metabolism is slowed in response to cold temperatures, and the animal is very sluggish.

Birds

Birds are endothermic, and because they fly, they require large amounts of energy, necessitating a high metabolic rate. Like mammals, which are also endothermic, birds have an insulating covering that keeps heat in the body: feathers. Specialized feathers called down feathers are especially insulating, trapping air in spaces between each feather to decrease the rate of heat loss. Certain parts of a bird's body are covered in down feathers, and the base of other feathers have a downy portion, whereas newly hatched birds are covered in down.

Feathers not only act as insulation but also allow for flight, enabling the lift and thrust necessary to become airborne. The feathers on a wing are flexible, so the collective feathers move and separate as air moves through them, reducing the drag on the wing. Flight feathers are asymmetrical, which affects airflow over them and provides some of the lifting and thrusting force required for flight. Two types of flight feathers are found on the wings, primary feathers and secondary feathers. Primary feathers are located at the tip of the wing and provide thrust. Secondary feathers are located closer to the body, attach to the forearm portion of the wing and provide lift. Contour feathers are the feathers found on the body, and they help reduce drag produced by wind resistance during flight. They create a smooth, aerodynamic surface so that air moves smoothly over the bird's body, allowing for efficient flight.

Mammals

Mammals are vertebrates that possess hair and mammary glands. Several other characteristics are distinctive to mammals, including certain features of the jaw, skeleton, integument, and internal anatomy. Modern mammals belong to three clades: monotremes, marsupials, and eutherians (or placental mammals).

The presence of hair is one of the most obvious signs of a mammal. Although it is not very extensive on certain species, such as whales, hair has many important functions for mammals. Mammals are endothermic, and hair provides insulation to retain heat generated by metabolic work. Hair traps a layer of air close to the body, retaining heat. Along with insulation, hair can serve as a sensory mechanism via specialized hairs called vibrissae, better known as whiskers. These attach to nerves that transmit information about sensation, which is particularly useful to nocturnal or burrowing mammals. Hair can also provide protective coloration or be part of social signaling, such as when an animal's hair stands "on end."

Mammalian integument, or skin, includes secretory glands with various functions. Sebaceous glands produce a lipid mixture called sebum that is secreted onto the hair and skin for water resistance and lubrication. Sebaceous glands are located over most of the body. Eccrine glands produce sweat, or perspiration, which is mainly composed of water. In most mammals, eccrine glands are limited to certain areas of the body, and some mammals do not possess them at all. However, in primates, especially humans, sweat figures prominently in thermoregulation, regulating the body through evaporative cooling. Sweat glands are located over most of the body surface in primates. Apocrine glands, or scent glands, secrete substances that are used for chemical communication, such as in skunks. Mammary glands produce milk that is used to feed newborns. While male monotremes and eutherians possess mammary glands, male marsupials do not. Mammary glands likely are modified sebaceous or eccrine glands, but their evolutionary origin is not entirely clear.

The skeletal system of mammals possesses many unique features. The lower jaw of mammals consists of only one bone, the dentary. The jaws of other vertebrates are composed of more than one bone. In mammals, the dentary bone joins the skull at the squamosal bone, while in other vertebrates, the quadrate bone of the jaw joins with the articular bone of the skull. These bones are present in mammals, but they have been modified to function in hearing and form bones in the middle ear (Figure 29.6.1). Other vertebrates possess only one middle ear bone, the stapes. Mammals have three ear bones: the malleus, incus, and stapes. The malleus originated from the articular bone, whereas the incus originated from the quadrate bone. This arrangement of jaw and ear bones aids in distinguishing fossil mammals from fossils of other synapsids.

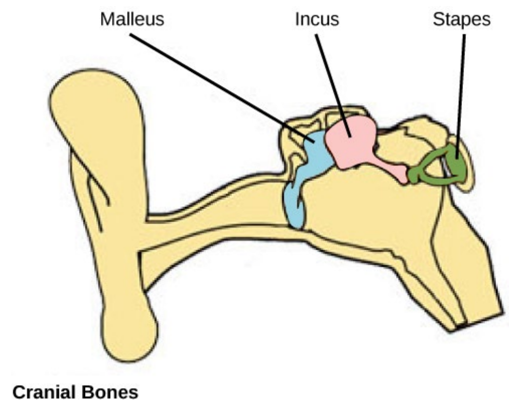


Figure 29.6.1: Bones of the mammalian inner ear are modified from bones of the jaw and skull. (Credit: NCI)

The adductor muscle that closes the jaw is composed of two muscles in mammals: the temporalis and the masseter. These allow side-to-side movement of the jaw, making chewing possible, which is unique to mammals. Most mammals have heterodont teeth, meaning that they have different types and shapes of teeth rather than just one type and shape of tooth. Most mammals are diphyodonts, meaning that they have two sets of teeth in their lifetime: deciduous or “baby” teeth, and permanent teeth. Other vertebrates are polyphyodonts, that is, their teeth are replaced throughout their entire life.

Mammals, like birds, possess a four-chambered heart. Mammals also have a specialized group of cardiac fibers located in the walls of their right atrium called the sinoatrial node, or pacemaker, which determines the rate at which the heart beats. Mammalian erythrocytes (red blood cells) do not have nuclei, whereas the erythrocytes of other vertebrates are nucleated.

The kidneys of mammals have a portion of the nephron called the loop of Henle or nephritic loop, which allows mammals to produce urine with a high concentration of solutes, higher than that of the blood. Mammals lack a renal portal system, which is a system of veins that moves blood from the hind or lower limbs and region of the tail to the kidneys. Renal portal systems are present in all other vertebrates except jawless fish. A urinary bladder is present in all mammals.

Mammalian brains have certain characteristics that differ from other vertebrates. In some, but not all mammals, the cerebral cortex, the outermost part of the cerebrum, is highly folded, allowing for a greater surface area than is possible with a smooth cortex. The optic lobes, located in the midbrain, are divided into two parts in mammals, whereas other vertebrates possess a single, undivided lobe. Eutherian mammals also possess a specialized structure that links the two cerebral hemispheres, called the corpus callosum.

Living Mammals

The eutherians, or placental mammals, and the marsupials together comprise the clade of therian mammals. Monotremes, or metatherians, form their sister clade.

There are three living species of monotremes: the platypus and two species of echidnas, or spiny anteaters. The leathery-beaked platypus belongs to the family Ornithorhynchidae ("bird beak"), whereas echidnas belong to the family Tachyglossidae ("sticky tongue") (Figure 29.6.3). The platypus and one species of echidna are found in Australia, and the other species of echidna is found in New Guinea. Monotremes are unique among mammals as they lay eggs, rather than giving birth to live young. The shells of their eggs are not like the hard shells of birds, but are a leathery shell, like the shells of reptile eggs. Monotremes have no teeth.

Figure 29.6.3: (a) The platypus, a monotreme, possesses a leathery beak and lays eggs rather than giving birth to live young. (b) The echidna is another monotreme. (Credit b: modification of work by Barry Thomas)

Marsupials are found primarily in Australia, though the opossum is found in North America. Australian marsupials include the kangaroo, koala, bandicoot, Tasmanian devil (Figure 29.6.4), and several other species. Most species of marsupials possess a pouch in which the very premature young reside after birth, receiving milk and continuing to develop. Marsupials differ from Eutherians in that there is a less complex placental connection: The young are born at an extremely early age and latch onto the nipple within the pouch.

Figure 29.6.4: The Tasmanian devil is one of several marsupials native to Australia. (Credit: Wayne McLean)

Eutherians are the most widespread of the mammals occurring throughout the world. There are 18 to 20 orders of placental mammals. Some examples are Insectivora, the insect eaters; Edentata, the toothless anteaters; Rodentia, the rodents; Cetacea, the aquatic mammals including whales; Carnivora, carnivorous mammals including dogs, cats, and bears; and Primates, which includes humans. Eutherian mammals are sometimes called placental mammals because all species possess a complex placenta that connects a fetus to the mother, allowing for gas, fluid, and nutrient exchange. While other mammals possess a less complex placenta or briefly have a placenta, all eutherians possess a complex placenta during gestation.

Plants

Photosynthesis

Plants are **producers**, also known as **autotrophs**, which means they can make, or produce, their own food. They also produce the "food" for other organisms. Plants are a type of autotroph that collects the energy from the sun and turns it into organic compounds. Using the energy from the sun, they produce complex organic compounds from simple inorganic molecules. So once again, how does a plant get the food it needs to survive?

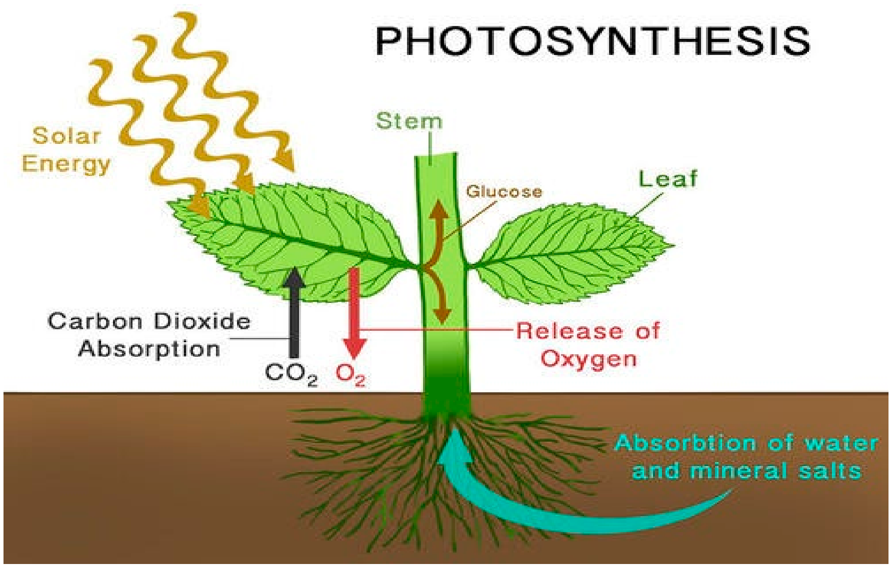
Through photosynthesis. **Photosynthesis** is the process plants use to make their own “food” from the sun's energy, carbon dioxide, and water. During photosynthesis, carbon dioxide and water combine with solar energy to create **glucose**, a carbohydrate ($C_6H_{12}O_6$), and oxygen.

The process can be summarized as:

in the presence of sunlight, carbon dioxide + water → glucose + oxygen.

Glucose, the main product of photosynthesis, is a sugar that acts as the "food" source for plants. The glucose is then converted into usable chemical energy, **ATP**, during **cellular respiration**. The oxygen formed during photosynthesis, which is necessary for animal life, is a waste product of the photosynthesis process.

All organisms obtain their energy from photosynthetic organisms. For example, if a bird eats a caterpillar, then the bird gets the energy that the caterpillar gets from the plants it eats. So, the bird indirectly gets energy that began with the glucose formed through photosynthesis. Therefore, the process of photosynthesis is central to sustaining life on Earth. In eukaryotic organisms, photosynthesis occurs in **chloroplasts**. Only cells with chloroplasts—plant cells and algal (protist) cells—can perform photosynthesis. Animal cells and fungal cells do not have chloroplasts and, therefore, cannot photosynthesize. That is why these organisms, as well as the non-photosynthetic protists, rely on other organisms to obtain their energy. These organisms are **heterotrophs.**



Credit: Laura Guerin; CK-12 Foundation
Source: CK-12 Foundation
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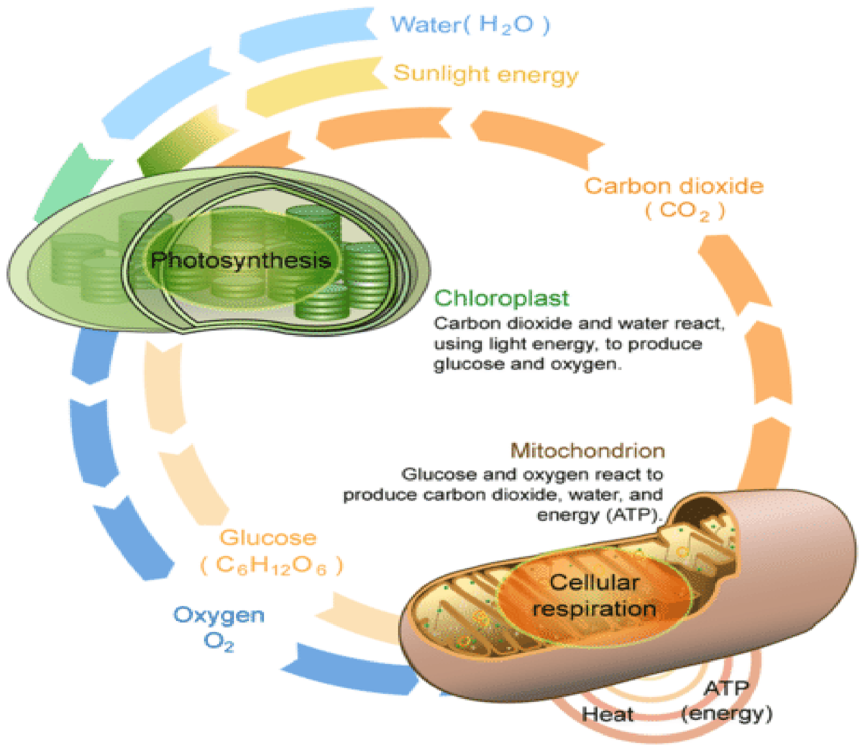
Photosynthesis and Cellular Respiration

What is the relationship between photosynthesis and cellular respiration? Does photosynthesis have to occur prior to cellular respiration? No. Though it is true that the products of photosynthesis are the reactants of cellular respiration, the two can occur simultaneously in the plant cell. The light reactions of photosynthesis also obviously occur during daylight hours, while the light-independent reactions of photosynthesis and the reactions of cellular respiration can occur whenever reactants are available.



This diagram compares photosynthesis (in the chloroplast) and cellular respiration (in the mitochondria). It also shows how the two processes are related.

Credit: Mariana Ruiz Villarreal (LadyofHats) for [CK-12 Foundation]
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Life Cycles of Sexually Reproducing Organisms

Fertilization and meiosis alternate in sexual life cycles. What happens between these two events depends on the organism. The process of meiosis reduces the resulting gamete's chromosome number by half. Fertilization, the joining of two haploid gametes, restores the diploid condition. There are three main categories of life cycles in multicellular organisms:

- diploid-dominant, in which the multicellular diploid stage is the most obvious life stage (and there is no multicellular haploid stage), as with most animals including humans;
- haploid-dominant, in which the multicellular haploid stage is the most obvious life stage (and there is no multicellular diploid stage), as with all fungi and some algae; and
- alternation of generations, in which the two stages, haploid and diploid, are apparent to one degree or another depending on the group, as with plants and some algae.

Most **fungi and algae** employ a life-cycle strategy in which the multicellular “body” of the organism is haploid. During sexual reproduction, specialized haploid cells from two individuals join to form a diploid zygote. The zygote immediately undergoes meiosis to form four haploid cells called spores (Figure 7.1.1 b).

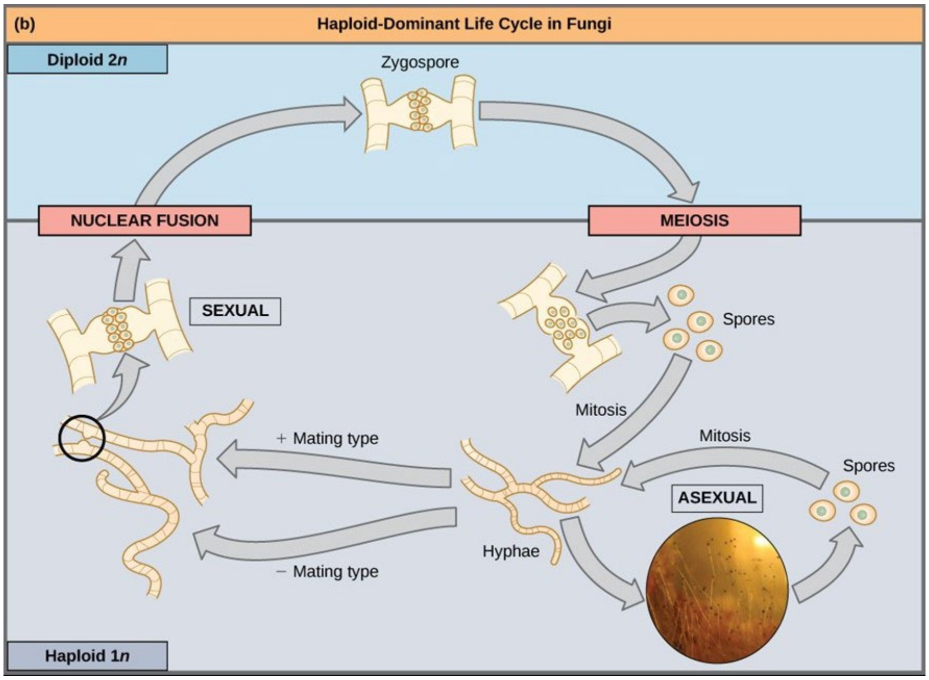


Figure 7.1.1: (b) Fungi, such as black bread mold (Rhizopus nigricans), have haploid-dominant life cycles.

The third life-cycle type, employed by some algae and all plants, is called alternation of generations. These species have both haploid and diploid multicellular organisms as part of their life cycle. The haploid multicellular plants are called gametophytes because they produce gametes. Meiosis is not involved in the production of gametes in this case, as the organism that produces gametes is already haploid. Fertilization between the gametes forms a diploid zygote. The zygote will undergo many rounds of mitosis and give rise to a diploid multicellular plant called a sporophyte. Specialized cells of the sporophyte will undergo meiosis and produce haploid spores. The spores will develop into gametophytes (Figure 7.1.1 c).

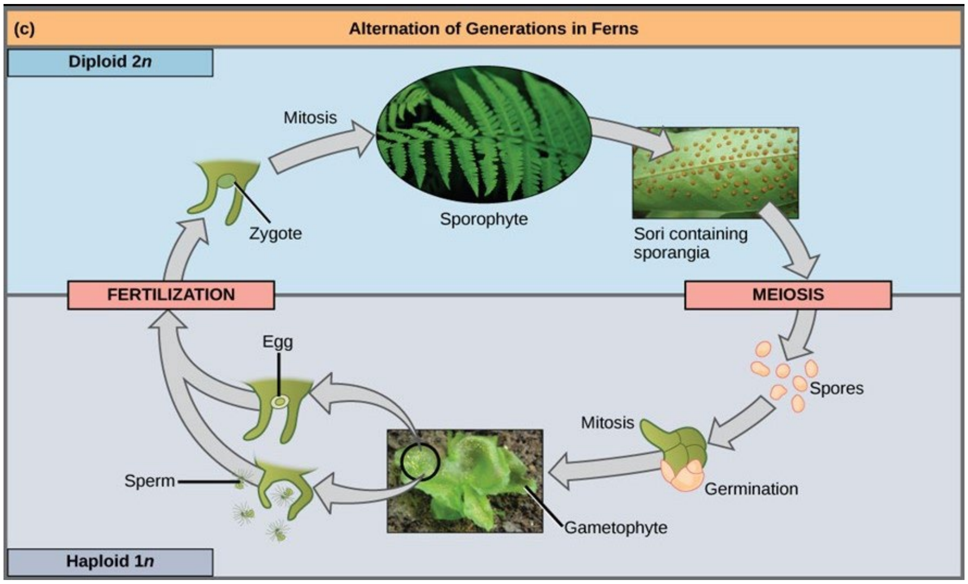


Figure 7.1.1: (c) Plants have a life cycle that alternates between a multicellular haploid organism and a multicellular diploid organism. (Credit c “fern”: modification of work by Cory Zanker; credit c “gametophyte”: modification of work by “Vlmastra”/Wikimedia Commons)

Flowering

The flowering plants (angiosperms) go through a phase of **vegetative growth** producing more stems and leaves and a flowering phase where they produce the organs for sexual reproduction.

In **annuals** the vegetative phase begins with germination of the seed. Flowering follows and ends with the senescence and death of the plant. In **biennials**, the vegetative phase takes up the first year; flowering followed by death occurs the second year.

In **perennials**, flowering typically occurs year after year when conditions are appropriate.

Angiosperms may be monoecious or dioecious and undergo sexual reproduction.

- A typical flower has four main parts, or whorls: the calyx (sepals), corolla (petals), androecium (male reproductive structure), and gynoecium (female reproductive structure).
- Angiosperms that contain both male and female gametophytes within the same flower are called complete and are androgynous or hermaphroditic.
- Angiosperms that contain only male or only female gametophytes are incomplete and are either staminate (contain only male structures) or carpellate (contain only female structures) flowers.

- Microspores develop in the microsporangium and form mature pollen grains (male gametophytes), which are then used to fertilize female gametophytes.
- During megasporogenesis, four megaspores are produced with one surviving; during megagametogenesism, the surviving megaspore undergoes mitosis to form an embryo sac (female gametophyte).
- The sperm, guided by the synergid cells, migrates to the ovary to complete fertilization; the diploid zygote develops into the embryo, while the fertilized ovule forms the other tissues of the seed.

Sexual Reproduction in Angiosperms

The lifecycle of angiosperms follows the alternation of generations. In angiosperms, the haploid gametophyte alternates with the diploid sporophyte during the sexual reproduction process of angiosperms. Flowers contain the plant's reproductive structures.

Flower Structure

A typical flower has four main parts, or whorls: the calyx, corolla, androecium, and gynoecium. The outermost whorl of the flower has green, leafy structures known as sepals, which are collectively called the calyx, and help to protect the unopened bud. The second whorl is comprised of petals, usually brightly colored, collectively called the corolla. The number of sepals and petals varies depending on whether the plant is a monocot or dicot. Together, the calyx and corolla are known as the perianth. The third whorl contains the male reproductive structures and is known as the androecium. The androecium has stamens with anthers that contain the microsporangia. The innermost group of structures in the flower is the gynoecium, or the female reproductive component(s). The carpel is the individual unit of the gynoecium and has a stigma, style, and ovary. A flower may have one or multiple carpels.

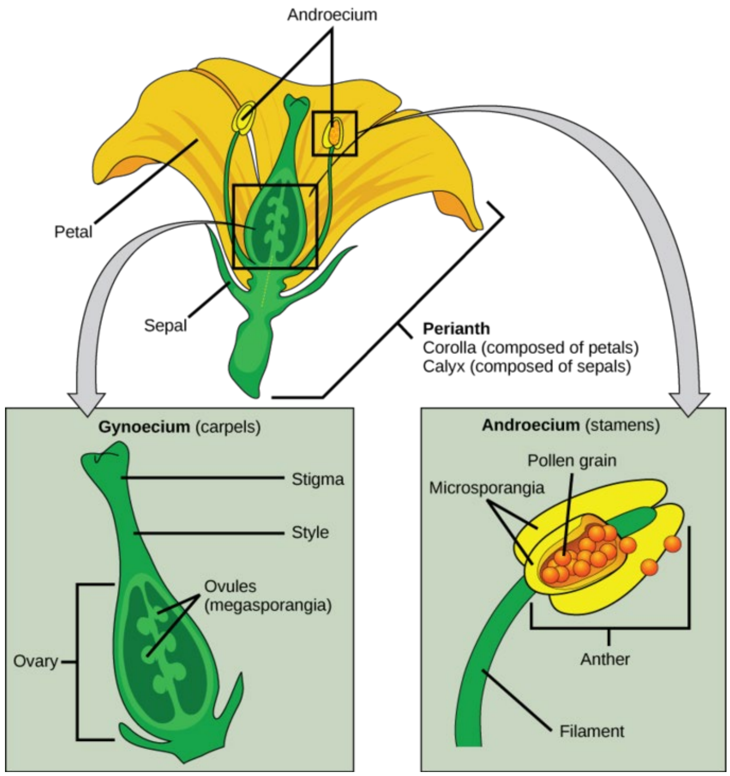


Figure 40.3C.1: **Structures of the flower**: The four main parts of the flower are the calyx, corolla, androecium, and gynoecium. The androecium is the sum of all the male reproductive organs, and the gynoecium is the sum of the female reproductive organs.

If all four whorls are present, the flower is described as complete. If any of the four parts is missing, the flower is known as incomplete. Flowers that contain both an androecium and a gynoecium are called perfect, androgynous, or hermaphrodites. There are two types of incomplete flowers: staminate flowers contain only an androecium; and carpellate flowers have only a gynoecium.

Figure 40.3C.1: **Staminate and carpellate flowers**: The corn plant has both staminate (male) and carpellate (female) flowers. Staminate flowers, which are clustered in the tassel at the tip of the stem, produce pollen grains. Carpellate flowers are clustered in the immature ears. Each strand of silk is a stigma. The corn kernels are seeds that develop on the ear after fertilization. Also shown is the lower stem and root.

If both male and female flowers are borne on the same plant (e.g., corn or peas), the species is called monoecious (meaning “one home”). Species with male and female flowers borne on separate plants (e.g., *C. papaya* or *Cannabis*) are termed dioecious, or “two homes.” The ovary, which may contain one or multiple ovules, may be placed above other flower parts (referred to as superior); or it may be placed below the other flower parts (referred to as inferior).

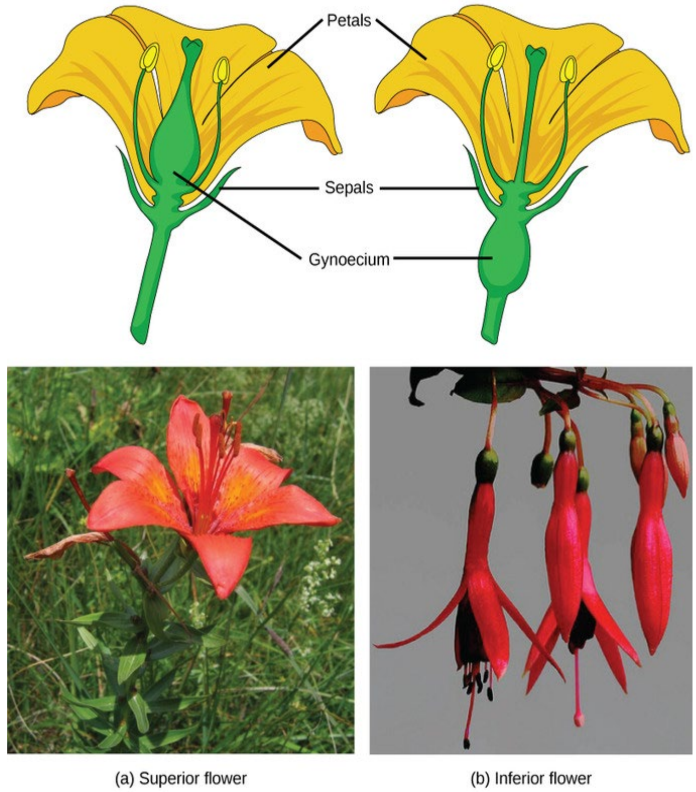


Figure 40.3C.1: **Superior and inferior flowers**: (a) The lily is a superior flower, which has the ovary above the other flower parts. (b) Fuchsia is an inferior flower, which has the ovary beneath other flower parts.

Male Gametophyte

The male gametophyte develops and reaches maturity in an immature anther. In a plant's male reproductive organs, development of pollen takes place in a structure known as the microsporangium. The microsporangia, usually bi-lobed, are pollen sacs in which the microspores develop into pollen grains.

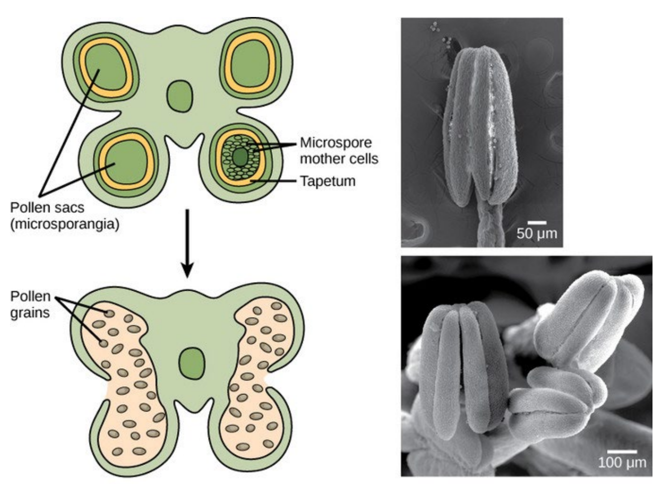


Figure 40.3C.1: **Microsporangium**: (a) Shown is a cross section of an anther at two developmental stages. The immature anther (top) contains four microsporangia, or pollen sacs. Each microsporangium contains hundreds of microspore mother cells that will each give rise to four pollen grains. The tapetum supports the development and maturation of the pollen grains. Upon maturation of the pollen (bottom), the pollen sac walls split open, and the pollen grains (male gametophytes) are released. (b) In these scanning electron micrographs, pollen sacs are ready to burst, releasing their grains.

Within the microsporangium, the microspore mother cell divides by meiosis to give rise to four microspores, each of which will ultimately form a pollen grain. An inner layer of cells, known as the tapetum, provides nutrition to the developing microspores, contributing key components to the pollen wall. Mature pollen grains contain two cells: a generative cell and a pollen tube cell. The generative cell is contained within the larger pollen tube cell. Upon germination, the tube cell forms the pollen tube through which the generative cell migrates to enter the ovary. During its transit inside the pollen tube, the generative cell divides to form two male gametes. Upon maturity, the microsporangia burst, releasing the pollen grains from the anther.

Each pollen grain has two coverings: the exine (thicker, outer layer) and the intine. The exine contains sporopollenin, a complex waterproofing substance supplied by the tapetal cells. Sporopollenin allows the pollen to survive under unfavorable conditions and to be carried by wind, water, or biological agents without undergoing damage.

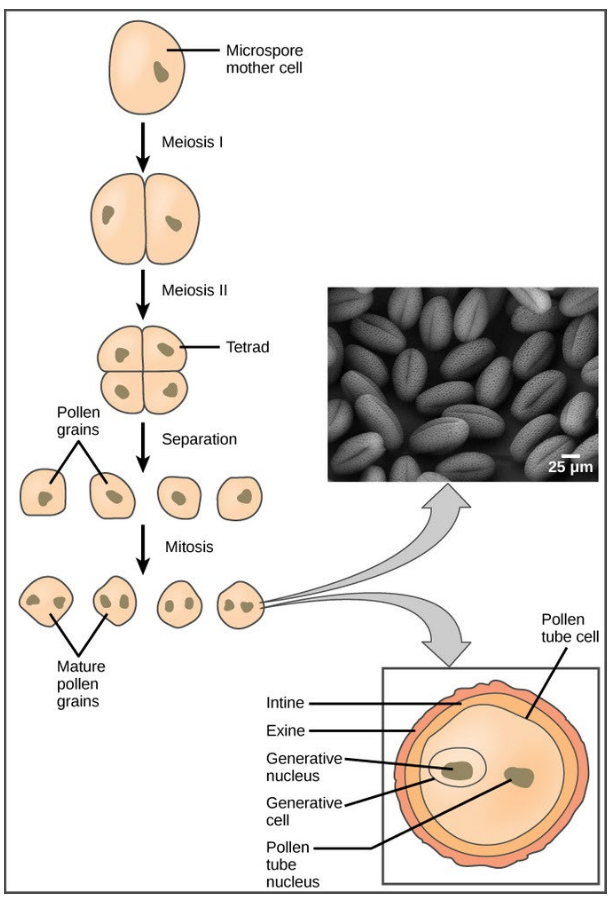


Figure 40.3C.1: **Pollen grain structure**: Pollen develops from the microspore mother cells. The mature pollen grain is composed of two cells: the pollen tube cell and the generative cell, which is inside the tube cell. The pollen grain has two coverings: an inner layer (intine) and an outer layer (exine). The inset scanning electron micrograph shows *Arabidopsis lyrata* pollen grains.

Female Gametophyte (Embryo Sac)

The overall development of the female gametophyte has two distinct phases. First, in the process of megasporogenesis, a single cell in the diploid megasporangium undergoes meiosis to produce four megaspores, only one of which survives. During the second phase, megagametogenesis, the surviving haploid megaspore undergoes mitosis to produce an eight-nucleate, seven-cell female gametophyte, also known as the megagametophyte, or embryo sac. The polar nuclei move to the equator and fuse, forming a single, diploid central cell. This central cell later fuses with sperm to form the triploid endosperm. Three nuclei position themselves at the end of the embryo sac opposite the micropyle and develop into the antipodal cells, which later degenerate. The nucleus closest to the micropyle becomes the female gamete, or egg cell, and the two adjacent nuclei develop into synergid cells. The synergids help guide the pollen tube for successful fertilization, after which they disintegrate. Once fertilization is complete, the resulting diploid zygote develops into the embryo; the fertilized ovule forms the other tissues of the seed.

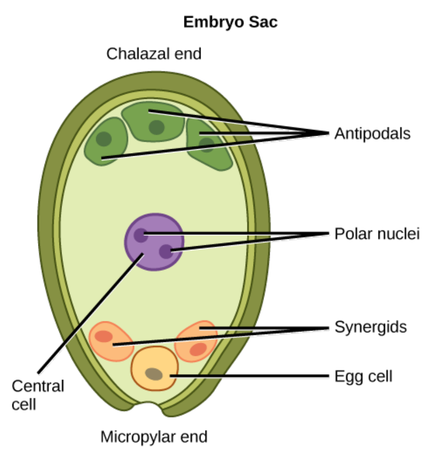


Figure 40.3C.1: **Embryo sac**: As shown in this diagram of the embryo sac in angiosperms, the ovule is covered by integuments and has an opening called a micropyle. Inside the embryo sac are three antipodal cells, two synergids, a central cell, and the egg cell.

A double-layered integument protects the megasporangium and, later, the embryo sac. The integument will develop into the seed coat after fertilization, protecting the entire seed. The ovule wall will become part of the fruit. The integuments, while protecting the megasporangium, do not enclose it completely, but leave an opening called the micropyle. The micropyle allows the pollen tube to enter the female gametophyte for fertilization.

Pollination

Plants can transfer pollen through self-pollination; however, the preferred method is cross-pollination, which maintains genetic diversity.

In angiosperms, pollination is defined as the placement or transfer of pollen from the anther to the stigma of the same or a different flower. In gymnosperms, pollination involves pollen transfer from the male cone to the female cone. Upon transfer, the pollen germinates to form the pollen tube and the sperm fertilizes the egg.

Self-Pollination and Cross-Pollination

Pollination takes two forms: self-pollination and cross-pollination. Self-pollination occurs when the pollen from the anther is deposited on the stigma of the same flower or another flower on the same plant. Cross-pollination is the transfer of pollen from the anther of one flower to the stigma of another flower on a different individual of the same species. Self-pollination occurs in flowers where the stamen and carpel mature at the same time and are positioned so that the pollen can land on the flower's stigma. This method of pollination does not require an investment from the plant to provide nectar and pollen as food for pollinators. These types of pollination have been studied since the time of Gregor Mendel. Mendel successfully carried out self-pollination and cross-pollination in garden peas while studying how characteristics were passed on from one generation to the next. Today's crops are a result of plant breeding, which employs artificial selection to produce the present-day cultivars. An example is modern corn, which is a result of thousands of years of breeding that began with its ancestor, teosinte. The teosinte that the ancient Mesoamericans originally began cultivating had tiny seeds, vastly different from today's relatively giant ears of corn. Interestingly, though these two plants appear to be entirely different, the genetic difference between them is minuscule.

Figure 40.4A.1: **Teosinte**: Teosinte (left) is the ancestor of modern corn (far-right). Although they are morphologically dissimilar, genetically they are not so different.

Genetic Diversity

Living species are designed to ensure survival of their progeny; those that fail become extinct. Genetic diversity is, therefore, required so that in changing environmental or stressful conditions, some of the progeny can survive. Self-pollination leads to the production of plants with less genetic diversity since genetic material from the same plant is used to form gametes and, eventually, the zygote. In contrast, cross-pollination leads to greater genetic diversity because the male and female gametophytes are derived from different plants. Because cross-pollination allows for more genetic diversity, plants have developed many ways to avoid self-pollination. In some species, the pollen and the ovary mature at different times. These flowers make self-pollination nearly impossible. By the time pollen matures and has been shed, the stigma of this flower is mature and can only be pollinated by pollen from another flower. Some flowers have developed physical features that prevent self-pollination. Primrose employs this technique. Primroses have evolved into two flower types with differences in anther and stigma length: the pin-eyed flower and the thrum-eyed flower. In the pin-eyed flower, anthers are positioned at the pollen tube's halfway point, and in the thrum-eyed flower, the stigma is found at this same location. This allows insects to easily cross-pollinate while seeking nectar at the pollen tube. This phenomenon is also known as heterostyly. Many plants, such as cucumbers, have male and female flowers located on different parts of the plant, thus making self-pollination difficult. In other species, the male and female flowers are borne on different plants, making them dioecious. All of these are barriers to self-pollination; therefore, the plants depend on pollinators to transfer pollen. Most pollinators are biotic agents such as insects (bees, flies, and butterflies), bats, birds, and other animals. Other plant species are pollinated by abiotic agents, such as wind and water.

Figure 40.4A.1: **Pollinators**: To maximize their avoidance of self-pollination, plants have evolved relationships with animals, such as bees, to ensure cross-pollination between members of the same species.

Pollination by Insects

1) Bees

Bees are perhaps the most important pollinator of many garden plants and most commercial fruit trees. The most common species of bees are bumblebees and honeybees. Since bees cannot see red, bee-pollinated flowers usually have shades of blue, yellow, or other colors. Bees collect energy -rich pollen or nectar for their survival and energy needs. They visit flowers that are open during the day, are brightly colored, have a strong aroma or scent, and have a tubular shape, typically with the presence of a nectar guide. A nectar guide includes regions on the flower petals that are visible only to bees, which help guide bees to the center of the flower, thus making the pollination process more efficient. The pollen sticks to the bees' fuzzy hair; when the bee visits another flower, some of the pollen is transferred to the second flower. Recently, there have been many reports about the declining population of honeybees. Many flowers will remain unpollinated, failing to bear seeds if honeybees disappear. The impact on commercial fruit growers could be devastating.

2) Flies

Many flies are attracted to flowers that have a decaying smell or an odor of rotting flesh. These flowers, which produce nectar, usually have dull colors, such as brown or purple. They are found on the corpse flower or voodoo lily (*Amorphophallus*), dragon arum (*Dracunculus*), and carrion flower *(Stapleia, Rafflesia*). Nectar provides energy while pollen provides protein. Wasps are also important insect pollinators, pollinating many species of figs.

3) Butterflies and Moths

Butterflies, such as the monarch, pollinate many garden flowers and wildflowers, which are usually found in clusters. These flowers are brightly colored, have a strong fragrance, are open during the day, and have nectar guides. The pollen is picked up and carried on the butterfly's limbs. Moths, on the other hand, pollinate flowers during the late afternoon and night. The flowers pollinated by moths are pale or white and are flat, enabling the moths to land. One well-studied example of a moth-pollinated plant is the yucca plant, which is pollinated by the yucca moth. The shape of the flower and moth have adapted in a way to allow successful pollination. The moth deposits pollen on the sticky stigma for fertilization to occur later. The female moth also deposits eggs into the ovary. As the eggs develop into larvae, they obtain food from the flower and developing seeds. Thus, both the insect and flower benefit from each other in this symbiotic relationship. The corn earworm moth and *Gaura* plant have a similar relationship.

Figure 40.4B.1: **Moths as pollinators**: A corn earworm (a moth) sips nectar from a night-blooming Gaura plant. Both the moth and plant benefit from each other as they have formed a symbiotic relationship; the plant is pollinated while the moth is able to obtain food.

Non-Insect Methods of Pollination

4) **Pollination by Bats**

In the tropics and deserts, bats are often the pollinators of nocturnal flowers such as agave, guava, and morning glory. The flowers are usually large and white or pale-colored so that they can be distinguished from their dark surroundings at night. The flowers have a strong, fruity, or musky fragrance and produce large amounts of nectar. They are naturally large and wide-mouthed to accommodate the head of the bat. As the bats seek the nectar, their faces and heads become covered with pollen, which is then transferred to the next flower.

5) **Pollination by Birds**

Many species of small birds, such as hummingbirds and sun birds, are pollinators for plants such as orchids and other wildflowers. Flowers visited by birds are usually sturdy and are oriented in a way to allow the birds to stay near the flower without getting their wings entangled in the nearby flowers. The flower typically has a curved, tubular shape, which allows access for the bird's beak. Brightly colored, odorless flowers that are open during the day are pollinated by birds. As a bird seeks energy-rich nectar, pollen is deposited on the bird's head and neck and is then transferred to the next flower it visits. Botanists determine the range of extinct plants by collecting and identifying pollen from 200-year-old bird specimens from the same site.

Figure 40.4C.1: **Pollination by birds**: Hummingbirds have adaptations that allow them to reach the nectar of certain tubular flowers, thereby aiding them in the process of pollination.

6) **Pollination by Wind**

Most species of conifers and many angiosperms, such as grasses, maples, and oaks, are pollinated by wind. Pinecones are brown and unscented, while the flowers of wind-pollinated angiosperm species are usually green, small, may have small or no petals, and produce large amounts of pollen. Unlike the typical insect-pollinated flowers, flowers adapted to pollination by wind do not produce nectar or scent. In wind-pollinated species, the microsporangia hang out of the flower, and, as the wind blows, the lightweight pollen is carried with it. The flowers usually emerge early in the spring before the leaves so that the leaves do not block the movement of the wind. The pollen is deposited on the exposed feathery stigma of the flower.

Figure 40.4C.: **Wind pollination**: This male (a) and female (b) catkins from the goat willow tree (*Salix caprea*) have structures that are light and feathery to better disperse and catch the wind-blown pollen.

7) **Pollination by Water**

Some weeds, such as Australian sea grass and pond weeds, are pollinated by water. The pollen floats on water. When it encounters the flower, it is deposited inside the flower.

8) Pollination by Deception

Orchids are highly valued flowers, with many rare varieties. They grow in a range of specific habitats, mainly in the tropics of Asia, South America, and Central America. At least 25,000 species of orchids have been identified.

Flowers often attract pollinators with food rewards, in the form of nectar. However, some species of orchid are an exception to this standard; they have evolved different ways to attract the desired pollinators. They use a method known as food deception, in which bright colors and perfumes are offered, but no food. *Anacamptis morio*, commonly known as the green-winged orchid, bears bright purple flowers and emits a strong scent. The bumblebee, its main pollinator, is attracted to the flower because of the strong scent, which usually indicates food for a bee. In the process, the bee picks up the pollen to be transported to another flower.

Other orchids use sexual deception. *Chiloglottis trapeziformis* emits a compound that smells the same as the pheromone emitted by a female wasp to attract male wasps. The male wasp is attracted to the scent, lands on the orchid flower, and, in the process, transfers pollen. Some orchids, like the Australian hammer orchid, use scent as well as visual trickery in yet another sexual deception strategy to attract wasps. The flower of this orchid mimics the appearance of a female wasp and emits a pheromone. The male wasp tries to mate with what appears to be a female wasp, but instead picks up pollen, which it then transfers to the next counterfeit mate.

Figure 40.4C.1: **Pollination by deception in orchids**: Certain orchids use food deception or sexual deception to attract pollinators. Shown here is a bee orchid (*Ophrys apifera*).

Germination

Many mature seeds enter a period of inactivity, or extremely low metabolic activity: a process known as dormancy, which may last for months, years or even centuries. Dormancy helps keep seeds viable during unfavorable conditions. **Germination** occurs when the embryo, which is dormant within a mature seed, resumes growth upon a return to favorable conditions. The embryo becomes a young seedling that is no longer confined within the seed coat.

In many seeds, the presence of a thick seed coat can inhibit germination through several mechanisms: (1) the embryo may not be able to break through the thick seed coat; (2) the seed coat may contain chemicals inhibitors; and (3) the seed coat prevents the embryo from accessing water and oxygen. Dormancy is also maintained by the relative hormone concentrations in the embryo itself.

Environmental Requirements for Germination

The requirements for germination depend on the species. Common environmental requirements include light, the proper temperature, presence of oxygen, and presence of water. Seeds of small-seeded species usually require light as a germination cue. This ensures the seeds only germinate at or near the soil surface (where the light is greatest). If they were to germinate too far underneath the surface, the developing seedling would not have enough food reserves to reach the sunlight. (That red light induces germination by converting the inactive form of phytochrome (Pr) to the active form (Pfr), which leads to the production of amylase. This enzyme breaks down the limited food reserves in the seed, facilitating germination.)

Not only do some species require a specific temperature to germinate, but they may also require a prolonged cold period prior to germination. In this case, cold conditions gradually break down a chemical germination inhibitor. This mechanism prevents seeds from germinating during an unseasonably warm spell in the autumn or winter in temperate climates. Similarly, plants growing in hot climates may have seeds that need a hot period in order to germinate, an adaptation to avoid germination in the hot, dry summers.

Water is always needed to allow vigorous metabolism to begin. Additionally, water can leach away inhibitors in the seed coat. This is especially common among desert annuals. Seeds that are dispersed by animals may need to pass through an animal digestive tract to remove inhibitors prior to germination. Similarly, some species require mechanical abrasion of the seed coat, which could be achieved by water dispersal. Other species are fire adapted, requiring fire to break dormancy

The Mechanism of Germination

The first step in germination starts with the uptake of water, also known as **imbibition**. After imbibition, enzymes are activated that start to break down starch into sugars consumed by embryo. The first indication that germination has begun is a swelling in the radicle.

Depending on seed size, the time taken for a seedling to emerge may vary. Species with large seeds have enough food reserves to germinate deep below ground, and still extend their epicotyl all the way to the soil surface while the seedlings of small-seeded species emerge more quickly (and can only germinate close to the surface of the soil).

During **epigenous germination**, the hypocotyl elongates, and the cotyledons extend above ground. During **hypogenous germination**, the epicotyl elongates, and the cotyledon(s) remain belowground (Figure 40.6.1.2). Some species (like beans and onions) have epigenous germination while others (like peas and corn) have hypogeous germination. In many epigenous species, the cotyledons not only transfer their food stores to the developing plant but also turn green and make more food by photosynthesis until they drop off.

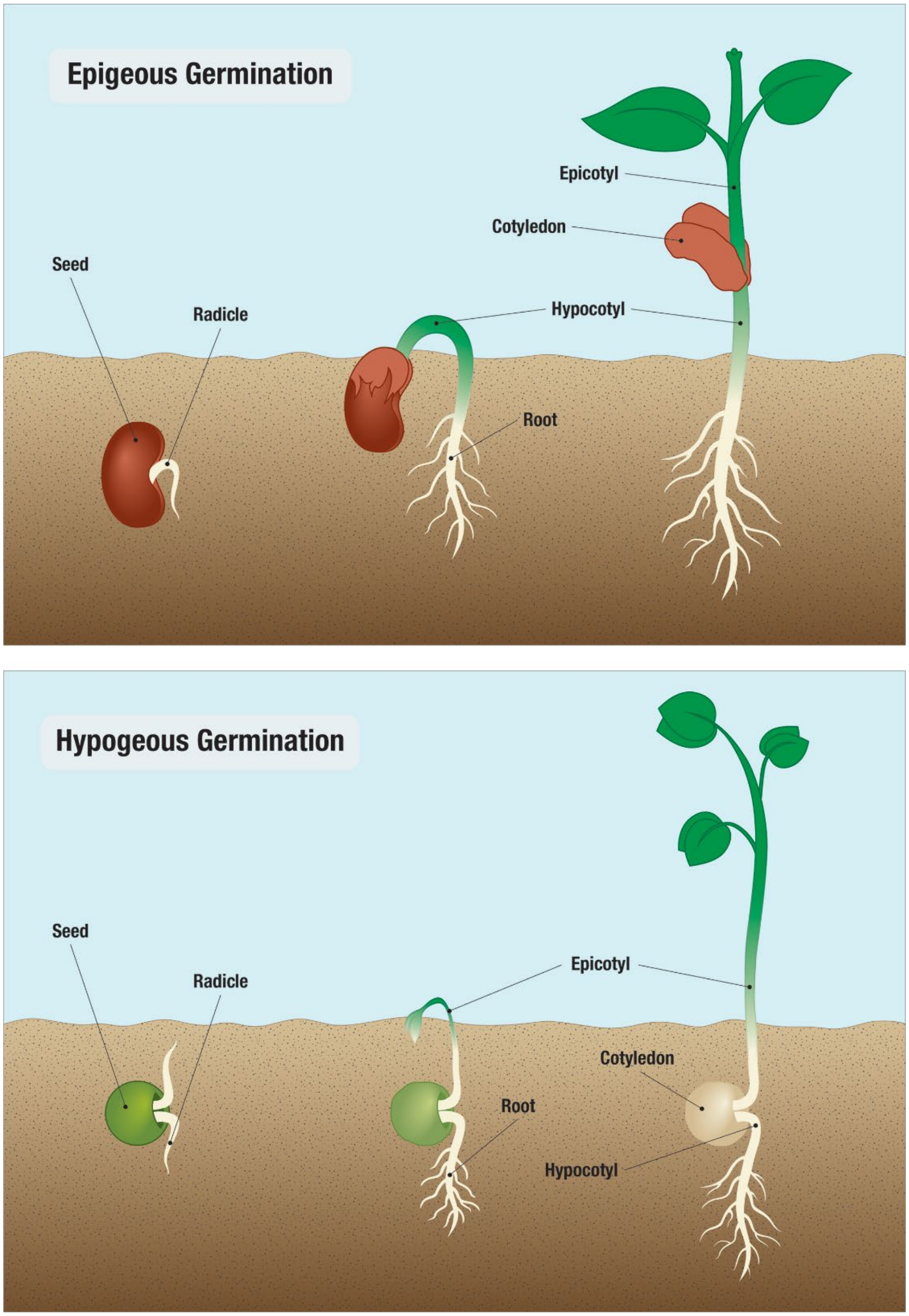


Figure 40.6.1.2: Epigeous germination in bean (top) and hypogenous germination in pea (bottom). For the bean, the radicle emerges from the seed. Next, the hypocotyl elongates, and the cotyledons are pushed aboveground. The epicotyl is just above the cotyledon. For the pea, the radicle also emerges from the seed. The epicotyl elongates, and the cotyledons remain below the ground. The hypocotyl remains short and lies between the root and cotyledon. Image by Jen Valenzuela (CC-BY).

Germination in Eudicots

Upon germination in eudicot seeds, the radicle emerges from the seed coat while the seed is still buried in the soil.

For epigenous eudicots (like beans), the hypocotyl is shaped like a hook with the plumule pointing downwards. This shape is called the plumule hook, and it persists if germination proceeds in the dark. Therefore, as the hypocotyl pushes through the tough and abrasive soil, the plumule is protected from damage. Additionally, the two cotyledons additionally protect them from mechanical damage. Upon exposure to light, the hypocotyl hook straightens out, the young foliage leaves face the sun and expand, and the epicotyl elongates (Figure 40.6.1.3).

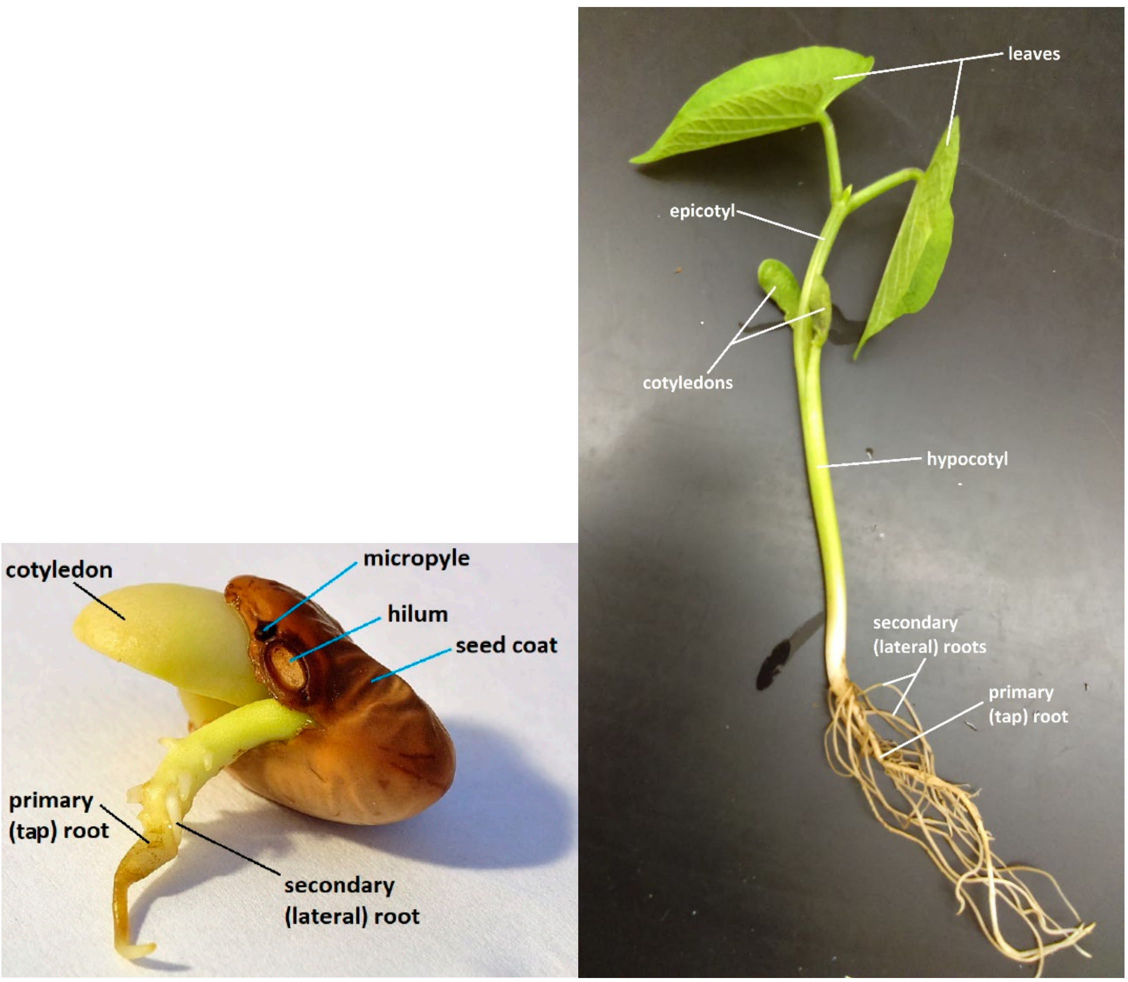


Figure 40.6.1.3: A bean seed begins to germinate (left) and a germinated bean seedling (right). Beans are epigenous eudicots, meaning that the hypocotyl elongates, pushing the cotyledons above the ground. On the left, the large cotyledons have just emerged from the seed coat. The oval hilum is next to a tiny, round micropyle on the seed coat. The primary (tap) root has emerged, and secondary (lateral) roots begin to branch from the primary root. On the right, the green hypocotyl has elongated, pushing the cotyledons aboveground. The cotyledons are green

and still have the shape of the bean seed. The epicotyl is the part of the stem above the cotyledons. Broad, heart-shaped leaves branch from it. Unlike the cotyledons, these are true leaves. At the tip of the stem, between the leaves is the shoot apical meristem. There is a central, thick root called the primary (tap) root. The roots that branch form it is secondary (lateral) roots. Left image by Doronenko (CC-BY-SA). Right image by Melissa Ha (CC-BY).

In hypogenous eudicots (like peas), the epicotyl rather than the hypocotyl forms a hook, and the cotyledons and hypocotyl thus remain underground. When the epicotyl emerges from the soil, the young foliage leaves expand. The epicotyl continues to elongate (Figure 40.6.1.4).

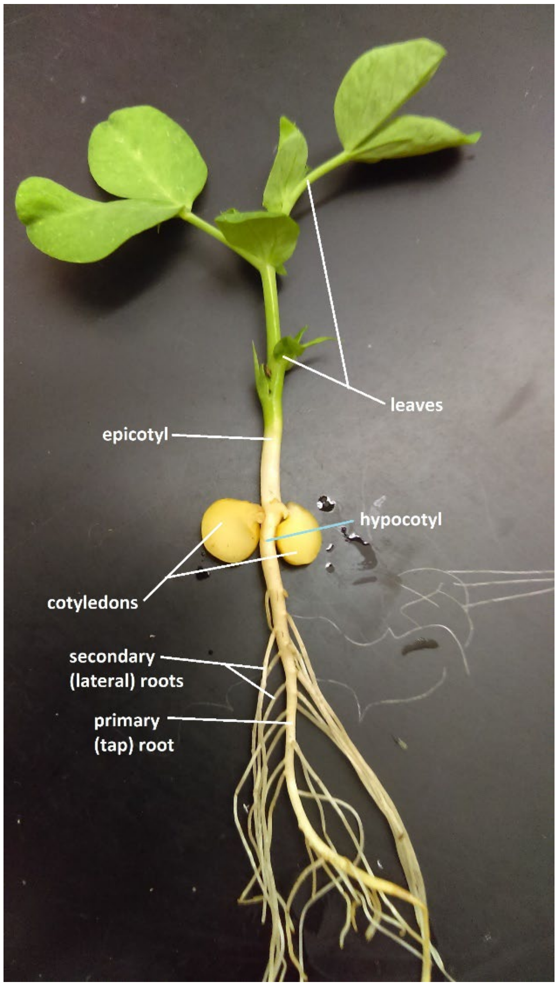


Figure 40.6.1.4: A germinated pea seedling. Peas are hypogenous eudicot. The hypocotyl never elongates, and the cotyledons remain below ground. The green and white epicotyl has elongated, giving rise to true leaves, and the cotyledons remain belowground. These true leaves are compound (are composed of smaller leaflets). This seedling has been uprooted and washed, but everything below the epicotyl was belowground. The hypocotyl is the short segment of stem between the cotyledons and roots. It never elongated enough to push the cotyledons above the ground. There is a central, thick root called the primary (tap) root. The roots that branch form it is secondary (lateral) roots. Image by Melissa Ha (CC-BY).

The radicle continues to grow downwards and ultimately produces the tap root. Lateral roots then branch off to all sides, producing the typical eudicot tap root system.

Germination in Monocots

As the seed germinates, the radicle emerges and forms the first root. In epigenous monocots (such as onion), the single cotyledon will bend, forming a hook and emerge before the coleoptile (Figure 40.6.1.5). In hypogenous monocots (such as corn), the cotyledon remains belowground, and the coleoptile emerges first. In either case, once the coleoptile has exited the soil and is exposed to light, it stops growing. The first leaf of the plumule then pieces the coleoptile (Figure 40.6.1.6), and additional leaves expand and unfold. At the other end of the embryonic axis, the first root soon dies while adventitious roots (roots that arise directly from the shoot system) emerge from the base of the stem (Figure 40.6.1.7). This gives the monocot a fibrous root system.

Figure 40.6.1.5: The scallion (spring onion) is an epigenous monocot. The curved structure emerging from the ground is the single cotyledon. Later in the process, the coleoptile will emerge, and be pierced by the first leaf of the plumule. Image by Dennis Brown (CC-BY-SA)

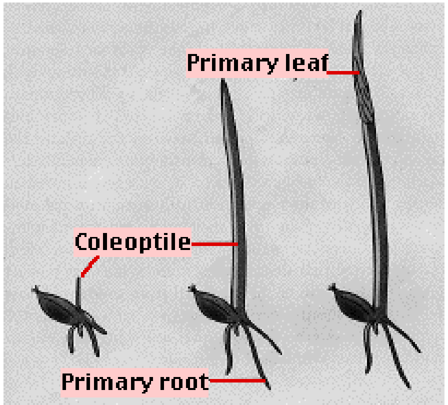


Figure 40.6.1.6: Germination of an oat seed, a hypogeous monocot. Here the first root formed by the radicle is labeled "primary root" but note that this differs from the primary (main) root of

a eudicot tap root system. Note that several adventitious roots have also formed and will ultimately produce a fibrous root system. The coleoptile is the first component of the shoot system to emerge in hypogeous monocots, but it is ultimately pieced by the first (primary) leaf of the plumule.

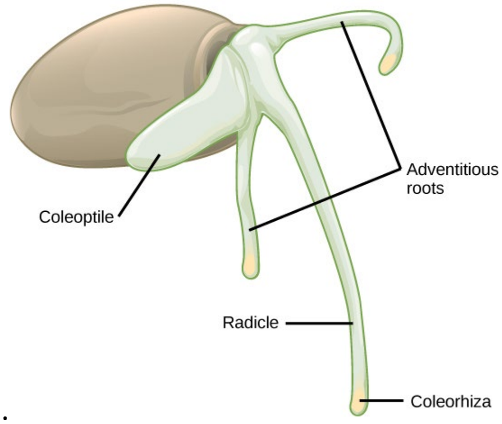


Figure 40.6.1.7: As this monocot grass seed germinates, the radicle emerges first, followed by the coleoptile, and the adventitious roots. The coleorhiza, a protective sheath that surrounded the radicle in the dormant seed, is now at the tip of the radicle.

Ecosystem and Nutrients

What Is an Ecosystem

Like other systems, an **ecosystem** is a set of interacting components that form a complex whole. The interacting components of an ecosystem are all its living things and its nonliving environment. The nonliving environment includes such abiotic factors as temperature, water, sunlight, and minerals in the soil. A community is the biotic part of an ecosystem. It consists of all the populations of all the species that live and interact in the ecosystem. The abiotic and biotic parts of an ecosystem are linked together by flows of energy and cycles of nutrients through the system.

There is no widely agreed upon way to delineate a specific ecosystem. Theoretically, ecosystems can vary tremendously in size. Consider a forest as an example. It might cover hundreds or even thousands of acres, forming a large ecosystem in which an individual tree is of little consequence. However, an individual tree can also be considered an ecosystem, with millions of organisms living in and on it, ranging from microbes to small mammals. Even a single leaf can be considered an ecosystem. Several generations of an aphid population can exist over the lifespan of the leaf, as in Figure 24.3.2. Each of the aphids, in turn, supports a diverse community of bacteria.

Figure 24.3.2: Tiny insects called aphids live on and feed off this leaf; along with bacteria, they form a miniature leaf ecosystem.

Ecosystem Processes

Ecosystem processes move energy and matter through the biotic and abiotic components of the system. These processes begin with primary production by producers. The energy that flows through almost all ecosystems is obtained primarily from the sun and enters ecosystems through the process of photosynthesis. This process is carried out by producers that may include plants, certain microbes, and/or algae. These producers capture energy from sunlight and use it to turn inorganic carbon dioxide (from the atmosphere) and water into organic carbon molecules and oxygen.

Figure 24.3.3: Fungi (mushrooms) are the primary decomposers of plant litter in many ecosystems.

Mineral Nutrient Recycling

Ecosystems continually take in energy from the wider environment around them. Mineral nutrients, on the other hand, are mostly recycled within ecosystems among living things and abiotic components of ecosystems. Nitrogen in the atmosphere, for example, is taken up by certain soil bacteria, which change the nitrogen to a form that plants can use. From plants, nitrogen cycles go to animals and eventually to decomposers, which return nitrogen to the soil. In most terrestrial ecosystems, nitrogen is a limiting factor in plant growth. A **limiting factor** is any factor that constrains the population size of one or more species in an ecosystem. Because most terrestrial ecosystems are nitrogen-limited, nitrogen cycling is an important control on ecosystem production. Other nutrients that are recycled within ecosystems include phosphorus, potassium, and magnesium.

Ecosystem Goods and Services

Ecosystems provide a variety of goods and services upon which people depend. Without healthy natural ecosystems, we could not survive as a species. Ecosystem goods include tangible, material products of ecosystem processes, including foods such as wild game and fruits, construction materials such as wood and bamboo, and medicinal plants such as the willow tree pictured in Figure 24.3.4. Ecosystem goods also include less-tangible things, such as ecosystem features that provide tourist attractions and recreational opportunities. The genes in wild plants and animals are another ecosystem good. These organisms provide a storehouse of genetic material that can be used to improve domestic species.

Figure 24.3.4: Many wild plants make chemical compounds that have proven to be useful as human medicines. Leaves of willow trees like this one have been used for pain and fever relief for more than 2,000 years. The leaves contain a compound that is now made artificially and sold as aspirin.

Biological Organization

All living things are made of cells; the **cell** itself is the smallest fundamental unit of structure and function in living organisms. In most organisms, these cells contain **organelles**, which provide specific functions for the cell. Living organisms have the following properties: all are highly organized, all require energy for maintenance and growth, and all grow over time and respond to their environment. All organisms adapt to the environment, and all reproduce, contributing genes to the next generation. Some organisms consist of a single cell and others are multicellular. **Organisms** are individual living entities. For example, each tree in a forest is an organism.

All the individuals of the same species living within a specific area are collectively called a **population**. Populations fluctuate based on several factors: seasonal and yearly changes in the environment, natural disasters such as forest fires and volcanic eruptions, and competition for resources between and within species. A **community** is the association of populations of two or more different species inhabiting a particular area. For instance, all the trees, insects, and other populations in a forest form the forest's community. The forest itself is an ecosystem.

An **ecosystem** consists of all the living organisms in a particular area together with the abiotic, non-living parts of that environment such as nitrogen in the soil or rainwater. Ecosystem limits can vary from small to large. For example, a patch of grass with a rabbit is an example of a small ecosystem. A lake or a pond can represent ecosystems. At the highest level of organization, the **biosphere** is the collection of all ecosystems, and it represents the zones of life on earth. It includes land, water, and even the atmosphere to a certain extent

We rely on ecosystem services. Earth's natural systems provide **ecosystem services** required for our survival such as: air and water purification, climate regulation, and plant pollination. We have degraded nature's ability to provide these services by depleting resources, destroying habitats, and generating pollution. The benefits people obtain from ecosystems include nutrient cycling, soil formation, and **primary production**. Another important service of natural ecosystems is provisioning like food production, production of wood, fibers, and fuel. Ecosystems are responsible for climate regulation, flood regulation together with disease regulation. Finally, ecosystems provide cultural and aesthetic services. As humans we benefit from observing natural habitats, recreation in waters and mountains. Nature is a source of inspiration for poets and writers. It is a source of aesthetic, religious and other nonmaterial benefits. Studying ecosystem structure in its original state is the only way we can make **anthropogenic** (man-made) systems like agricultural fields, reservoirs, fracking operations, and dammed rivers work for human benefit with minimal impact on our and other organisms' health.

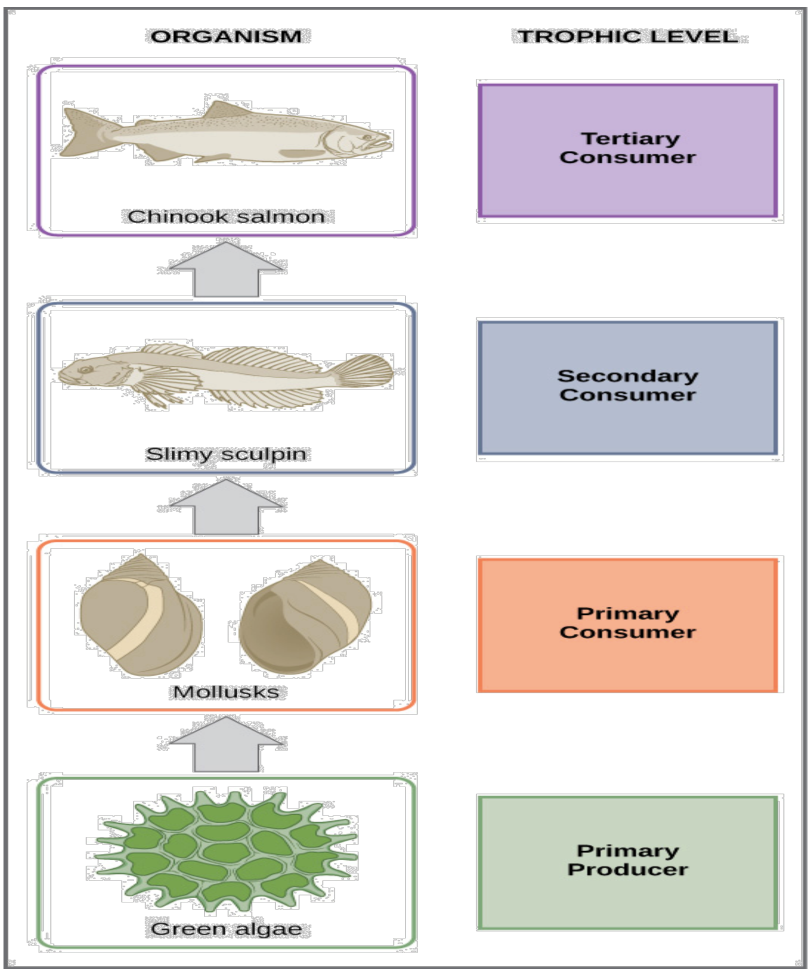
Food Chain

In ecology, a **food chain** is a series of organisms that eat one another (so that energy and nutrients flow from one to the next). For example, if you had a hamburger for lunch, you might be part of a food chain that looks like: grass → cow → human.

A **food chain** is a linear sequence of organisms through which nutrients and energy pass as one organism eats another. Let us look at the parts of a typical food chain, starting from the bottom (the producers) and moving upward.

- At the base of the food chain lie the **primary producers**. The primary producers are autotrophs and are most often photosynthetic organisms (such as plants, algae, or cyanobacteria).
- The organisms that eat the primary producers are called **primary consumers**. Primary consumers are usually **herbivores** (plant-eaters), though they may be algae or bacteria eaters.
- The organisms that eat the primary consumers are called **secondary consumers**. Secondary consumers are meat-eaters (**carnivores**).
- The organisms that eat the secondary consumers are called **tertiary consumers**. These are carnivore-eating carnivores, like eagles or big fish.
- Some food chains have additional levels, such as **quaternary consumers** (carnivores that eat tertiary consumers). Organisms at the very top of a food chain are called the **apex consumers**.

We can see examples of these levels in the diagram below. The green algae are primary producers that get eaten by mollusks (the primary consumers). The mollusks then become lunch for the slimy sculpin fish, a secondary consumer, which is itself eaten by a larger fish, the Chinook salmon (tertiary consumer).



Decomposers

One other group of consumers deserves mention, although it does not always appear in drawings of food chains. This group consists of **decomposers**, organisms that break down dead organic material and waste.

Decomposers are sometimes considered their own trophic level. As a group, they eat dead matter and waste products that come from organisms at various other trophic levels (for instance, they would happily consume decaying plant matter, the body of a half-eaten squirrel, and the remains of a deceased eagle). In this sense, the decomposer level kind of runs in parallel to the standard hierarchy of primary, secondary, and tertiary consumers.

Fungi and bacteria are the key decomposers in many ecosystems, using the chemical energy in dead matter and wastes to fuel their metabolic processes.

Remember

- **a)** **Producers**, or autotrophs, make their own organic molecules. **Consumers**, or heterotrophs, get organic molecules by eating other organisms.
- b) A **food chain** is a linear sequence of organisms through which nutrients and energy pass as one organism eats another.
- c) In a food chain, each organism occupies a different **trophic level**, defined by how many energy transfers separate it from the basic input of the chain.
- **d)** **Food webs** consist of many interconnected food chains and are a more realistic representation of consumption relationships in ecosystems.
- e) Energy transfer between trophic levels is inefficient (with a typical efficiency around 10%). This inefficiency limits the length of food chains.

Biogeochemical Cycles

The water and chemical elements that organisms need continuously cycle through ecosystems, passing repeatedly through their biotic and abiotic components. These cycles are called biogeochemical cycles because they are cycles of *chemicals* that include both organisms *(bio)* and abiotic components such as the ocean or rocks *(geo).* As matter moves through a biogeochemical cycle, it may be held for various periods of time in different components of the cycle. A component of a biogeochemical cycle that holds an element or water for a long period of time is called a reservoir. For example, the deep ocean is a reservoir for water. It may hold water for thousands of years.

Water Cycle

Water is essential to all living things on Earth because virtually all biochemical reactions take place in water. Water can dissolve almost anything, so it also provides an efficient way to transfer substances between and within cells. The water cycle, also known as the hydrological cycle, describes the continuous movement of water on, above, and below Earth's surface. As it cycles, water moves from one exchange pool or reservoir to another. In different parts of the cycle, water exists as a liquid (water), solid (ice), or gas (water vapor). Therefore, the water cycle includes several physical processes by which water changes state.

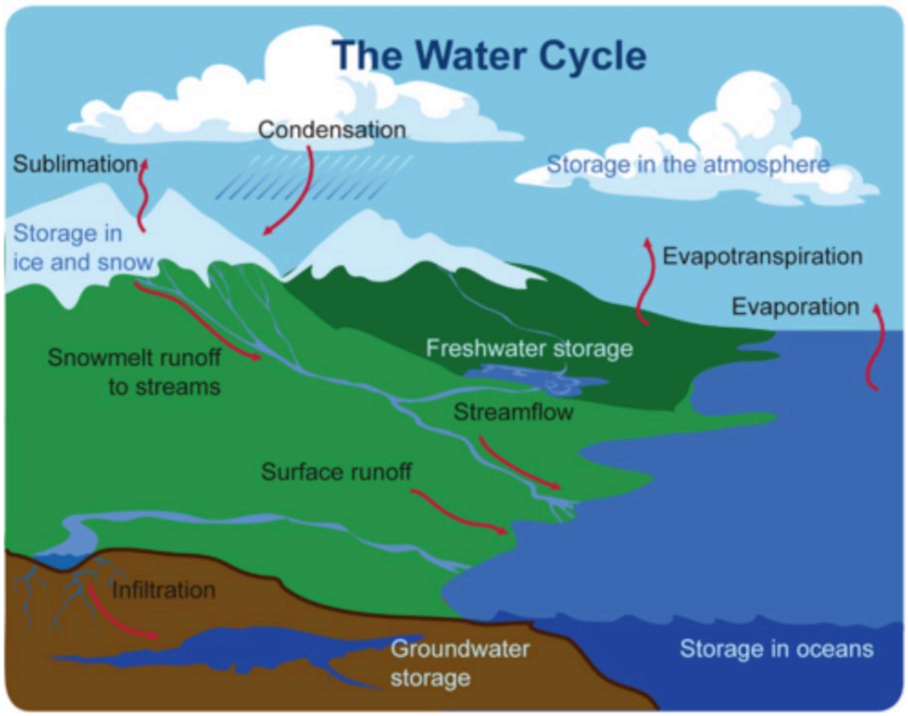


Figure 24.6.2: Like other biogeochemical cycles, the water cycle has no beginning or end. It just keeps repeating. Note that the term "evapotranspiration" in this diagram refers to the evaporation of water from Earth's land and water plus the transpiration of water from the leaves of plants. When ice turns into steam, it is referred to as sublimation. As water condenses and cools it falls as precipitation (rainfall.) Rainwater and snowmelt run off to streams. Some water is infiltrated by the layers of material in the earth's crust. Water is stored underground and, in the oceans, lakes, snow, and clouds.

Movement through the water cycle

- Evaporation occurs when water on Earth's surface changes to water vapor. When the sun heats water, it gives water molecules enough energy to escape into the atmosphere.
- Sublimation occurs when ice and snow change directly to water vapor without first melting to form liquid water. Sublimation occurs because of the heat from the sun.
- Transpiration occurs when plants release water vapor through leaf pores called stomata. Plants take up more water through their roots than they need for photosynthesis and other processes. Much of this excess water is given off via transpiration.

- Condensation is the process in which water vapor changes to liquid water, forming water droplets. If enough water droplets are present, they may form a visible cloud. If the droplets become large enough, they fall to Earth because of gravity as precipitation (such as rain, snow, sleet, or hail).
- Precipitation that falls on land may flow over the surface of the ground. This water is called runoff, and it may eventually flow into a body of water.
- Some of the precipitation that falls on land may soak into the ground and become groundwater. Groundwater may seep out of the ground at a spring or into a body of water such as a lake or the ocean. Some groundwater may be taken up by plant roots. Some may flow deeper underground to an aquifer.

Carbon Cycle

Carbon is the basis of life on Earth. Chains of carbon bonded together to form the backbone of many biochemical molecules. Carbon is also an important component of rocks and minerals, and carbon exists in the atmosphere in compounds such as carbon dioxide. The carbon cycle is the biogeochemical cycle in which carbon moves through the biotic and abiotic components of ecosystems. The carbon cycle is represented by the diagram in Figure 24.6.3.

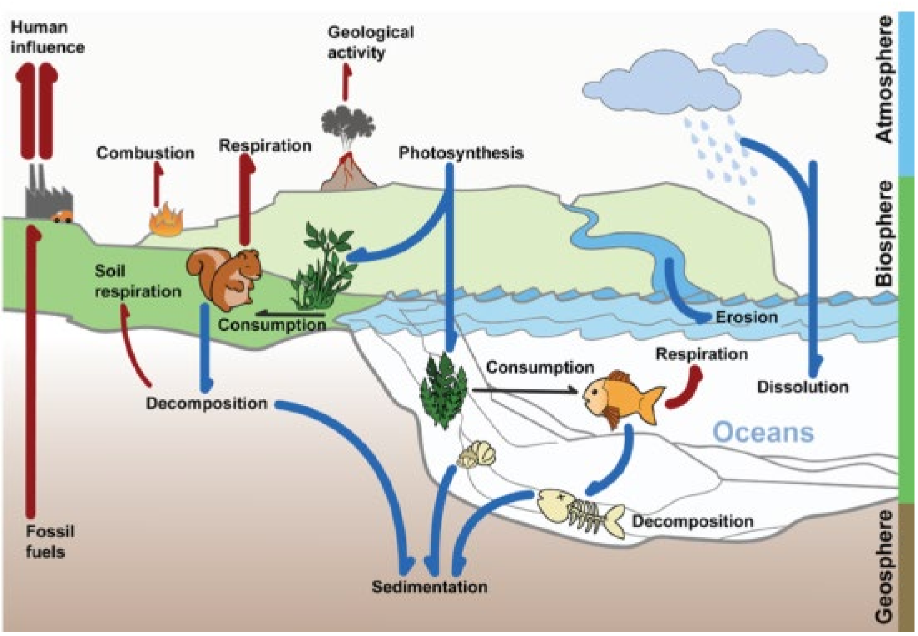


Figure 24.6.3: Carbon moves from one carbon store to another in the carbon cycle. Carbon is stored in ocean water and plants via photosynthesis. Carbon is released into the environment when fossil fuels are burned, animals respired consumed food (plants), animals are decomposed when they die, and geological activities (volcanoes.)

Carbon cycles quickly between organisms and the atmosphere. Cellular respiration by living things releases carbon into the atmosphere as carbon dioxide. Photosynthesis by producers such as plants removes carbon dioxide from the atmosphere and uses it to make organic carbon compounds. Carbon in organic compounds moves through ecosystem communities from producers to consumers, as modeled by food chains and food webs that show feeding relationships. Carbon is also released back into the environment when organisms decompose.

Several human actions release huge amounts of additional carbon into the atmosphere. The most significant of these actions is the burning of fossil fuels. Large amounts of carbon in the gas methane are also released into the atmosphere from the decomposition of livestock manure and the wastes in landfills. Some natural events can also quickly add carbon to the atmosphere. Wildfires produce carbon dioxide as a product of combustion, and volcanic eruptions release carbon dioxide from molten rock (magma). Large volcanic eruptions (like the one in Figure 24.6.4) can release enormous amounts of carbon dioxide in a short period of time.

Figure 24.6.4: The 1980 eruption of Mount St. Helens in Washington State released tremendous amounts of carbon-containing gases into the atmosphere.

Carbon generally cycles more slowly through other processes. For example, running water slowly dissolves carbon in rocks, and most of this carbon ends up in the ocean. The top layer of ocean water dissolves some carbon dioxide out of the atmosphere, and carbon also enters ocean water from the decomposition of aquatic organisms. Carbon from these sources may settle to the bottom of the ocean as sediment. Over millions of years, this carbon may form fossil fuels or carbon-containing rocks. Carbon can remain in these reservoirs for millions of years.

Nitrogen Cycle

Nitrogen makes up 78 percent of Earth's atmosphere. It is also an important element in living things. Nitrogen is needed for proteins, nucleic acids, and many other organic molecules, including chlorophyll, without which plants and other photoautotrophs could not carry out photosynthesis. The nitrogen cycle is the biogeochemical cycle that recycles nitrogen through the biotic and abiotic components of ecosystems. Figure 24.6.5 shows how nitrogen cycles through a terrestrial ecosystem. Nitrogen passes through aquatic ecosystems in a similar cycle.

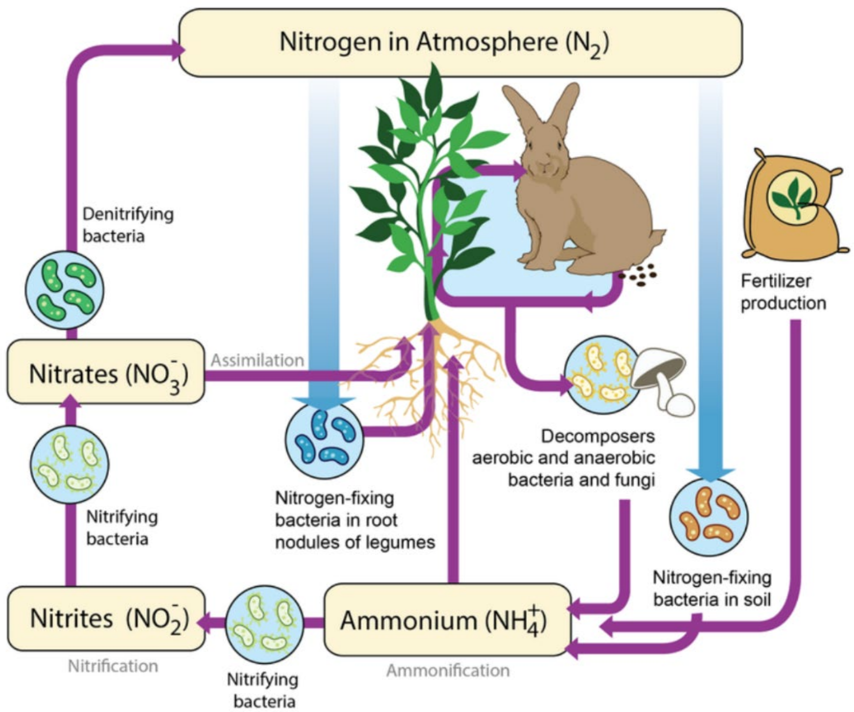


Figure 24.6.5: Nitrogen cycle. Gaseous Nitrogen is converted to usable Nitrogen form by soil bacteria. This process is called Nitrogen fixing. Some Nitrogen fixing bacteria live in the roots of some plants. Plants use that Nitrogen to increase their biomass. Consumers feed on plants and animal waste. When animals die the denitrifying bacteria release nitrogen back into the atmosphere. Fertilizer addition is not part of the natural Nitrogen cycle.

Plants cannot use nitrogen gas in the air to make organic compounds for themselves and the organisms that consume them. However, they can use nitrogen in the form of compounds such as nitrates, which they can absorb through their roots. The process of changing nitrogen gas to nitrates is called nitrogen fixation. It is carried out by bacteria, called nitrogen-fixing bacteria, that live in soil or on the roots of legumes such as peas. Nitrogen fixation is the primary source of nitrogen used by plants in most ecosystems.

When plants and other organisms die or release waste, decomposers break down their organic compounds. In the process, they release nitrogen in the form of ammonium ions into the soil. The ammonium ions can be absorbed by plant roots. The ions can also be changed to nitrates by soil bacteria called nitrifying bacteria.

Not all the nitrates produced by nitrogen-fixing and nitrifying bacteria are used by plants. Some of the nitrates are changed back to nitrogen gas by soil bacteria called denitrifying bacteria. This nitrogen returns to the atmosphere, thus completing the cycle.

Biological Molecules

Life on Earth is primarily made up of four major classes of biological molecules, or biomolecules. These include carbohydrates, lipids, proteins, and nucleic acids.

Most people are familiar with **carbohydrates**, one type of macromolecule, especially when it comes to what we eat. Carbohydrates are, in fact, an essential part of our diet; grains, fruits, and vegetables are all natural sources of carbohydrates. Carbohydrates provide energy to the body, particularly through **glucose**, a simple sugar that is a component of **starch** and an ingredient in many staple foods.

Lipids include a diverse group of compounds such as fats, oils, waxes, phospholipids, and steroids that are largely nonpolar in nature. Nonpolar molecules are hydrophobic or insoluble in water. These lipids have important roles in energy storage, as well as in the building of cell membranes throughout the body.

Proteins are one of the most abundant organic molecules in living systems and have the most diverse range of functions of all macromolecules. Proteins may be structural, regulatory, contractile, or protective; they may serve in transport, storage, or membranes; or they may be toxins or enzymes. Each cell in a living system may contain thousands of proteins, each with a unique function. Their structures, like their functions, vary greatly. For example, **enzymes,** which are produced by living cells, speed up biochemical reactions (like digestion) and are usually complex proteins. Each enzyme has a specific shape or formation based on its use. The enzyme may help in breakdown, rearrangement, or synthesis reactions.

Nucleic acids are the most important macromolecules for the continuity of life. They carry the genetic blueprint of a cell and carry instructions for the functioning of the cell. The two main types of nucleic acids are **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**. DNA is the genetic material found in all living organisms, ranging from single-celled bacteria to multicellular mammals. DNA controls all the cellular activities by turning the genes “on” or “off.” The other type of nucleic acid, RNA, is mostly involved in protein synthesis. DNA has a double-helix structure (**Figure 1.3**).

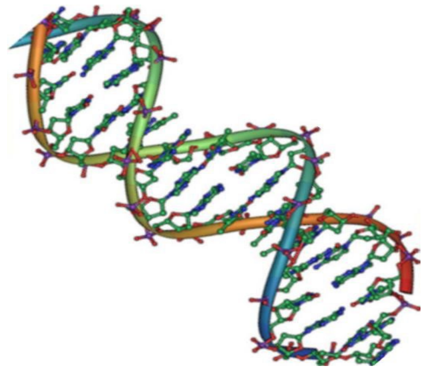


Figure 1.3. Native DNA is an antiparallel double helix. The phosphate backbone (indicated by the curvy lines) is on the outside, and the bases are on the inside. Each base from one strand interacts via hydrogen bonding with a base from the opposing strand. (Credit: Jerome Walker/Dennis Myts).

Behaviors

Behavior is an action that alters the relationship between an organism and its environment. Behavior may occur as a result of

- an external stimulus (e.g., sight of a predator),
- internal stimulus (e.g., hunger),
- or a mixture of the two (e.g., mating behavior).

Innate behavior

Behavior determined by the "hard-wiring" of the nervous system. It is usually inflexible, a given stimulus triggering a given response. A salamander raised away from water until long after its siblings begin swimming successfully will swim every bit as well as them the very first time it is placed in the water. Clearly this rather elaborate response is "built in" in the species and not something that must be acquired by practice.

Instincts

Instincts are complex behavior patterns which, like reflexes, are inborn, rather inflexible, and valuable at adapting the animal to its environment. They differ from reflexes in their complexity. The entire body participates in instinctive behavior, and an elaborate series of actions may be involved.

The scratching behavior of a dog is part of their genetic heritage. The widespread behavior of scratching with a hind limb crossed over a forelimb in common to most birds, reptiles, and mammals. So, instincts are inherited just as the structure of tissues and organs is. Other examples:

- the African peach-faced lovebird, Agapornis roseicollis, carries nesting materials to the nesting site by tucking them in its feathers.
- Its close relative, the Fischer's lovebird, uses its beak to transport nesting materials.
- The two species can hybridize. When they do so, the offspring succeed only in carrying nesting material in their beaks. Nevertheless, they invariably go through the motions of trying to tuck the materials in their feathers first.

Learned Behavior

Behavior that is permanently altered as a result of the experience of the individual organism (e.g., learning to play baseball well).

Habituation

Habituation is a reduction in a previously displayed response when no reward or punishment follows. If you make an unusual sound in the presence of the family dog, it will respond usually by turning its head toward the sound. If the stimulus is given repeatedly and nothing either pleasant or unpleasant happens to the dog, it will soon cease to respond. This lack of response is not a result of fatigue or sensory adaptation and is long-lasting; when fully habituated, the dog will not respond to the stimulus even though weeks or months have elapsed since it was last presented.

Sensitization

Sensitization is an **increase** in the response to an innocuous stimulus when that stimulus occurs after a punishing stimulus.

Imprinting

If newly hatched geese are exposed to a moving object of reasonable size and emitting reasonable sounds, they will begin to follow it just as they would normally follow their mother. This is called **imprinting**. The time of exposure is quite critical. A few days after hatching, imprinting no longer occurs. Prior to this time, though, the results can be quite remarkable. A gosling imprinted to a moving box or clucking person will try to follow this object for the rest of its life. In fact, when the gosling reaches sexual maturity, it will make the imprinted object - rather than a member of its own species - the goal of its sexual drive.

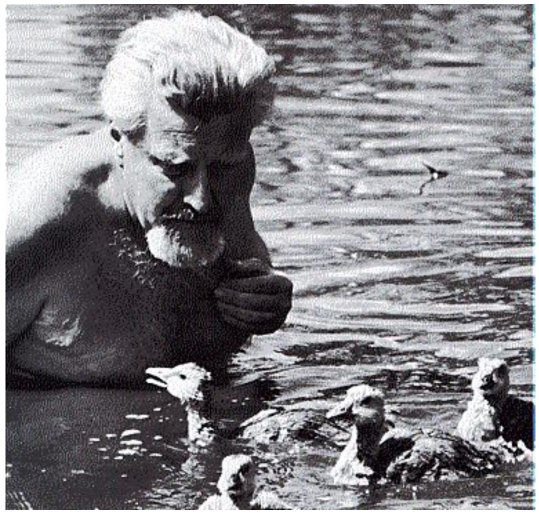


Figure 15.11.3.2 Konrad Lorenz and his imprinted goslings

Much of our knowledge of imprinting was learned from the research of Konrad Lorenz, shown here with some of his imprinted goslings. Lorenz received a Nobel Prize in 1973 for his discoveries. (Photo by Tom McAvoy; courtesy of LIFE Magazine, ©1955, Time, Inc.)

The Conditioned Response (CR)

The conditioned response is probably the simplest form of learned behavior. It is a response that as a result of experience comes to be caused by a stimulus different from the one that originally triggered it. The Russian physiologist Ivan Pavlov found that placing meat powder in a dog's mouth would cause it to salivate.

The meat powder, an **unconditioned stimulus** (**US**), triggers a simple inborn reflex involving taste receptors, sensory neurons, networks of interneurons in the brain, and autonomic motor neurons running to the salivary glands thus producing an **unconditioned response** (**UR**).

Pavlov found that if he rang a bell every time he put the meat powder in the dog's mouth, the dog eventually salivated upon hearing the bell alone. This is the **conditioned response** (**CR**). The dog has learned to respond to a substitute stimulus, the **conditioned stimulus** (**CS**).

We assume that the physiological basis of the conditioned response is the transfer, by appropriate neurons, of nervous activity in the auditory areas of the brain to the motor neurons controlling salivation. This involves the development and/or strengthening of neural circuits, which - we may also assume - is characteristic of all forms of learning.

The conditioned response has proved to be an excellent tool for determining the sensory capabilities of other animals. For example, honeybees can be conditioned to seek food on a piece of blue cardboard. By offering other colors to a blue-conditioned bee, Karl von Frisch (who shared the 1973 Nobel Prize with Lorenz) found that honeybees can discriminate between yellow-green, blue-green, blue-violet, and ultraviolet.

Instrumental Conditioning

Pavlov's dogs were restrained, and the response being conditioned (salivation) was innate. But the principles of conditioning can also be used to train animals to perform tasks that are not innate. In these cases, the animal is placed in a setting where it can move about and engage in different activities. The experimenter chooses to reward only one, e.g., turning to the left. By first rewarding (e.g., with a pellet of food) even the slightest movement to the left and then only more complete turns, a skilled experimenter can in about 2 minutes train a naive pigeon to make a complete turn. A little more work and the pigeon will pace out a figure eight.

In the example shown here, the pigeon - presented with two spots of light - pecks at the brighter and reaches down to pick up the grain of food, that is its reward.

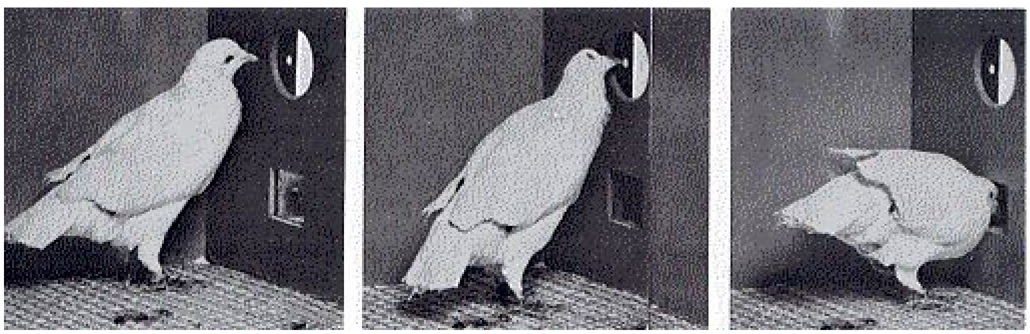


Figure 15.11.3.3 Instrumental conditioning on pigeons. (Photos courtesy of Roy DeCarava and **Scientific American**.)

Such training is known as **instrumental conditioning** or **operant conditioning**. The latter term was coined by B. F. Skinner, whose skill with the technique enabled him to train pigeons to play ping-pong and even a toy piano! It is also called **trial-and-error** learning because the animal is free to try various responses before finding the one that is rewarded.

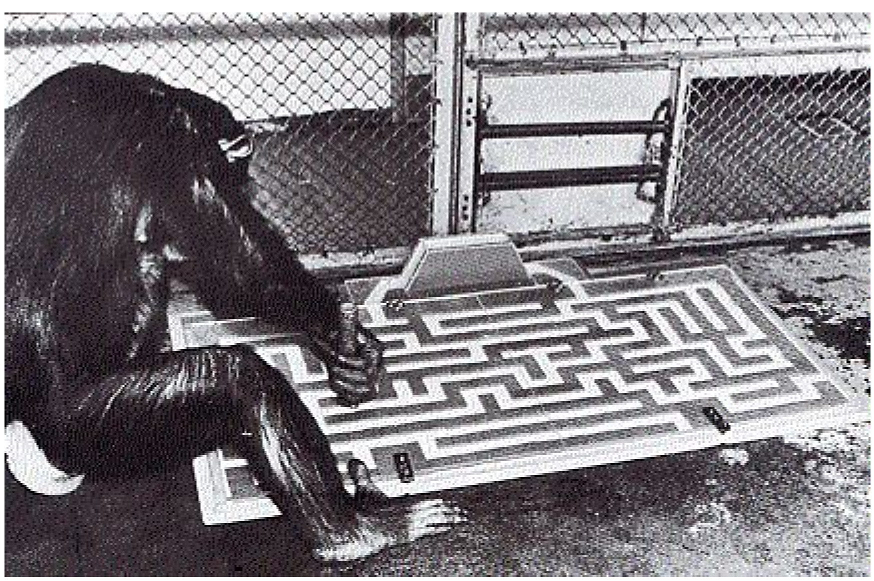


Figure 15.11.3.4 Chimpanzee solving a maze with a magnet

Maze problems are a form of instrumental conditioning in which the animal is faced with a sequence of alternatives.

In this photo (Courtesy of B. Rensch), Julia, a chimpanzee, uses a magnet to move an iron ring through a maze. Julia can solve mazes like this on her first attempt most (86%) of the time and sometimes faster than biology students can!

Concepts

Although most animals solve mazes and other problems by trial and error, Julia (and biology students) usually make only one or two random attempts at solving a problem and then, suddenly, "get it". They have made an abstract generalization about the specific problem; that is, have formed a **concept**. **Oddity problems** are an example. This young rhesus monkey has learned that food will be found - not under any particular object - but under whichever object is different from the others.

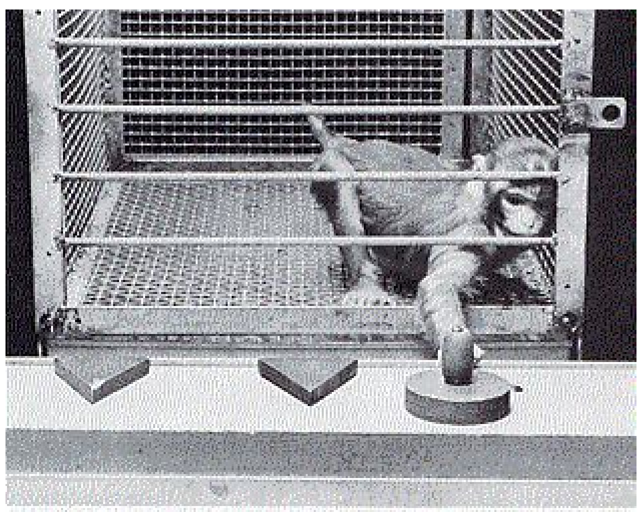


Figure 15.11.3.5 Oddity problems (Photo courtesy of H. F. Harlow, University of Wisconsin Primate Laboratory.)

In monkeys (and probably humans as well), concept formation depends on activity in the prefrontal cortex of the brain. Recent research suggests that honeybees can also solve simple oddity problems!

Health

Immune System

The immune system is a host defense system. It comprises many biological structures —ranging from individual white blood cells to entire organs — as well as many complex biological processes. The function of the immune system is to protect the host from pathogens and other causes of disease such as tumor cells. To function properly, the immune system must be able to detect a wide variety of pathogens. It also must be able to distinguish the cells of pathogens from the host's own cells and to distinguish cancerous or damaged host cells from healthy cells. In humans and most other vertebrates, the immune system consists of layered defenses that have increased specificity for particular pathogens or tumor cells. The layered defenses of the human immune system are usually classified into two subsystems called the innate immune system and the adaptive immune system.

Innate Immune System

Any discussion of the innate immune response usually begins with the physical barriers that prevent pathogens from entering the body, destroy them after they enter, or flush them out before they can establish themselves in the hospitable environment of the body's soft tissues. Barrier defenses are part of the body's most basic defense mechanisms. The barrier defenses are not a response to infections, but they are continuously working to protect against a broad range of pathogens.

Phagocytes are the body's fast acting first line of immunological defense against organisms that have breached barrier defenses and have entered the vulnerable tissues of the body. For example, certain leukocytes (white blood cells) engulf and destroy pathogens they encounter in the process called phagocytosis. The body's response again a pathogen's breach is also called Inflammation.

Adaptive Immune System

The adaptive immune system is activated if pathogens successfully enter the body and manage to evade the general defenses of the innate immune system. An adaptive response is specific to the particular type of pathogen that has invaded the body or to cancerous cells. It takes longer to launch a specific attack, but once it is underway, its specificity makes it very effective. An adaptive response also usually leads to immunity. This is a state of resistance to a specific pathogen due to the ability of the adaptive immune system to "remember" the pathogen and immediately mount a strong attack tailored to that particular pathogen if it invades again in the future.

Self vs. Non-Self

Both innate and adaptive immune responses depend on the ability of the immune system to distinguish between self and non-self molecules. Self molecules are those components of an organism's body that can be distinguished from foreign substances by the immune system. Virtually all body cells have surface proteins that are part of a complex called the major histocompatibility complex (MHC). These proteins are one way the immune system recognizes body cells as self. Non-self proteins, in contrast, are recognized as foreign because they are different from self proteins.

Antigens and Antibodies

Many non-self molecules comprise a class of compounds called antigens. Antigens, which are usually proteins, bind to specific receptors on immune system cells and elicit an adaptive immune response. Some adaptive immune system cells (B cells) respond to foreign antigens by producing antibodies. An antibody is a molecule that precisely matches and binds to a specific antigen. This may target the antigen (and the pathogen displaying it) for destruction by other immune cells.

Antigens on the surface of pathogens are how the adaptive immune system recognizes specific pathogens. Antigen specificity allows for the generation of responses tailored to the specific pathogen. It is also how the adaptive immune system "remembers" the same pathogen in the future.

Immune Surveillance

Another important role of the immune system is to identify and eliminate tumor cells. This is called immune surveillance. The transformed cells of tumors express antigens that are not found in normal body cells. The main response of the immune system to tumor cells is to destroy them. This is carried out primarily by aptly named killer T cells of the adaptive immune system.

Pathogens

Any agent that can cause disease is called a pathogen. Most pathogens are microorganisms, although some, such as the Schistosoma worm, are much larger. In addition to worms, common types of pathogens of human hosts include bacteria, viruses, fungi, and single-celled organisms called protists. You can see examples of each of these types of pathogens in Table 20.2.1. Fortunately for us, our immune system can keep most potential pathogens out of the body or to quickly destroy them if they do manage to get in.

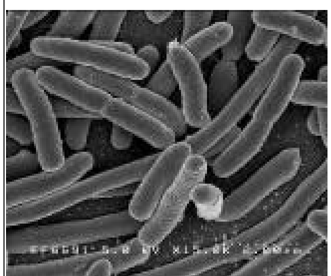
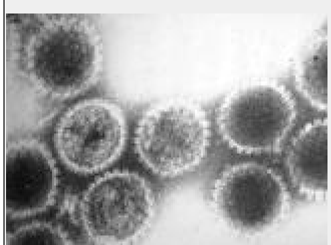
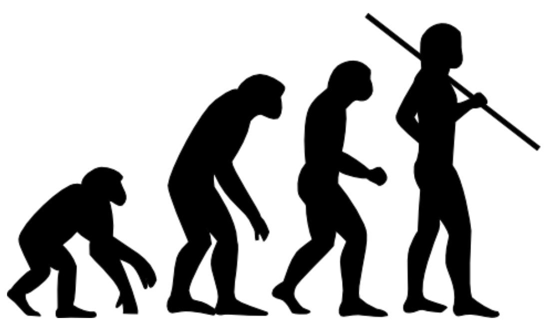
Table 20.2.1: Types of Pathogens			
Type of Pathogen	Example and their Image	Description	Human Disease caused by pathogens of that type
Bacteria	 such as *Escherichia coli*	Single-celled organisms without a nucleus	Strep throat, staph infections, tuberculosis, food poisoning, tetanus, pneumonia, syphilis
Viruses	 such as Herpes simplex	Particles that reproduce by taking over living cells.	Common cold, flu, genital herpes, cold sores, measles, AIDS, genital warts, chickenpox, smallpox
Fungi	 such as *Trichophyton rubrum*	Organisms with a nucleus that grow as single cells or tread-like filaments	Ringworm, athlete's foot, tineas, candidiasis, histoplasmosis

Table 20.2.1: Types of Pathogens			
Type of Pathogen	Example and their Image	Description	Human Disease caused by pathogens of that type
Protozoa	 Such as *Giarida lamblia*	A single-celled organism with a nucleus	Malaria, Traveler's diarrhea, giardiasis, trypanosomiasis (sleeping sickness)

Theory of evolution

The Theory of Evolution

Evolution means change over time. Darwin's theory of **evolution** says that organisms change over time. Evolution is seen in the fossil record. It is seen in the way organisms develop. Evolution is evident in the geographic locations where organisms are found. It is evident in the genes of living organisms. Evolution has a mechanism called **natural selection**. The organism that is best suited to its environment is most likely to survive.



The theory of evolution maintains that modern humans evolved from ape-like ancestors.

Darwin and Descent with Modification

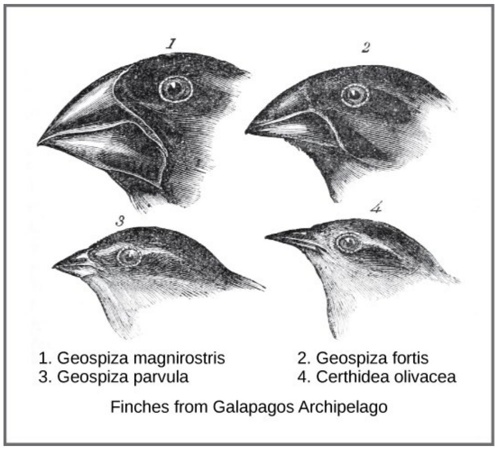


Figure 1. Darwin observed that beak shape varies among finch species. He postulated that the beak of an ancestral species had adapted over time to equip the finches to acquire different food sources.

Charles Darwin is best known for his discovery of natural selection. In the mid-nineteenth century, the actual mechanism for evolution was independently conceived of and described by two naturalists: Charles Darwin and Alfred Russel Wallace. Importantly, each naturalist spent time exploring the natural world on expeditions to the tropics. From 1831 to 1836, Darwin traveled around the world on *H.M.S. Beagle*, including stops in South America, Australia, and the southern tip of Africa. Wallace traveled to Brazil to collect insects in the Amazon rainforest from 1848 to 1852 and to the Malay Archipelago from 1854 to 1862. Darwin's journey, like Wallace's later journeys to the Malay Archipelago, included stops at several island chains, the last being the Galápagos Islands west of Ecuador. On these islands, Darwin observed species of organisms on different islands that were clearly similar yet had distinct differences. For example, the ground finches inhabiting the Galápagos Islands comprised several species with a unique beak shape (Figure 1).

Natural selection can only take place if there is **variation**, or differences, among individuals in a population. Importantly, these differences must have some genetic basis; otherwise, the selection will not lead to change in the next generation. This is critical because variation among individuals can be caused by non-genetic reasons such as an individual being taller because of better nutrition rather than different genes.

Genetic diversity in a population comes from two main mechanisms: mutation and sexual reproduction. Mutation, a change in DNA, is the ultimate source of new alleles, or new genetic variation in any population. The genetic changes caused by mutation can have one of three outcomes on the phenotype. A mutation affects the phenotype of the organism in a way that gives it reduced fitness—lower likelihood of survival or fewer offspring. A mutation may produce a phenotype with a beneficial effect on fitness. And many mutations will also have no effect on the fitness of the phenotype; these are called neutral mutations. Mutations may also have a whole range of effect sizes on the fitness of the organism that expresses them in their phenotype, from a small effect to a great effect. Sexual reproduction also leads to genetic diversity: when two parents reproduce, unique combinations of alleles assemble to produce unique genotypes and thus phenotypes in each of the offspring.

A heritable trait that helps the survival and reproduction of an organism in its present environment is called adaptation. Scientists describe groups of organisms becoming adapted to their environment when a change in the range of genetic variation occurs over time that increases or maintains the “fit” of the population to its environment. The webbed feet of platypuses are an adaptation for swimming. The snow leopards’ thick fur is an adaptation for living in the cold. The cheetahs’ fast speed is an adaptation for catching prey.

Whether or not a trait is favorable depends on the environmental conditions at the time. The same traits are not always selected because environmental conditions can change. For example, consider a species of plant that grew in a moist climate and did not need to conserve water. Large leaves were selected because they allowed the plant to obtain more energy from the sun. Large leaves require more water to maintain than small leaves, and the moist environment provided favorable conditions to support large leaves. After thousands of years, the climate changed, and the area no longer had excess water. The direction of natural selection shifted so that plants with small leaves were selected because those populations were able to conserve water to survive the new environmental conditions.

The evolution of species has resulted in enormous variation in form and function. Sometimes, evolution gives rise to groups of organisms that become tremendously different from each other. When two species evolve in diverse directions from a common point, it is called divergent evolution. Such **divergent evolution** can be seen in the forms of the reproductive organs of flowering plants which share the same basic anatomies; however, they can look very different as a result of selection in different physical environments and adaptation to different kinds of pollinators (Figure 1).

(a) (b)

Figure 1. Flowering plants evolved from a common ancestor. Notice that the (a) dense blazing star (*Liatrus spicata*) and the (b) purple coneflower (*Echinacea purpurea*) vary in appearance, yet both share a similar basic morphology. (Credit a: modification of work by Drew Avery; credit b: modification of work by Cory Zanker)

In other cases, similar phenotypes evolve independently in distantly related species. For example, flight has evolved in both bats and insects, and they both have structures we refer to as wings, which are adaptations to flight. However, the wings of bats and insects have evolved from very different original structures. This phenomenon is called **convergent evolution**, where similar traits evolve independently in species that do not share a recent common ancestry. The two species came to the same function, flying, but did so separately from each other.

These physical changes occur over enormous spans of time and help explain how evolution occurs. **Natural selection** acts on individual organisms, which in turn can shape an entire species. Although natural selection may work in a single generation on an individual, it can take thousands or even millions of years for the genotype of an entire species to evolve. It is over these long time spans that life on earth has changed and continues to change.

Practice Activity

The following are questions that will help you review what you have learned in this chapter, as well as identify those concepts that you need to reinforce. If when reading a question you are still not sure of the concept you should know to answer it, you have the possibility to look again in the section of the book where you can find the answer. You should keep in mind that this activity is intended to help you reviewing concepts. High school equivalency exams are different. In them you will be presented with texts, graphs, tables and charts containing information related to a science topic and you have to interpret the information, analyze it, evaluate it, make generalizations, applying your knowledge. To make reading the information presented easier, it is recommended that you have previous knowledge of the topics that the information presented could deal with.

1. The ___________ is the basic unit of life.
    - A. organism
    - B. cell
    - C. tissue
    - D. organ

2. Which of these do all prokaryotes and eukaryotes share?
    1. nuclear envelope
    2. cell walls
    3. organelles
    4. pili

3. Which of the following is found both in eukaryotic and prokaryotic cells?
    - A. nucleus
    - B. mitochondrion
    - C. vacuole

D. ribosome

4. Which of the following is not a component of the endomembrane system?
   A. Mitochondrion
   B. Golgi apparatus
   C. endoplasmic reticulum
   D. lysosome

5. Which plasma membrane component can be either found on its surface or embedded in the membrane structure?
   A. protein
   B. cholesterol
   C. carbohydrate
   D. phospholipid

6. The tails of the phospholipids of the plasma membrane are composed of _____ and are _______.
   A. phosphate groups; hydrophobic
   B. fatty acid groups; hydrophilic
   C. phosphate groups; hydrophilic
   D. fatty acid groups; hydrophobic

7. Water moves via osmosis _________.
   A. throughout the cytoplasm
   B. from an area with a high concentration of other solutes to a lower one
   C. from an area with a low concentration of solutes to an area with a higher one
   D. from an area with a low concentration of water to one of higher concentration
   E.
8. The principal force driving movement in diffusion is __________.
   A. temperature
   B. particle size
   C. concentration gradient
   D. membrane surface area

9. Active transport must function continuously because __________.
   A. plasma membranes wear out
   B. cells must be in constant motion
   C. facilitated transport opposes active transport
   D. diffusion is constantly moving the solutes in the other direction

10. Imagine that you are performing a cross involving seed color in garden pea plants. What traits would you expect to observe in the F1 offspring if you cross true-breeding parents with green seeds and yellow seeds? Yellow seed color is dominant over green.
    A. only yellow-green seeds
    B. only yellow seeds
    C. 1:1 yellow seeds: green seeds
    D. 1:3 green seeds: yellow seeds

11. Imagine that you are performing a cross involving seed texture in garden pea plants. You cross true-breeding round and wrinkled parents to obtain F1 offspring. Which of the following experimental results in terms of numbers of plants are closest to what you expect in the F2 progeny?
    A. 810 round seeds
    B. 810 wrinkled seeds
    C. 405:395 round seeds: wrinkled seeds
    D. 610:190 round seeds: wrinkled seeds

12. The observable traits expressed by an organism are described as its ________.
    A. phenotype
    B. genotype
    C. alleles
    D. Zygote

13. A recessive trait will be observed in individuals that are ________ for that trait.
    A. heterozygous
    B. homozygous or heterozygous
    C. homozygous diploid

14. What are the types of gametes that can be produced by an individual with the genotype AaBb?
    A. Aa, Bb
    B. AA, aa, BB, bb
    C. AB, Ab, aB, ab
    D. AB, ab

15. What is the reason for doing a test cross?
    A. to identify heterozygous individuals with the dominant phenotype
    B. to determine which allele is dominant and which is recessive
    C. to identify homozygous recessive individuals in the F2
    D. to determine if two genes assort independently

16. Which of the following does cytosine pair with?
    A. guanine
    B. thymine

C. adenine
D. a pyrimidine

17. Prokaryotes contain a ________chromosome, and eukaryotes contain ________ chromosomes.
    A. single-stranded circular; single-stranded linear
    B. single-stranded linear; single-stranded circular
    C. double-stranded circular; double-stranded linear
    D. double-stranded linear; double-stranded circular

18. In gel electrophoresis of DNA, the different bands in the final gel form because the DNA molecules ________.
    A. are from different organisms
    B. have different lengths
    C. have different nucleotide compositions
    D. have different genes

19. In the reproductive cloning of an animal, the genome of the cloned individual comes from ________.
    A. a sperm cell
    B. an egg cell
    C. any gamete cell
    D. a body cell

20. What carries a gene from one organism into a bacteria cell?
    A. a plasmid
    B. an electrophoresis gel
    C. a restriction enzyme
    D. polymerase chain reaction

21. Does hormones are chemical messenger molecules?
    A. True
    B. False

22. Excretion is the removal of metabolic waste.
    A. False
    B. True

23. What is the regulation of the amounts of water and minerals in the body?
    A. Osmoregulation
    B. Thermoregulation
    C. Chemical regulation

24. Like all organ systems, the reproductive system plays a significant role in the homeostasis of the organism.
    A. True
    B. False

25. The endocrine system has a regulatory effect on other organ systems in the human body.
    A. True
    B. False

26. A woman whose ovaries are removed early in life may have impaired bone development.
    A. True
    B. False

27. What hormones are produced by the adrenal glands to initiate the fight- or- flight response?
    A. Thyroxine
    B. Cortisol and Adrenaline
    C. Glucagon

28. Cortisol and adrenaline affect other organ systems. Which systems would these most likely include?
    A. Cardiovascular and nervous system
    B. Digestive and urinary system

29. The endocrine system is controlled by the hypothalamus in the brain.
    A. True
    B. False

30. Which is the master gland of the endocrine system?
    A. The Thymus gland
    B. The pituitary gland
    C. The Thyroid gland
    D. The endocrine gland

31. What is the source of carbon in a glucose molecule produced by photosynthesis?
    A. CO_2
    B. Light energy
    C. H_2O
    D. Glucose

32. What step in photosynthesis may occur during day and night?
    A. Light independent reactions

B. Light dependent reactions
C. Photolysis

33. What process occurs in both animal and plant cells?
    A. Kreb's cycle
    B. Calvin cycle
    C. Light reactions
    D. Dark reactions

34. What is a by-product of light reactions?
    A. O_2
    B. H_2O
    C. Glucose
    D. NADPH

35. Where do the protons used to drive chemiosmosis during photosynthesis come from?
    A. H_2O
    B. O_2
    C. Glucose
    D. NADPH

36. What part of photosynthesis involves an electron transport chain?
    A. Light dependent reactions
    B. Light independent reactions
    C. Calvin cycle

37. Plants are a type of autotroph that makes food by converting light energy into what type of energy:
    A. Light energy
    B. Electrochemical energy
    C. Radioactive energy
    D. Chemical energy

38. Most of an ecosystem's energy is degraded into:
    A. Water
    B. Heat
    C. Calories

39. Organisms require a constant input of energy, as the work they must do uses up the energy they take in.
    A. True
    B. False

40. Which of the following cannot be recycled?

A. Energy
B. Matter

41. All living things require an ongoing source of energy to do the work of life.
    A. True
    B. False

42. The processes of photosynthesis and respiration are the same as they follow the same sequence of chemical reactions.
    A. True
    B. False

43. Do photosynthesis and cellular respiration depend on each other?
    A. Yes
    B. No

44. What type of organism produces their own food using the energy from the sun?
    A. Heterotroph
    B. Autotroph
    C. Herbivore
    D. Omnivore

45. According to Darwin, what is the main mechanism involved in Theory of Evolution, often called "the survival of the fittest?"
    A. Natural selection
    B. Darwinism
    C. Diversity
    D. Adaptation

Answers:

1. B
2. D
3. D
4. A
5. A
6. D
7. C
8. C
9. D
10. B
11. D
12. A
13. C

14. C
15. A
16. A
17. C
18. B
19. D
20. A
21. A
22. B
23. A
24. B
25. A
26. A
27. B
28. A
29. A
30. B
31. A
32. A
33. A
34. A
35. A
36. A
37. D
38. B
39. A
40. A
41. A
42. B
43. A
44. B
45. A

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Chapter 3: Earth and Space Science

Earth

Atmospheric Circulation

Our **atmosphere** is the gaseous mass or envelope surrounding the Earth and retained by the Earth's gravitational field. Other planets and moons in the Solar System have atmospheres. The atmosphere plays many important roles in moving water in the world's ocean basins, and for supporting life on Earth!

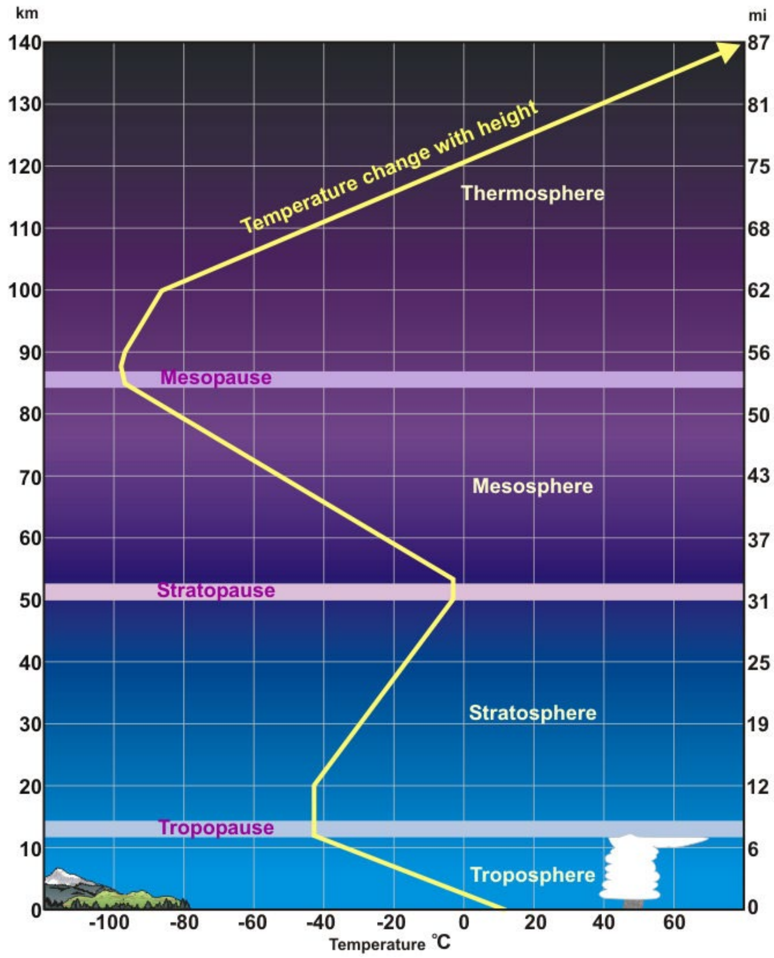
Earth's atmosphere:

- **Density stratified** - air is compressed and most dense near the surface and grows increasingly ***rarefied*** skyward.

- About **100 kilometers thick** between the ocean/land surface and the vacuum of space.

- **Composed mostly of gases,** mostly nitrogen (as N_2) and oxygen (as O_2), and trace amounts of other gases (including CO_2, argon, water vapor); **and traces of liquids and solids in suspension or falling as precipitation**: suspended water (clouds, water droplets and ice crystals), traces of organic compounds, and suspended particles of dust from a variety of sources.

Structure of the Atmosphere



The Earth's atmosphere is subdivided into levels:

* The **troposphere** is the lowest portion (**up to about 6-8 miles** [10-13 km]) where all weather takes place and contains about 80% of the air's mass and **99% of water vapor**.

* The overlying **stratosphere** contains an abundance of ozone which absorbs ultraviolet radiation, protecting life on land and in the shallow ocean; extends **up to about 31 miles** (50 km).

*The **mesosphere** is the part of the earth's upper atmosphere above the stratosphere in which temperature decreases with altitude to the atmosphere's absolute minimum.

* The **thermosphere** is the region of the atmosphere above the mesosphere and below the height at which the atmosphere ceases to have the properties of a continuous medium (about 60 miles [100 km]). The thermosphere is characterized throughout by an increase in temperature with height, where the charged atomic particle of the solar wind begins to interact with atmospheric gases.

Energy Transfer through the Atmosphere

The amount of energy coming into the Earth from the Sun **is equal to** the energy **reflected** and **radiated** back into space. The atmosphere, oceans, and land **absorb and release energy**. Living things also absorb and release energy. Some of the energy stored in organic matter is preserved when it is buried in sediments. **Geothermal energy** is also a trace of the energy radiated into space. The rate of energy transfer also varies due to cloud cover and ice and snow coverage.

Incoming solar radiation involves all wavelengths of the **electromagnetic spectrum**. The atmosphere is transparent to most wavelengths, but part of the solar spectrum is absorbed by certain **greenhouse gases** in the atmosphere including water vapor, carbon dioxide, ozone, methane, and other gases. Shorter wavelengths (UV and blue light) are diffused in the air—making the sky blue. Longer wavelengths are less diffused—making sunsets and sunrises red.

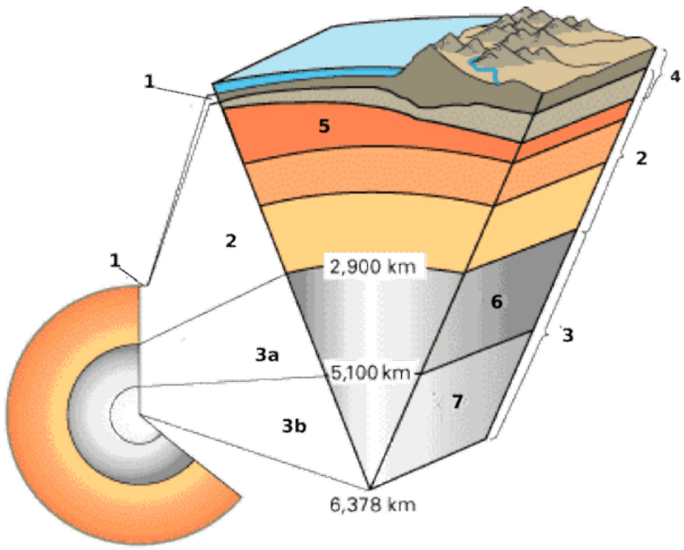
Energy that is not reflected into space is radiated back into space in wavelengths longer than visible light (mostly in the thermal infrared portion of the electromagnetic spectrum).

Composition of the Atmosphere

- Nitrogen (N_2) 78%
- Oxygen (O_2) 21%
- Argon 0.9%
- Carbon Dioxide (CO2) 0.036%
- Others < 1 %: Neon, Helium, Methane (CH_4), Krypton, Hydrogen (H_2), traces of other compounds.

Other trace gases in variable amounts include nitrogen oxides, ozone (O_3), sulfur dioxide, hydrocarbons, and more. These gases are released by volcanic eruptions, lightning, wildfires, erosion, and pollutants of many kinds from human activity. Major sources of air pollutants included gases and smoke released by fossil-fuel energy consumption, industrial releases, agriculture, and leaks of refrigerator and air conditioner coolant compounds.

Physical Structure of Earth



A cross section of Earth showing the following layers: (1) crust (2) mantle (3a) outer core (3b) inner core (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

Credit: Courtesy of the US Geological Survey
Source: http://commons.wikimedia.org/wiki/File:Earth_cross_section-i18.png
License: Public Domain

Core, mantle, and crust are divisions based on composition:

1. The **crust** is less than 1% of Earth by mass. The **oceanic crust** is mafic, while **continental crust** is often more felsic rock.

2. The **mantle** is hot, ultramafic rock. It represents about 68% of Earth's mass.

3. The **core** is mostly iron metal. The core makes up about 31% of the Earth.

   Lithosphere and asthenosphere are divisions based on mechanical properties:

1. The lithosphere is composed of both the crust and the portion of the upper mantle that behaves as a brittle, rigid solid.

2. The asthenosphere is partially molten upper mantle material that behaves plastically and can flow.

Crust and Lithosphere

Earth's outer surface is its crust; a cold, thin, brittle outer shell made of rock. The crust is very thin, relative to the radius of the planet. There are two very different types of crust, each with its own distinctive physical and chemical properties, which are summarized in the table below.

Crust	Thickness	Density	Composition	Rock types
Oceanic	5-12 km (3-8 mi)	3.0 g/cm^3	Mafic	Basalt and gabbro
Continental	Avg. 35 km (22 mi)	2.7 g/cm^3	Felsic	All types

Oceanic crust is composed of mafic magma that erupts on the seafloor to create basalt lava flows or cools deeper down to create the intrusive igneous rock gabbro (figure below).

Gabbro from ocean crust. The gabbro is deformed because of intense faulting at the eruption site. **Credit:** Courtesy of National Oceanic and Atmospheric Administration/University of Washington).

Sediments, primarily mud and the shells of tiny sea creatures, coat the seafloor. Sediment is thickest near the shore where it comes off the continents in rivers and on wind currents.

Continental crust is made up of many different types of igneous, metamorphic, and sedimentary rocks. The average composition is granite, which is much less dense than the mafic rocks of the oceanic crust (figure below). Because it is thick and has relatively low density, continental crust rises higher on the mantle than oceanic crust, which sinks into the mantle to form basins. When filled with water, these basins form the planet’s oceans.

This granite from Missouri is more than 1 billion years old.

Credit: Courtesy of US Geological Survey.

The **lithosphere** is the outermost mechanical layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 kilometers thick. The definition of the lithosphere is based on how earth materials behave, so it includes the crust and the uppermost mantle, which are both brittle. Since it is rigid and brittle, when stress acts on the lithosphere, it breaks. This is what we experience as an earthquake.

Mantle

The two most important things about the mantle are: (1) it is made of solid rock, and (2) it is hot. Scientists know that the mantle is made of rock based on evidence from seismic waves, heat flow, and meteorites. The properties fit the ultramafic rock peridotite, which is made of iron- and magnesium-rich silicate minerals (figure below). Peridotite is rarely found on Earth's surface.

Peridotite is formed of crystals of olivine (green) and pyroxene (black).

Credit: Image copyright Marcin Sylwia Ciesielski, 2013.

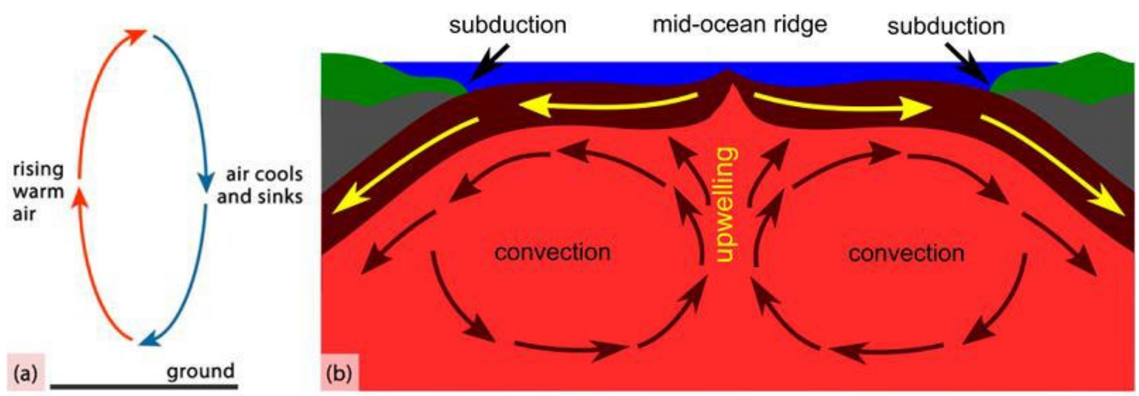
Scientists know that the mantle is extremely hot because of the heat flowing outward from it and because of its physical properties.

Heat flows in two different ways within the Earth:

1. **Conduction**: Heat is transferred through rapid collisions of atoms, which can only happen if the material is solid. Heat flows from warmer to cooler places until all are the same temperature. The mantle is hot mostly because of heat conducted from the core.

2. **Convection:** If a material can move, even if it moves very slowly, convection currents can form.

Convection in the mantle is the same as convection in a pot of water on a stove. Convection currents within Earth's mantle form as material near the core heats up. As the core heats the bottom layer of mantle material, particles move more rapidly, decreasing their density and causing it to rise. The rising material begins the convection current. When the warm material reaches the surface, it spreads horizontally. The material cools because it is no longer near the core. It eventually becomes cool and dense enough to sink back down into the mantle. At the bottom of the mantle, the material travels horizontally and is heated by the core. It reaches the location where warm mantle material rises, and the mantle **convection cell** is complete (figure below).



In a convection cell, warm material rises and cool material sinks. In mantle convection, the heat source is the core.

Diagram of convection within Earth's mantle.

Convections

(Credit: Hana Zavadska. **Source:** CK-12 Foundation. **License:** CC BY-NC 3.0)

Core

At the planet's center lies a dense metallic core. Scientists know that the core is metal because:

1. The density of Earth's surface layers is much less than the overall density of the planet, as calculated from the planet's rotation. If the surface layers are less dense than average, then the interior must be denser than average. Calculations indicate that the core is about 85% iron metal with nickel metal making up much of the remaining 15%.
2. Metallic meteorites are thought to be representative of the core. The 85% iron/15% nickel calculation above is also seen in metallic meteorites (figure below).

An iron meteorite is the closest thing to the Earth's core that we can hold in our hands.

Credit: Kevin Walsh.

If Earth's core were not metal, the planet would not have a magnetic field. Metals such as iron are magnetic, but rock, which makes up the mantle and crust, is not.

Scientists know that the outer core is liquid, and the inner core is solid because:

1. S-waves stop at the inner core.
2. The strong magnetic field is caused by convection in the liquid outer core. Convection currents in the outer core are due to heat from the even hotter inner core.

The heat that keeps the outer core from solidifying is produced by the breakdown of radioactive elements in the inner core.

The Theory of Plate Tectonics

Plate tectonics theory says that slabs of continents move around on Earth's surface. The mechanism for that movement is seafloor spreading. Plate tectonics explain many things about Earth: (1) geological activity, why it happens where it does; (2) natural resources, why many are found where they are; and (3) the past and future, what happened in the past and what will happen in the future.

Rocks

A rock is a naturally formed, non-living earth material. Rocks are made of collections of mineral grains that are held together in a firm, solid mass.

Three Main Categories of Rocks

Rocks are classified into three major groups according to how they form. Rocks can be studied in hand samples that can be moved from their original location. Rocks can also be studied in **outcrops**, exposed rock formations that are attached to the ground, at the location where they are found.

Igneous rocks form from cooling magma. Magma that erupts onto Earth's surface is lava, as seen in figure below. The chemical composition of the magma and the rate at which it cools determine what rock forms as the minerals cool and crystallize.

This flowing lava is molten rock that will harden into an igneous rock.

Credit: jmarti20.

Sedimentary rocks form by the compaction and cementing together of **sediments**, broken pieces of rock-like gravel, sand, silt, or clay (Figure below). Those sediments can be formed from the weathering and erosion of preexisting rocks. Sedimentary rocks also include chemical **precipitates**, the solid materials left behind after a liquid evaporates.

This sedimentary rock is made of sand that is cemented together to form a sandstone.

Credit: Kevin Walsh

Metamorphic rocks form when the minerals in an existing rock are changed by heat or pressure within the Earth. See figure below for an example of a metamorphic rock.

Quartzite is a metamorphic rock formed when quartz sandstone is exposed to heat and pressure within the Earth.

Credit: James St. John.

Weather and Natural Disasters

Weather is the state of the atmosphere at any place and time regarding **conditions**: sunshine, heat, dryness, cloud cover, wind, precipitation (rain, sleet, snow, hail), etc.

Clouds

Clouds form when the invisible water vapor in the air condenses into visible water droplets or ice crystals. The **dew point** is when the **relative humidity** reaches **100%**. The base of a cloud marks the boundary where relative humidity has reached saturation. Cloud tops can rise until they encounter warmer air in the stratosphere. There, they stop rising and spread-out forming anvil-shaped thunderhead shapes.

General types of clouds (there are many sub-types):

- **Cirro-form:** high level, ***wispy - fair weather*** clouds if ice crystals, typically above 20,000 ft (6000 m)
- **Cumulo-form**: low to high level ***cotton-like puffy*** clouds with flat base at 100% humidity level, can rise to 60,000 feet.
- **Nimbo-form**: ***rain clouds*** (low to mid-level) - clouds typically thicken and lower as precipitation begins.
- **Strato-form**. uniform flat cloud layer at any level, forms fog at the surface (coastal ***marine layer*** an example).

Names of clouds can include combinations of forms as they change. For instance, a small, puffy white **cumulus** cloud can build up and become an **altocumulus** cloud, before rising even further to become a **cumulonimbus** (thunderstorm) that can develop a high anvil-shaped top as the rising moist air at top the cloud encounters the stratosphere and can't rise any higher.

Weather and Climate

Weather and climate are related but they differ in the time scales of changes and their predictability. They can be defined as follows.

Weather is the instantaneous state of the atmosphere around us. It consists of **short-term variations** over minutes to days of variables such as temperature, precipitation, humidity, air pressure, cloudiness, radiation, wind, and visibility. Due to the non-linear, chaotic nature of its governing equations, weather **predictability is limited** to days.

Climate is the statistics of weather over a long period. It can be thought of as the **average** weather that varies slowly over periods of months, or longer. It does, however, also include other statistics such as probabilities or frequencies of *extreme events*. Climate is **potentially predictable** if the *forcing* is known because Earth's average temperature is controlled by energy conservation. For climate, not only the state of the atmosphere is important but also that of the ocean, ice, land surface, and biosphere.

In short: 'Climate is what you expect. Weather is what you get.'

The Climate System

Earth's climate system consists of interacting **components** (Fig. 1.11.1). The **atmosphere**, which is the air and clouds above the surface, is about 10 km thick (more than two thirds of its mass is contained below that height). The **ocean** covers more than two thirds of Earth's surface and has an average depth of roughly 4 km. Contrast those numbers with Earth's radius which is approximately 6,400 km and you'll find that Earth's atmosphere and ocean are very thin layers compared to the size of the planet itself. In fact, they are about 1,000 times thinner. They are comparable perhaps to the outer layer of an onion or the water on a wet soccer ball. Yet all life is constrained to these thin layers. The major ocean basins are the Pacific, the Atlantic, the Indian, and the Southern Ocean. Ice and snow comprise the **cryosphere**, which includes sea ice, mountain glaciers and ice sheets on land. Sea ice is frozen sea water, up to several meters thick, floating on the ocean. Ice sheets on land, made from compressed snow, can be several kilometers thick. The **biosphere** includes all living things on land and in the sea from the smallest microbes to trees and whales. The **lithosphere**, which is the solid Earth (upper crust and mantle), could also be considered an active part of Earth's climate system because it responds to ice load and impacts atmospheric carbon dioxide (CO_2) concentrations and climate on long timescales through the movements of the continents.

Figure 1.11.1: The blue marble. A composite image of Earth from space. It shows all four components of Earth's climate system. The atmosphere with its complex cloud patterns. The ocean, which covers about 70% of Earth's surface. The cryosphere is visible as the white areas on the top: sea ice covering the Arctic Ocean and the Greenland ice sheet. Green colors on land and turquoise shades along the ocean's margin indicate the biosphere as forests and phytoplankton blooms. Notice in the lower left the thin layer of the atmosphere surrounding Earth. From nasa.gov.

The components **interact** with each other by exchanging energy, water, momentum, and carbon thus creating a deliciously complex coupled system. Imagine water evaporating from the tropical ocean heated by the sun (Fig. 1.11.1). The air containing that water rises and cools. The water *condenses* into a cloud. The cloud is carried by wind over land where it rains. The rain sustains a forest. Trees are dark, having a low albedo. This influences the amount of sunlight absorbed by the Earth. Dark surfaces absorb more sunlight and get warmer compared to bright surfaces such as desert sand or snow. Air warmed by the surface rises and affects the wind.

Processes

Figure 1.21.2 illustrates some of the important processes that contribute to the complex interactions within the climate system. Earth's energy source is the sun. Both solar and terrestrial *radiation* are affected by gases, *aerosols*, and clouds in the atmosphere. Thus, the atmospheric composition affects the heating and cooling of the earth. Heating and cooling affect the temperature and circulation of the atmosphere and oceans. Circulations of the air and sea affect temperatures and precipitation over both ocean and land, which impact the biosphere and cryosphere. Atmosphere and oceans exchange heat, water (evaporation and precipitation), and momentum. Wind blowing over the ocean pushes the surface water ahead. Air temperatures and snow fall affect the growth and melting of glaciers and ice sheets. Water from melting ice flows through rivers into the ocean affecting its salinity, its density and movement. Variations in solar irradiance can cause global climate to change. Volcanoes can eject large amounts of aerosol into the atmosphere with climatic implications. Humans are influencing the climate system through emissions of *greenhouse gases*, *aerosols*, and *land use changes*.

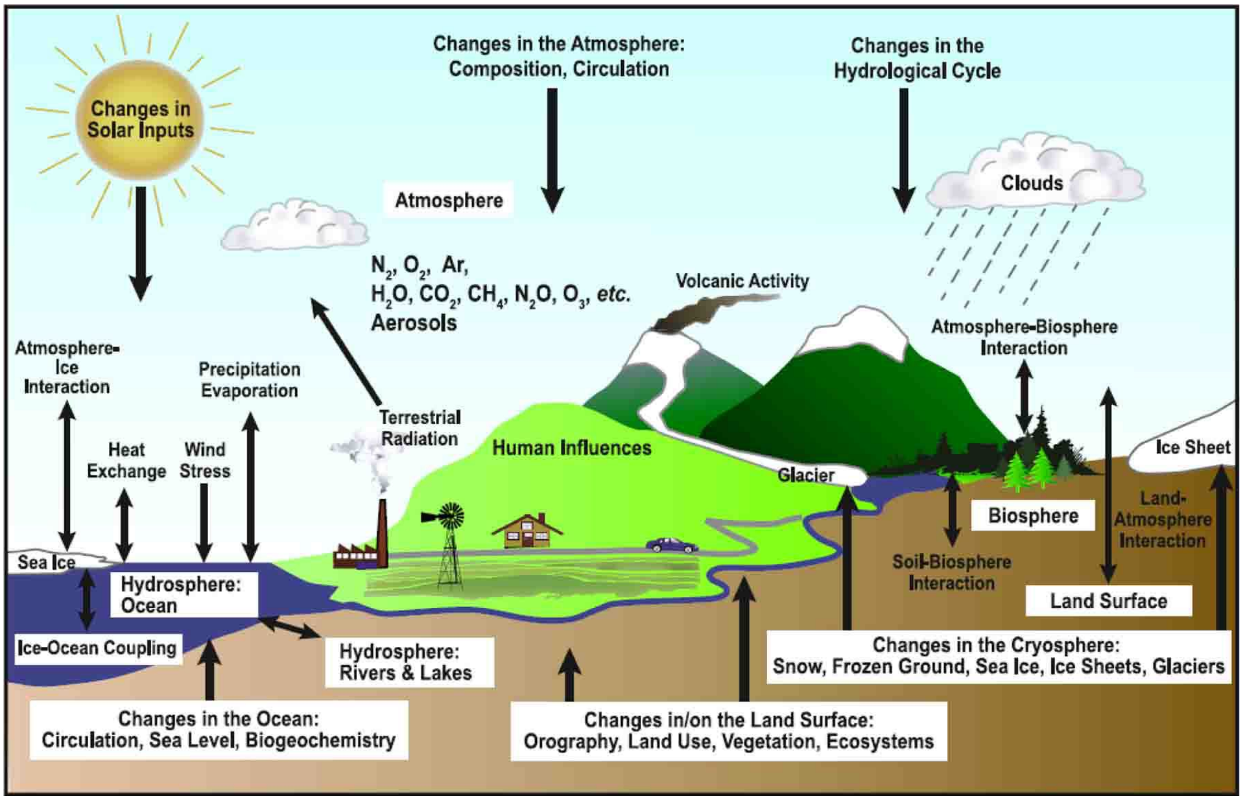


Figure 1.21.2: Schematic view of components of the climate system and processes involved in their interactions. From Le Treut et al. (2007).

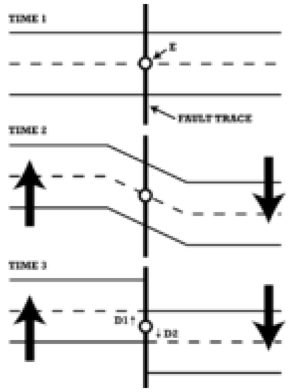
The complexity makes studying the climate system challenging. Scientists from many disciplines contribute such as physicists, chemists, biologists, geologists, oceanographers, atmospheric scientists, paleoclimatologists, mathematicians, statisticians, and computer scientists.

The Nature of Earthquakes

An **earthquake** is sudden ground movement caused by the sudden release of energy stored in rocks. Earthquakes happen when so much stress builds up in the rocks that the rocks rupture. Energy is transmitted by seismic waves.

Causes of Earthquakes

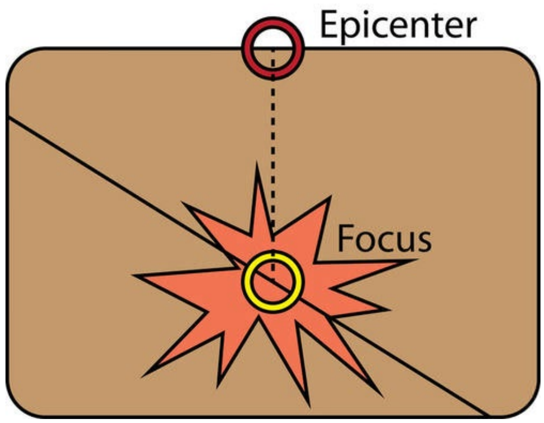
The description of how earthquakes occur is called **elastic rebound theory** (Figure below).



Elastic rebound theory. Stresses build on both sides of a fault, causing the rocks to deform plastically (Time 2). When the stress becomes too great, the rocks break and end up in a different location (Time 3). This releases the built-up energy and creates an earthquake.

Credit: Christopher AuYeung. **Source:** CK-12 Foundation. **License:** CC BY-NC 3.0

In an earthquake, the initial point where the rocks rupture in the crust is called the **focus**. The **epicenter** is the point on the land surface that is directly above the focus. In about 75% of earthquakes, the focus is in the top 10 to 15 kilometers (6 to 9 miles) of the crust. Shallow earthquakes cause the most damage because the focus is near where people live. However, it is the epicenter of an earthquake that is reported by scientists and the media (Figure above).



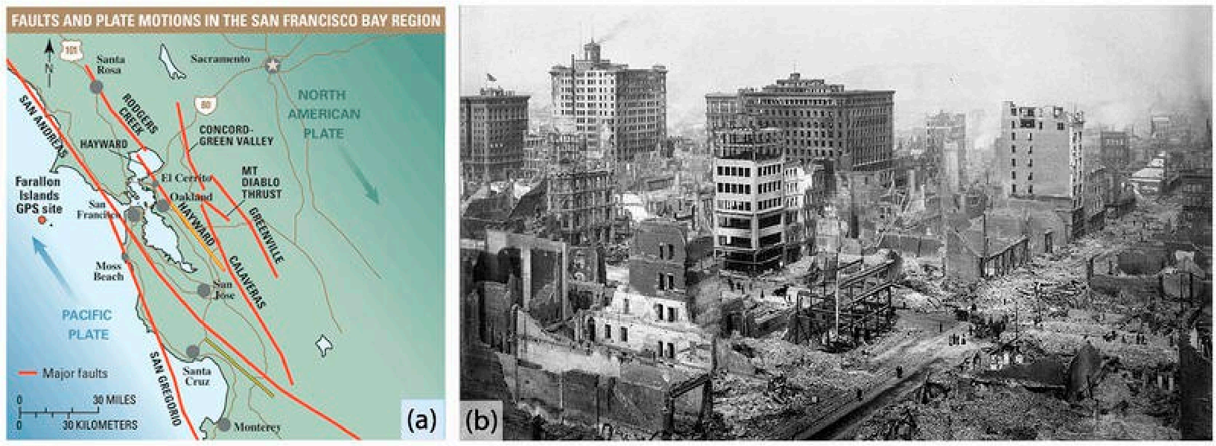
In the vertical cross section of crust, there are two features labeled - the focus and the epicenter, which is directly above the focus.

Credit: Jodi So. **Source:** CK-12 Foundation. **License:** CC BY-NC 3.0

Transform plate boundaries

Deadly earthquakes occur at transform plate boundaries. Transform faults have shallow focus earthquakes. The faults along the San Andreas Fault zone produce around 10,000 earthquakes a year. Most are tiny, but occasionally one is massive. In the San Francisco Bay Area, the

Hayward Fault was the site of a magnitude 7.0 earthquake in 1868. The 1906 quake on the San Andreas Fault had a magnitude estimated at about 7.9 (Figure below).



(a) The San Andreas Fault zone in the San Francisco Bay Area. (b) The 1906 San Francisco earthquake is still the costliest natural disaster in California history. About 3,000 people died and 28,000 buildings were lost, mostly in the fire.

Credit: (a) Courtesy of US Geological Survey; (b) Photographed by HD Chadwick and courtesy of National Archives and Records Administration

Convergent plate boundaries

Earthquakes at convergent plate boundaries mark the motions of subducting lithosphere as it plunges through the mantle. Eventually the plate heats up enough deform plastically and earthquakes stop.

Convergent plate boundaries produce earthquakes all around the Pacific Ocean basin. The Philippine Plate and the Pacific Plate subduct beneath Japan, creating a chain of volcanoes and as many as 1,500 earthquakes annually.

The Pacific Northwest of the United States is at risk from a potentially massive earthquake that could strike any time. Subduction of the Juan de Fuca plate beneath North America produces active volcanoes, but large earthquakes only hit every 300 to 600 years. The last was in 1700, with an estimated magnitude of around 9.

Divergent Plate Boundaries

Earthquakes at mid-ocean ridges are small and shallow because the plates are young, thin, and hot. On land where continents split apart, earthquakes are larger and stronger.

Intraplate Earthquakes

Intraplate earthquakes are the result of stresses caused by plate motions acting in solid slabs of lithosphere.

Tsunami are deadly ocean waves from an earthquake. The sharp jolt of an undersea quake forms a set of waves that travel through the sea entirely unnoticed. When they come onto shore, they can grow to enormous heights. Fortunately, few undersea earthquakes generate tsunami.

The Richter Magnitude Scale

Charles Richter developed the **Richter magnitude scale** in 1935. The Richter scale measures the magnitude of an earthquake's largest jolt of energy. This is determined by using the height of the waves recorded on a seismograph.

The Richter scale is logarithmic. The magnitudes jump from one level to the next. The height of the largest wave increases 10 times with each level. So, the height of the largest seismic wave of a magnitude 5 quake is 10 times that of a magnitude 4 quake. A magnitude 5 is 100 times that of a magnitude 3 quake. With each level, thirty times more energy is released. A difference of two levels on the Richter scale equals 900 times more released energy.

The Richter scale has limitations. A single sharp jolt measures higher on the Richter scale than a very long intense earthquake. Yet, this is misleading because the longer quake releases more energy. Earthquakes that release more energy are likely to do more damage. As a result, another scale was needed.

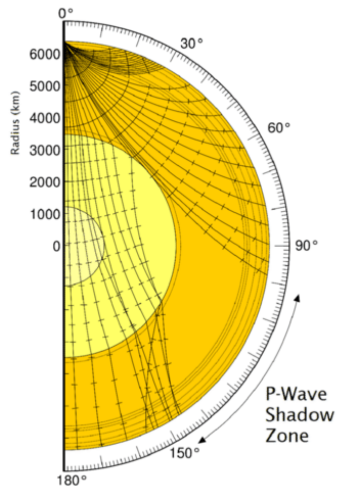
The Moment Magnitude Scale

The **moment magnitude scale** is the favored method of measuring earthquake magnitudes. It measures the total energy released by an earthquake. Moment magnitude is calculated by two things. One is the length of the fault break. The other is the distance the ground moves along the fault.

Seismic Waves

One ingenious way scientists learn about Earth's interior is by looking at how energy travels from the point of an earthquake. These are **seismic waves**. Seismic waves travel outward in all directions from where the ground breaks at an earthquake. These waves are picked up by seismographs around the world. Two types of seismic waves are most useful for learning about Earth's interior.

- **P-waves** (primary waves) are fastest, traveling at about 6 to 7 kilometers (about 4 miles) per second, so they arrive first at the seismometer. P-waves move in a compression/expansion type motion, squeezing and decompressing earth materials as they travel. This produces a change in volume for the material. P-waves bend slightly when they travel from one layer into another. Seismic waves move faster through denser or more rigid material. As P-waves encounter the liquid outer core, which is less rigid than the mantle, they slow down. This makes the P-waves arrive later and further away than would be expected. The result is a P-wave shadow zone. No P-waves are picked up at seismographs 104° to 140° from the earthquake's focus.



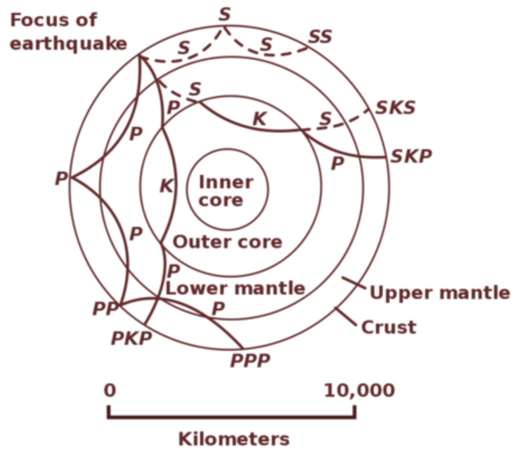
How P-waves travel through Earth's interior.

Credit: User: Lies Van Rompaey/Wikimedia Commons, based on image from the US Geological Survey

- **S-waves** (secondary waves) are about half as fast as P-waves, traveling at about 3.5 km (2 miles) per second, and arrive second at seismographs. S-waves move in an up and down motion perpendicular to the direction of wave travel. This produces a change in shape for the earth materials they move through. Only solids resist a change in shape, so S-waves are only able to propagate through solids. S-waves cannot travel through liquid.

- P-waves slow down at the mantle core boundary, so we know the outer core is less rigid than the mantle.

- S-waves disappear at the mantle core boundary, so the outer core is liquid.



Letters describe the path of an individual P-wave or S-wave. Waves traveling through the core take on the letter K.

Credit: Courtesy of US Geological Service

The environment

Climate change refers to any significant change in the measures of climate lasting for an extended period. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer. **Global warming** refers to the recent and ongoing rise in global average temperature near Earth's surface. It is caused mostly by increasing concentrations of greenhouse gases in the atmosphere. Global warming is causing climate patterns to change. However, global warming itself represents only one aspect of climate change.

The Theory of Climate Change

The theory of climate change is very new. In fact, scientists don't even call it a theory. But it meets the requirements. These are the things we know: (1) average global temperatures are rising, (2) greenhouse gases trap heat in the atmosphere, (3) CO_2 is released into the atmosphere when fossil fuels are burned, (4) CO_2 is a greenhouse gas, (5) more CO_2 in the atmosphere traps more heat so global temperature is rising. No information contradicts this theory, although some details have not been worked out. The theory is very effective at predicting future events, which are already taking place.

What is the Greenhouse Effect?

The **greenhouse effect** is the trapping of the sun's warmth in an Earth's lower atmosphere. This happens due to the greater transparency of the atmosphere to visible radiation from the Sun than to thermal infrared radiation emitted from the surface. A glass green house will let sunlight in but captures some of the thermal energy within the enclosed interior. A **greenhouse gas** is any gas that absorbs and emits energy in the **Thermal infrared range**. Primary greenhouse gases in earth's atmosphere include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3).

Global Warming and Earth's Greenhouse

Earth is currently growing warmer at an alarming rate. The weather records compiled from around the world indicated that there has been a significant rise in global temperatures over the past century. This rise in temperature is linked to the increasing amount of carbon dioxide and other greenhouse gases accumulating in the atmosphere. The rise in carbon dioxide and other greenhouse gases is a result of consumption of fossil fuels, deforestation, and other human impacts since the start of the Industrial Revolution in the 19th century.
There are many known and unknown aspects about the future of **global warming**. Highlights include sea-level rise, climate changes, changes in storm intensity and regional precipitation, changes in air and ocean chemistry (acidification), and other impacts on humanity and natural ecosystems.

Natural Resources

Non-renewable Resources: Sufficient, reliable sources of energy are a necessity for industrialized nations. Energy is used for heating, cooking, transportation and manufacturing. Energy can be generally classified as non-renewable and renewable. Over 85% of the energy used in the world is from non-renewable supplies. Most developed nations are dependent on **non-renewable** energy sources such as fossil fuels (coal and oil) and nuclear power. These sources are called non-renewable because they cannot be renewed or regenerated quickly enough to keep pace with their use. Industrialized societies depend on non-renewable energy sources. Fossil fuels are the most used types of non-renewable energy. They were formed when incompletely decomposed plant and animal matter was buried in the earth's crust and converted into carbon-rich material that is useable as fuel. This process occurred over millions of years. The three main types of fossil fuels are coal, oil, and natural gas. Two other less-used sources of fossil fuels are oil shales and tar sands.

Renewable Natural sources are often considered alternative sources because, in general, most industrialized countries do not rely on them as their main energy source. Instead, they tend to rely on non-renewable sources such as fossil fuels or nuclear power. Because the energy crisis in the United States during the 1970s, dwindling supplies of fossil fuels and hazards associated with nuclear power, usage of renewable energy sources such as solar energy, hydroelectric, wind, biomass, and geothermal has grown.

Renewable energy comes from the sun (considered an "unlimited" supply) or other sources that can theoretically be renewed at least as quickly as they are consumed. If used at a sustainable rate, these sources will be available for consumption for thousands of years or longer. Unfortunately, some potentially renewable energy sources, such as biomass and geothermal, are being depleted in some areas because the usage rate exceeds the renewal rate.

Changes in the Earth

Soil Degradation

Soil can take hundreds or thousands of years to mature. Therefore, once fertile topsoil is lost, it is not easily replaced. **Soil degradation** refers to deterioration in the quality of the soil and the concomitant reduction in its capacity to produce. Soils are degraded primarily by erosion, organic matter loss, nutrient loss and salinization. Such processes often arise from poor soil management during agricultural activities. In extreme cases, soil degradation can lead to desertification (conversion of land to desert-like conditions) of croplands and rangelands in semi-arid regions.

Erosion is the biggest cause of soil degradation. Soil productivity is reduced as a result of losses of nutrients, water storage capacity and organic matter. The two agents of erosion are wind and water, which act by removing the finer particles from the soil. This leads to soil compaction and poor soil tilth. Human activities such as construction, logging, and off-road vehicle use promote erosion by removing the natural vegetation cover protecting the soil.

Agricultural practices such as overgrazing and leaving plowed fields bare for extended periods contribute to farmland erosion. Each year, an estimated two billion metric tons of soil are eroded from farmlands in the United States alone. The soil transported by the erosion processes can also create problems elsewhere (e.g., by clogging waterways and filling ditches and low-lying land areas).

Wind erosion occurs mostly in flat, dry areas and moist, sandy areas along bodies of water. Wind not only removes soil, but also dries and degrades the soil structure. During the 1930s, poor cultivation and grazing practices -- coupled with severe drought conditions -- led to severe wind erosion of soil in a region of the Great Plains that became known as the "Dust Bowl." Wind stripped large areas of farmlands of topsoil and formed clouds of dust that traveled as far as the eastern United States.

Water erosion is the most prevalent type of erosion. It occurs in several forms, for example: rain splash erosion, sheet erosion, rill erosion and gully erosion. **Rain splash** erosion occurs when the force of individual raindrops hitting uncovered ground splashes soil particles into the air. These detached particles are more easily transported and can be further splashed down slope, causing deterioration of the soil structure. **Sheet erosion** occurs when water moves down slope as a thin film and removes a uniform layer of soil. **Rill erosion** is the most common form of water erosion and often develops from sheet erosion. Soil is removed as water flows through little streamlets across the land. **Gully erosion** occurs when rills enlarge and flow together, forming a deep gully.

Weathering

Weathering is the term used for the *chemical decomposition and physical disintegration of bedrock at and just below the earth's surface*. Weathering acts upon all bedrock near the surface, although with greatly varying nature and rate depending upon several factors.

Sediment comes from the breakdown of rocks into smaller, transportable components. This occurs via two processes: **physical weathering** and **chemical weathering**. Physical weathering consists of breaking apart rocks and crystals. The results of physical weathering are smaller components of the same material that is being weathered. There is no change in composition. In contrast, chemical weathering consists of changing the composition of at least some components of the rock that is weathering. The sediment does not have the same composition as the original rock.

Physical Weathering: Physical weathering occurs via:

1. **Freeze-thaw action**. Water in cracks expands when it freezes, putting force on the cracks. The cracks grow, and eventually crystals and pieces of rock break off into smaller components. Obviously, this process is most important in environments where temperatures cycle across the freezing point of water.

2. **Salt crystal growth**. When water evaporates, salts precipitate. If this happens in fractures in rock, the growth of the salt crystals can put pressure on the cracks, causing them to grow. This process is most important near oceans where rocks are exposed to lots of saltwater spray and in arid environments where water evaporates rapidly.

3. **Temperature changes**. Minerals contract and expand as temperature decreases and increases, respectively, and different parts of the rock are heated in different amounts. Those in direct sunlight expand as they heat, whereas the interiors and shaded areas do not. Differential expansion and contraction produce stresses which can result in cracks and physical weathering. This process is most important when temperatures change dramatically from day to night, a characteristic of many desert environments.

Physical weathering tends to produce mostly sand-sized sediment and larger grains because most of the fracturing occurs along mineral boundaries. Physical weathering of fine grained or finely crystalline rock can produce abundant very fine grains, but most of the sediment from these rock types consists of rock fragments (called lithic clasts).

Image of physically weathered rocks in New Zealand:

Chemical weathering occurs via:

1. **Dissolution** of minerals. Some minerals like halite and other evaporites dissolve very easily in water. Other minerals, particularly silicates, do not dissolve easily. Carbonates are in between and dissolve in acidic waters. (Rainwater has a pH of ~5.7 due to dissolved CO_2, even without "acid rain" pollution.) The results of dissolution are ions in water that are transported downstream. Ions are not deposited until the water evaporates, they react with other minerals, or organisms use them to make shells. Often, only part of a rock dissolves, leaving altered grains that can be transported by wind, water, for example.

2. **Alteration** of minerals. Silicate minerals do not dissolve very easily, but they do react with water to form new minerals. Feldspars react with water to form clay minerals and ions; olivine reacts with water and O_2 to form oxides, clay minerals and ions; pyrite reacts with water and O_2 to form oxides, acidity and sulfate ions. Iron oxides, such as hematite, are commonly red, giving weathered rocks a rusty hue. Alteration of minerals is one of the main sources of clay minerals and mud-sized grains.

Space

The Sun

Our Sun is a **star**, a sphere of plasma held together by gravity. It is an ordinary star that is extraordinarily important. The Sun provides light and heat to our planet. This star supports almost all life on Earth.

The Sun is the center of the **solar system**, which includes all the planets and other bodies that orbit it. It is by far the largest part of the solar system (Figure below). Added together, all the planets make up just 0.2% of the solar system's mass. The Sun makes up the remaining 99.8% of all the mass in the solar system!

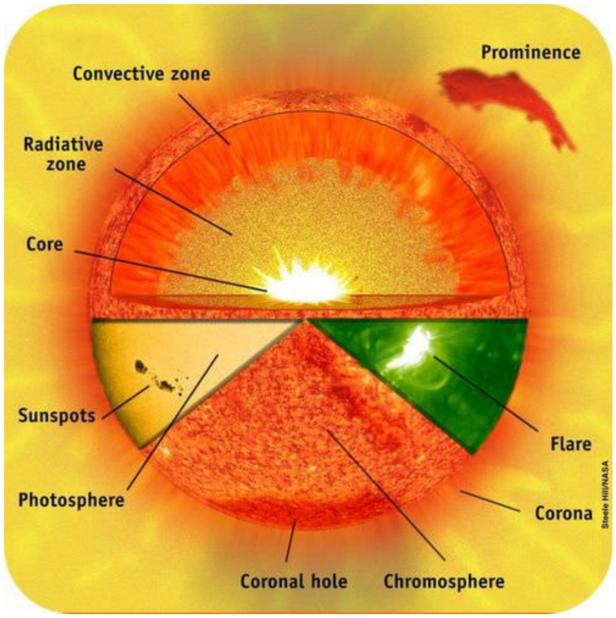
The sizes of the planets relative to the Sun, if the Sun were the size of a basketball.

Layers of the Sun

The Sun is made almost entirely of hydrogen and helium. The Sun has no solid material. Most atoms in the Sun exist as **plasma**. Plasma is superheated gas with an electrical charge. Because the Sun is made of gases, it does not have a defined outer boundary. Like Earth, the Sun has an internal structure. The inner three layers make up what we would call “the Sun.”

Internal Structure

Because the Sun is not solid, it does not have a defined outer boundary. It does, however, have a definite internal structure with identifiable layers. Since the layers are not solid, the boundaries are fuzzy and indistinct. From inward to outward, the layers are the core, the radiative zone, and the convection zone.



The layers of the Sun.

The Core

The **core** is the Sun's innermost layer. The core is plasma. It has a temperature of around 15 million degrees Celsius (°C). Nuclear fusion reactions create immense temperature. In these reactions, hydrogen atoms fuse to form helium. This releases vast amounts of energy. The energy moves toward the outer layers of the Sun. Energy from the Sun's core powers most of the solar system.

Radiative Zone

The **radiative zone** is the next layer out. It has a temperature of about 4 million °C. Energy from the core travels through the radiative zone. Energy travels at an extremely slow rate. Light particles are called **photons**. In the radiative zone, photons can travel only a few millimeters before they hit another particle. The particles are absorbed and then released again. It may take 50 million years for a photon to travel all the way through the radiative zone.

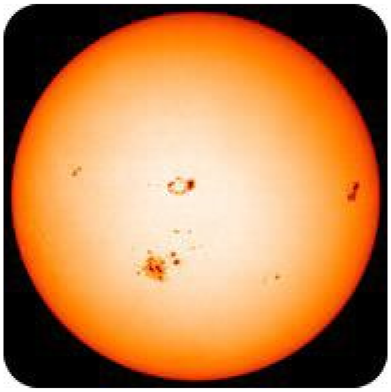
The Convection Zone

The **convection zone** surrounds the radiative zone. In the convection zone, hot material from near the Sun’s center rises. This material cools at the surface and then plunges back downward. The material then receives more thermal energy from the radiative zone.

Sunspots

The most noticeable magnetic activity of the Sun is the appearance of sunspots. **Sunspots** are cooler, darker areas on the Sun’s surface. Sunspots occur in an 11-year cycle. The number of sunspots begins at a minimum. The number gradually increases to the maximum. Then the number returns to a minimum again.

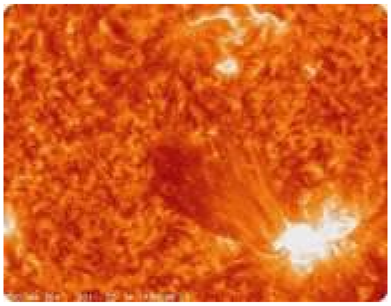
Sunspots form because loops of the Sun's magnetic field break through the surface. Sunspots usually occur in pairs. The loop breaks through the surface where it comes out of the Sun. It breaks through again where it goes back into the Sun. Sunspots disrupt the transfer of heat from the Sun's lower layers.



The darker regions in this image are sunspots.

Solar Flares

A loop of the Sun's magnetic field may break. This creates **solar flares**. Solar flares are violent explosions that release massive amounts of energy. The streams of high energy particles they emit make up the **solar wind**. Solar wind is dangerous to spacecraft and astronauts. Solar flares can even cause damage on Earth. They have knocked out entire power grids and can disturb radio, satellite, and cell phone communications.



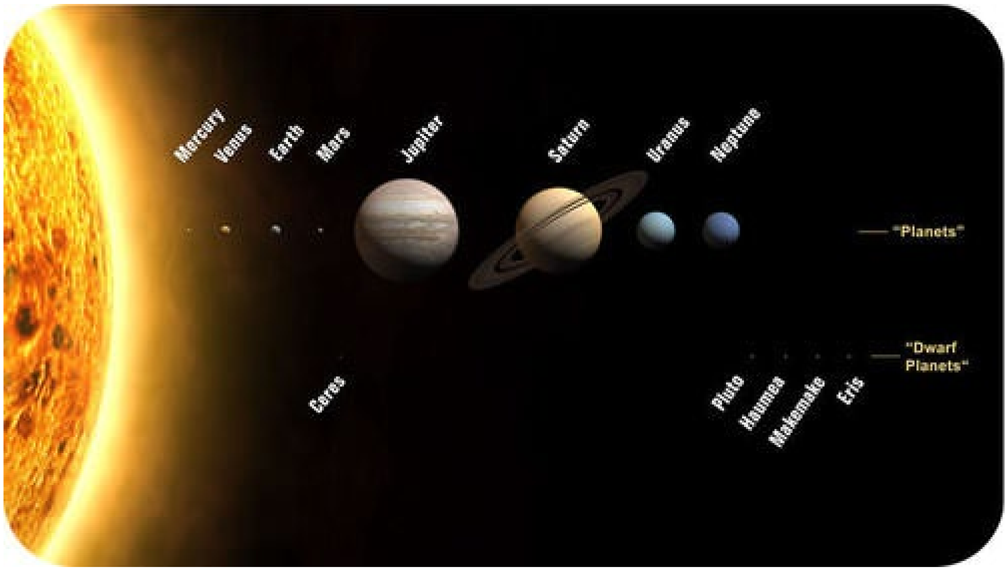
The solar flare is the bright area in the lower right.

Solar Prominences

Another amazing feature of the Sun is **solar prominence**. Plasma flows along the loop that connects sunspots. This plasma forms a glowing arch. The arch is a solar prominence. Solar prominences can reach thousands of kilometers into the Sun's atmosphere. Prominence can last for a day to several months. Prominence can be seen during a total solar eclipse.

Solar System Objects

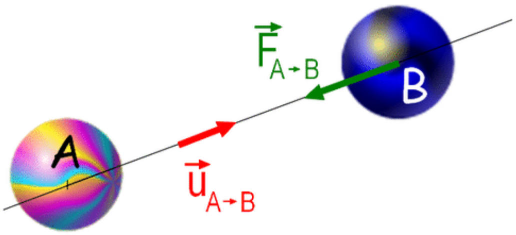
Astronomers now recognize eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune), five dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids, and other small objects. These objects move in regular and predictable paths around the Sun.



Relative sizes of the Sun, planets, and dwarf planets and their positions relative to each other are in scale. The relative distances are not in scale.

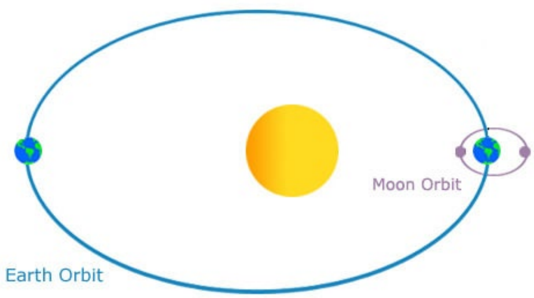
The Role of Gravity

All objects in the universe have an attraction to each other. This attraction is known as **gravity** (figure below). The strength of the force of gravity depends on two things; one is the mass of objects, and the other is the distance between the objects. As an object's mass increases, the attraction increases. As the distance between the objects increases, the attraction decreases.



The strength of the force of gravity between objects A and B depends on the mass of the objects and the distance (*u*) between them.

Isaac Newton first described gravity as the force that causes objects to fall to the ground. Gravity is also the force that keeps the Moon circling Earth. Gravity keeps Earth circling the Sun. Without gravity, these objects would fly off into space.



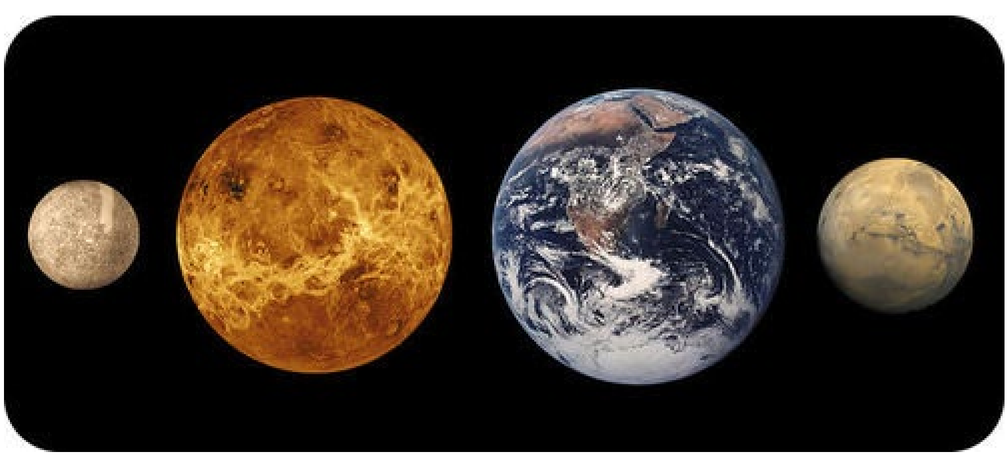
The Moon orbits the Earth, and the Earth-Moon system orbits the Sun.

Earth's gravity pulls any object on or near Earth toward the planet's center.

The Inner Planets

The four planets closest to the Sun—Mercury, Venus, Earth, and Mars—are the **inner planets** or **terrestrial planets** (figure below). They are like Earth. All are solid, dense, and rocky. None of the inner planets has rings. Compared to the outer planets, the inner planets are small. They have shorter orbits around the Sun, and they spin more slowly. Venus spins backward and spins the slowest of all the planets.

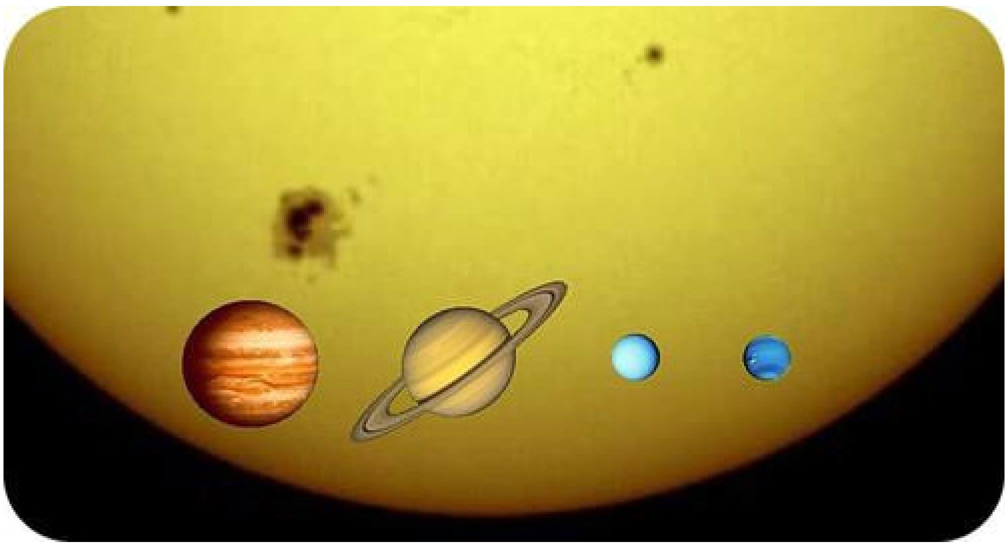
All the inner planets were geologically active at one time. They are all made of cooled igneous rock with inner iron cores. Earth has one big, round moon, while Mars has two very small, irregular moons. Mercury and Venus do not have moons.



This composite shows the relative sizes of the four inner planets. From left to right, they are Mercury, Venus, Earth, and Mars.

The Outer Planets

Jupiter, Saturn, Uranus, and Neptune are the **outer planets** of our solar system. These are the four planets farthest from the Sun. The outer planets are much larger than the inner planets. Since they are made mostly of gases, they are also called **gas giants**. Pictured below are the relative sizes of the outer planets and the Sun.

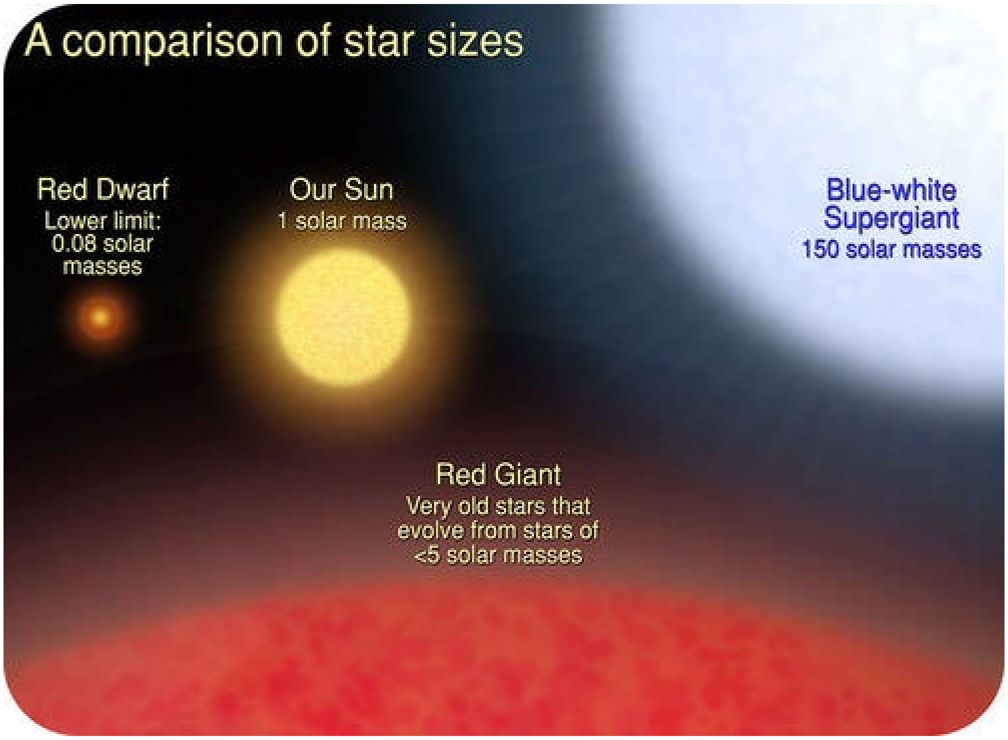


This image shows the four outer planets and the Sun, with sizes to scale. From left to right, the outer planets are Jupiter, Saturn, Uranus, and Neptune.

The gas giants are made mostly of hydrogen and helium. These are the same elements that make up most of the Sun. Astronomers think that most of the nebula that formed the solar system was hydrogen and helium. The inner planets lost these light gases. Their gravity was too low to keep them, and they floated away into space. The Sun and the outer planets had enough gravity to keep the hydrogen and helium.

All the outer planets have numerous moons. They also have **planetary rings** made of dust and other small particles. Only the rings of Saturn can be easily seen from Earth.

Stars



Relative sizes of stars of different masses.

This illustration (figure above) shows the relative sizes of stars and their mass compared to the Sun. **Red dwarfs** are less massive and much smaller in size than the Sun. This means they have an exceptionally long lifetime. Our Sun is a common type of star and has an average lifespan. **Red giants** are what some main sequence stars (like our Sun) become near the end of their lives. They are much larger than our Sun. **Supergiants** are very massive stars and are larger than our Sun but have a smaller radius than red giants. Supergiants have short lifetimes.

Star Systems

Our solar system has only one star. But many stars are in **star systems** of two or more stars. Two stars that orbit each other are called a binary star system. If more than two stars orbit each other, it is called a multiple star system. Pictured below are two binary star systems orbiting each other (figure below). This creates an unusual quadruple star system. The distance separating the two pairs is about the same as the distance from our Sun to Pluto.

This is an artist's depiction of HD 98800. This is a quadruple star system made of two binary star systems.

Star Clusters

Star clusters are small groups of stars. A star cluster is smaller than a galaxy. There are two main types, open clusters and globular clusters. Both types are held together by gravity.

Open Clusters

Open clusters are groups of up to a few thousand stars. The Jewel Box (Figure below) is an open cluster. Open clusters tend to be blue in color. They often contain glowing gas and dust. The stars in an open cluster are young stars that all formed from the same nebula.

These hot blue stars are in an open cluster known as the Jewel Box. The red star is a young red supergiant.

Globular Clusters

Globular clusters (**Figure** below) are groups of tens to hundreds of thousands of stars. Gravity holds these stars tightly together. Globular clusters have a definite, spherical shape. They contain mostly old, reddish stars. Near the center of a globular cluster, the stars are closer together. The heart of the globular cluster M13 has hundreds of thousands of stars. M13 is 145 light years in diameter. The cluster contains red and blue giant stars.

The globular cluster M13 contains red and blue giant stars.

Galaxies

Compared to Earth, the solar system is a big place. Compared to the solar system a star cluster is a big place. But galaxies are bigger—a lot bigger.

A **galaxy** is a very large group of stars held together by gravity. How enormous a galaxy is and how many stars it contains is impossible for us to really understand. A galaxy contains up to a few billion stars. Our solar system is in the Milky Way Galaxy. It is so large that if our solar system were the size of your fist, the galaxy's disk would be wider than the entire United States. There are several different types of galaxies, and there are billions of galaxies in the Universe.

Types of Galaxies

Galaxies are divided into three types, according to shape. There are spiral galaxies, elliptical galaxies, and irregular galaxies.

Spiral Galaxies

A **spiral galaxy** is a rotating disk of stars and dust. In the center is a dense bulge of material. Several **spiral arms** come out from the center. Spiral galaxies have lots of gas and dust and many young stars. Figure below shows a spiral galaxy from the side. You can see the disk and central bulge.

The Pinwheel Galaxy is a spiral galaxy displaying prominent arms.

The closest spiral galaxy, the Andromeda Galaxy (figure below) is 2,500,000 light years away and contains one trillion stars!

The Andromeda Galaxy is the closest major galaxy to our own.

Elliptical Galaxies

Pictured below is a typical **elliptical galaxy**. These galaxies are elliptical, or egg-shaped. The smallest elliptical galaxies are as small as some globular clusters. Giant elliptical galaxies can contain over a trillion stars. Elliptical galaxies are reddish to yellowish in color because they contain mostly old stars.

The large, reddish-yellow object in the middle of this figure is a typical elliptical galaxy.

Irregular Galaxies and Dwarf Galaxies

Galaxies that are not clearly elliptical galaxies nor spiral galaxies are called **irregular galaxies**. Most irregular galaxies were once spiral or elliptical galaxies. They were then deformed either by gravitational attraction to a larger galaxy or by a collision with another galaxy.

This galaxy called NGC 1427A is an irregular galaxy. It has neither a spiral nor an elliptical shape.

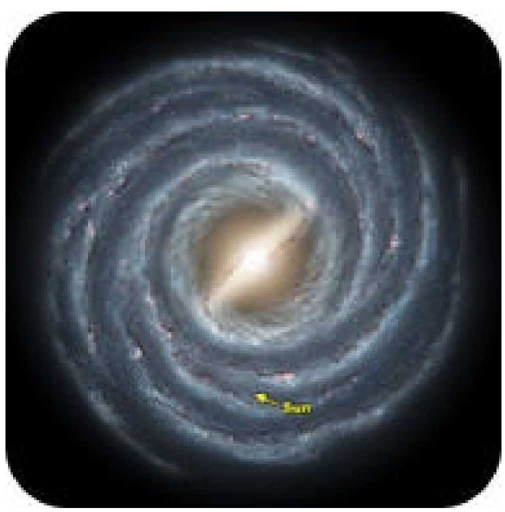
Dwarf galaxies are small galaxies containing only a few million to a few billion stars. Most dwarf galaxies are irregular in shape. However, there are also *dwarf elliptical galaxies* and *dwarf spiral galaxies*. Dwarf galaxies are the most common type in the Universe. However, because they are relatively small and dim, we don't see as many dwarf galaxies as we do their full-sized cousins.

The Milky Way Galaxy

The **Milky Way Galaxy** is our galaxy. It is made of millions of stars along with a lot of gas and dust. It looks different from other galaxies because we are looking at the main disk from within the galaxy. Astronomers estimate that the Milky Way contains 200 billion to 400 billion stars.

Shape and Size

It is difficult to know what the shape of the Milky Way Galaxy is because we are inside of it. Astronomers have identified it as a typical spiral galaxy containing about 100 billion to 400 billion stars (**Figure** below).



An artist's rendition of what astronomers think the Milky Way Galaxy would look like seen from above. The sun is located approximately where the arrow points (in yellow).

Like other spiral galaxies, our galaxy has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across and 3,000 light-years thick. Most of the Galaxy's gas, dust, young stars, and open clusters are in the disk.

Where Are We?

Our solar system, including the Sun, Earth, and all the other planets, is within one of the spiral arms in the disk of the Milky Way Galaxy. Most of the stars we see in the sky are also in this spiral arm. We are about 26,000 light-years from the center of the galaxy. We are a little more than halfway out from the center of the galaxy to the edge.

Just as Earth orbits the Sun, the solar system orbits the center of the galaxy. Astronomers have recently discovered that at the center of the Milky Way and most other galaxies, is a supermassive black hole.

The Moon

Earth's Moon

The Moon is Earth's only natural satellite. The Moon is about one-fourth the size of Earth, 3,476 kilometers in diameter. Gravity on the Moon is only one-sixth as strong as it is on Earth. If you weigh 120 pounds on Earth, you would weigh only 20 pounds on the Moon. You can jump six times as high on the Moon as you can on Earth. The Moon makes no light of its own. Like every other body in the solar system, it only reflects light from the Sun.

Orbit

The Moon rotates on its axis once for every orbit it makes around Earth. This means that the same side of the Moon always faces Earth. The side of the Moon that always faces Earth is called the near side. The side of the Moon that always faces away from Earth is called the far side. From Earth, people have seen only the Moon's near side. The far side has been seen only by spacecraft and Apollo astronauts.

Atmosphere

The Moon has no atmosphere. With no atmosphere, the Moon is not protected from extreme temperatures. The average surface temperature during the day is approximately 107°C (225°F). Daytime temperatures can reach as high as 123°C (253°F). At night, the average temperature drops to -153°C (-243°F). The lowest temperatures measured are as low as -233°C (-397°F).

Lunar Surface

We all know what the Moon looks like. It's always looked the same during our lifetime. In fact, the Moon has looked the same to every person and even the dinosaurs, trilobites, or cyanobacteria; we all would have seen more-or-less the same thing. This is not true of Earth.

Natural processes continually alter Earth's surface. The Moon does have more craters than it did in the long distant past, of course.

Even though we can't see it from Earth, the Moon has changed recently too. Astronauts' footprints are now on the Moon. They will remain unchanged for thousands of years, because there is no wind, rain, or living thing to disturb them. A falling meteorite could destroy them. Tiny micrometeorites bombard the Moon's surface and smooth it over time too.

Craters

The surface of the Moon is very different from Earth. The lunar landscape is covered by **craters** caused by meteoroid impacts (Figure below). (**Lunar** means relating to the Moon.) The craters are bowl-shaped basins on the Moon's surface. Because the Moon has no water, wind, or weather, the craters remain unchanged.

The Moon's coldest temperatures are found deep in the craters. The coldest craters are at the south pole on the Moon's far side. The Sun never shines on the bottoms of the deepest craters. These temperatures are amongst the coldest in our entire solar system.

Craters, like the ones shown in this image, are found on the surface of the Moon.

Maria

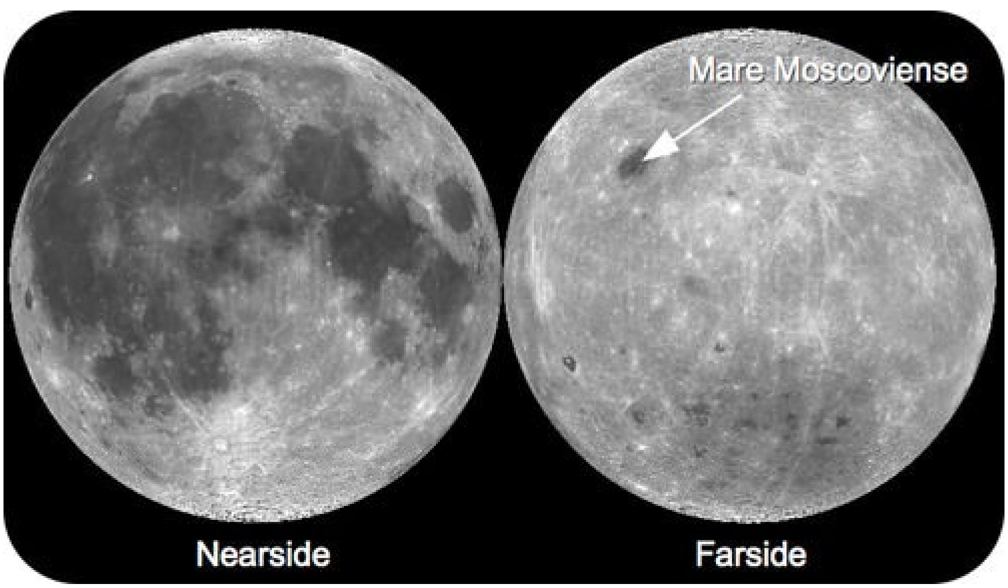
When you look at the Moon from Earth, you notice dark and light areas. **Maria** are dark, solid, flat areas of lava (mostly basalt). Maria cover around 16% of the Moon's surface, mostly on the near side. Maria formed about 3.0 to 4.0 billion years ago, when the Moon was continually bombarded by meteoroids (Figure below). Large meteorites broke through the Moon's newly formed surface. This eventually caused magma to flow out and fill the craters. Scientists estimate volcanic activity on the Moon ended about 1.2 billion years ago.

Maria (the dark areas) and Terrae (the light areas) cover the Moon.

Terrae

The lighter parts on the Moon are called **terrae**, or highlands (**Figure** above). They are higher than the maria and include several high mountain ranges. The rock that makes up the highlands is composed mostly of feldspar, which is lighter in color and crystallized more slowly than the maria. The rock looks light because it reflects more of the Sun's light.

The figure below shows the near and far sides of the Moon (**Figure** below). They are different!



The Mare Moscovinse is one of the few maria, or dark, flat areas, on the far side.

The rocks of the terrae formed while the lunar magma ocean cooled just after the Moon formed. The maria formed later.

Water

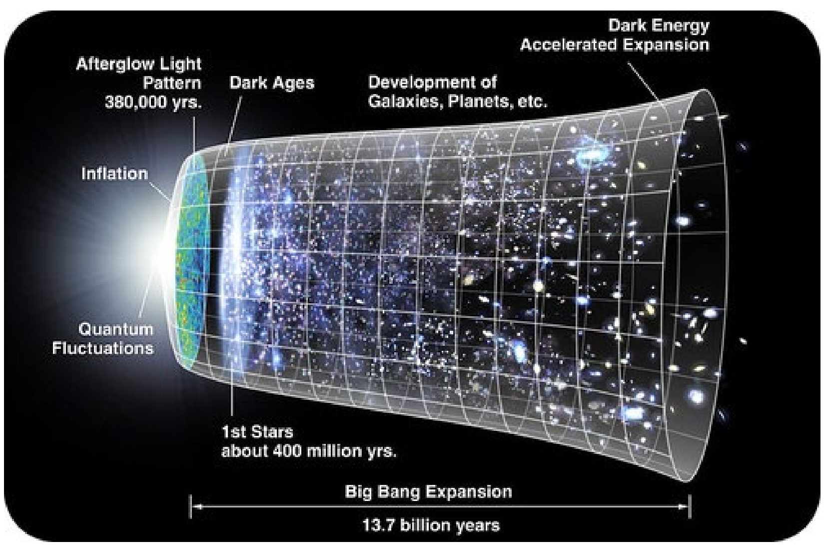
There is no running water and no atmosphere on the moon's surface. This means that there is no erosion. NASA scientists have discovered a large number of water molecules mixed in with lunar dirt. There is also surface water ice in some of the frigid places that are always in shadow. Even though there is a very small amount of water, there is no atmosphere. Temperatures are extreme. So, it comes as no surprise that there has not been evidence of life on the Moon.

Lunar Interior

Like Earth, the Moon has a distinct crust, mantle, and core. The crust is composed of igneous rock. This rock is rich in oxygen, silicon, magnesium, and aluminum. On the near side, the Moon's crust is about 30 kilometers thick. On the far side, the crust is about 100 kilometers thick. The mantle is made of rock like Earth's upper mantle. The Moon has a small metallic core, perhaps 300 to 500 kilometers in diameter. The composition of the core is probably mostly iron with some sulfur and nickel. We learned this both from the rock samples gathered by astronauts and from spacecraft sent to the Moon.

Theories

Big Bang



Timeline of the Big Bang and the expansion of the Universe.

The **Big Bang theory** is the most widely accepted cosmological explanation of how the Universe formed. Think about the expanding Universe, then reverse it. If we start at the present and go back into the past, the Universe gets smaller. What is the result of a contracting Universe? A point.

According to the Big Bang theory, the Universe began about 13.7 billion years ago. Everything that is now in the Universe was squeezed into a point. It was all in a single, hot, chaotic mass. Then an enormous explosion—a big bang—took place. The big bang caused the Universe to start expanding rapidly. All the matter and energy, even space itself, came out of this explosion (Figure above).

Closed Universe Theory

Space-time curves back on itself; finite size, no center, no edge, and positive curvature. It is spherical and has a finite volume.

Big Crunch: the expanding universe will begin to contract matter back into a Big Bang state.

Flat Universe Theory

Infinite and un-curved space-time model of the universe; it has zero curvature.

Open Universe Theory

Model of an infinite universe: curved space-time; does not curve back on itself. It has negative curvature.

Practice Activity

1. Although California is prone to many natural hazards, including volcanic eruptions at Mt. Shasta or Mt. Lassen, and landslides on coastal cliffs, the natural hazard the state is linked with is earthquakes. An earthquake is sudden ground movement caused by the sudden release of energy stored in rocks. Each year there are more than 150,000 earthquakes strong enough to be felt by people and 900,000 recorded by seismometers. How do scientists study earthquakes?
    A. Measuring the distance from the epicenter
    B. Studying the energy transmitted by seismic waves.
    C. Comparing P-waves and S-waves
    D. Analyzing the initial point where the rocks rupture in the crust.

2. Nearly 80% of the air's mass and 99% of the water vapor in the air occurs within
    A. the stratosphere.
    B. the troposphere.
    C. the upper atmosphere.
    D. outer space.

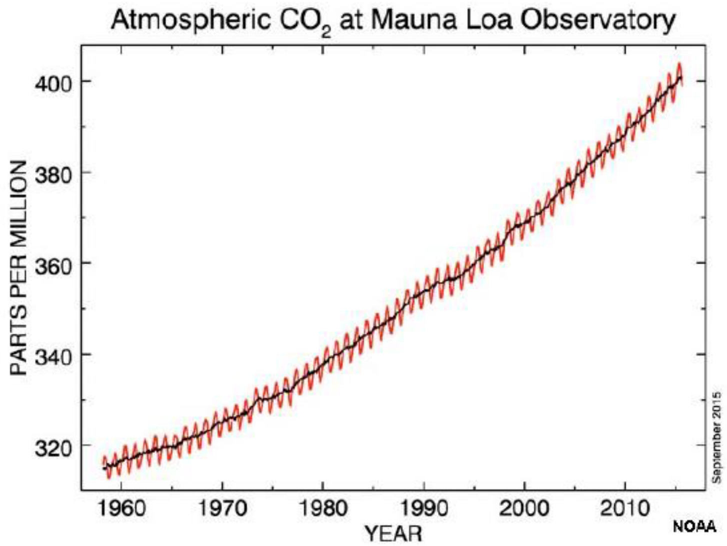
3. Incoming solar radiation involves all wavelengths of the electromagnetic spectrum. The atmosphere is transparent to most wavelengths, but part of the solar spectrum is absorbed by certain greenhouse gases in the atmosphere. Which of the following is NOT considered a **greenhouse gas**?

A. water vapor (H_2O)
B. oxygen (O2)
C. carbon dioxide (CO2)
D. methane (CH_4)

4. When a warm, moist air mass (a ***maritime-tropical air mass***) encounters a cold, dry air mass (a ***polar continental air mass***), what happens?
   A. Cold air moves in over the warm air, causing precipitation.
   B. Both warm fronts and cold fronts can form, possibly resulting in precipitation.
   C. Cold air rises, forming clouds, resulting in snow.
   D. Warm air sinks, forming clouds, resulting in rain.

5. The fog often called the **marine layer** in coastal California is generally most often what kind of cloud?
   A. Cirro-form
   B. Cumulo-form
   C. Nimbo-form
   D. Strato-form

6. The figure below shows the record of changing carbon-dioxide concentrations in the atmosphere as recorded by NOAA at its atmospheric research lab on Mauna Loa in Hawaii. The graph shows that:
   A. Carbon-dioxide concentrations have been steadily increasing for the last 50 years.
   B. seasonal growth and decay of plant leaves in the northern hemisphere cause minor but measurable fluctuations in carbon-dioxide concentrations.
   C. Carbon-dioxide created by the burning of fossil fuels is being produced faster than the oceans can absorb and consume the gases.
   D. All the choices are correct.



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Answers:

1. B
2. B
3. B
4. B
5. D
6. A

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Chapter 4: Physical Science – Chemistry

Science is the process by which we learn about the natural universe by observing, testing, and then generating models that explain our observations. Because the physical universe is so vast, there are many different branches of science. Chemistry is one branch of science; it is the study of matter. Mathematics is the language of science, and we will use it to communicate some of the ideas of chemistry.

Matter-Elements-Atoms

At its most fundamental level, life is made up of matter. **Matter** occupies space and has mass. All matter is composed of **elements**, substances that cannot be broken down or transformed chemically into other substances. Each element is made of atoms, each with a constant number of protons and unique properties. A total of 118 elements have been defined; however, only 92 occur naturally, and fewer than 30 are found in living cells. The remaining 26 elements are unstable and, therefore, do not exist for very long or are theoretical and have yet to be detected. Each element is designated by its chemical symbol (such as H, N, O, C, and Na), and possesses unique properties. These unique properties allow elements to combine and to bond with each other in specific ways.

What is an Atom?

An **atom** is the smallest unit of matter that retains all the chemical properties of an element. For example, one gold atom has all the properties of gold in that it is a solid metal at room temperature. A gold coin is simply many gold atoms molded into the shape of a coin and containing tiny amounts of other elements known as impurities. Gold atoms cannot be broken down into anything smaller while still retaining the properties of gold. An atom is composed of two regions: the **nucleus**, which is in the center of the atom and contains protons and neutrons, and the outermost region of the atom which holds its electrons in orbit around the nucleus, as illustrated in Figure 1.1. Atoms contain protons, electrons, and neutrons, among other subatomic particles. The only exception is hydrogen (H), which is made of one proton and one electron with no neutrons.

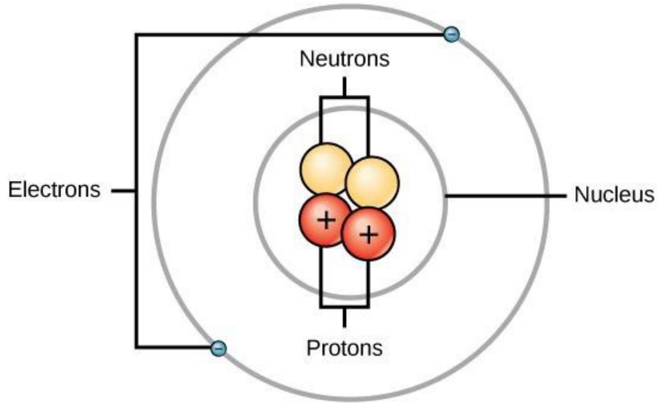


Figure 1.1. Elements, such as helium depicted here, are made up of atoms. Atoms are made up of protons and neutrons located within the nucleus, with electrons in orbitals surrounding the nucleus.

Protons and neutrons have approximately the same mass, about 1.67×10^{-24} grams.

Scientists arbitrarily define this amount of mass as one atomic mass unit (amu) (Table 1.2). Although similar in mass, protons and neutrons differ in their electric charge.

A **proton** is positively charged whereas a **neutron** is uncharged. Therefore, the number of neutrons in an atom contributes significantly to its mass, but not to its charge.

Table 1.2. Protons, neutrons, and electrons

	Charge	**Mass (amu)**	**Location in atom**
Proton	+1	1	Nucleus
Neutron	0	1	Nucleus
Electron	-1	0	Orbitals

Electrons are much smaller in mass than protons, weighing only 9.11×10^{-28} grams, or about 1/1800 of an atomic mass unit. Hence, they do not contribute much to an element's overall atomic mass. Although not significant contributors to mass, electrons do contribute to the atom's charge, as each electron has a negative charge equal to the positive charge of a proton. In uncharged, neutral atoms, the number of electrons orbiting the nucleus is equal to the number of protons inside the nucleus. In these atoms, the positive and negative charges cancel each other out, leading to an atom with no net charge. Accounting for the sizes of protons, neutrons, and electrons, most of the volume of an atom—greater than 99 percent—is, in fact, empty space. With all this empty space, one might ask why so-called solid objects do not just pass through one another. The reason they do not is that the electrons that surround all atoms are negatively charged, and negative charges repel each other. When an atom gains or loses an electron, an **ion** is formed. Ions are charged forms of atoms. A positively charged ion, such as sodium (Na^+), has lost one or more electrons. A negatively charged ion, such as chloride (Cl^-), has gained one or more electrons.

Molecules

Molecules are formed when two or more atoms join through chemical bonds to form a unit of matter. For example, a molecule of carbon dioxide gas: its chemical formula is CO_2, indicating that this molecule is made up of one carbon atom and two oxygen atoms. Some molecules are charged due to the ions they contain. This is the case for nitrate (NO_3^-), a common source of nitrogen in plants. It contains one nitrogen atom and three oxygen atoms and has an overall charge of negative one.

Periodic Table of Elements

As early chemists worked to purify ores and discovered more elements, they realized that various elements could be grouped together by their similar chemical behaviors.

- One such grouping includes lithium (Li), sodium (Na), and potassium (K): These elements all are shiny, conduct heat and electricity well, and have similar chemical properties.
- A second grouping includes calcium (Ca), strontium (Sr), and barium (Ba), which also are shiny, good conductors of heat and electricity, and have chemical properties in common.

However, the specific properties of these two groupings are notably different from each other. For example: Li, Na, and K are much more reactive than are Ca, Sr, and Ba; Li, Na, and K form compounds with oxygen in a ratio of two of their atoms to one oxygen atom, whereas Ca, Sr, and Ba form compounds with one of their atoms to one oxygen atom. Fluorine (F), chlorine (Cl), bromine (Br), and iodine (I) also exhibit similar properties to each other, but these properties are drastically different from those of any of the elements above.

Dimitri Mendeleev in Russia (1869) and Lothar Meyer in Germany (1870) independently recognized that there was a periodic relationship among the properties of the elements known at that time. Both published tables with the elements arranged according to increasing atomic mass. But Mendeleev went one step further than Meyer: He used his table to predict the existence of elements that would have properties like aluminum and silicon but were yet unknown. The discoveries of gallium (1875) and germanium (1886) provided great support for Mendeleev’s work. Although Mendeleev and Meyer had a long dispute over priority, Mendeleev’s contributions to the development of the periodic table are now more widely recognized.

By the twentieth century, it became apparent that the periodic relationship involved atomic numbers rather than atomic masses. The modern statement of this relationship, the periodic law, is as follows: *the properties of the elements are periodic functions of their atomic numbers*.

A modern periodic table arranges the elements in increasing order of their atomic numbers and groups atoms with similar properties in the same vertical column. Each box represents an element and contains its atomic number, symbol, average atomic mass, and (sometimes) name. The elements are arranged in seven horizontal rows, called periods or series, and 18 vertical columns, called groups. Groups are labeled at the top of each column.

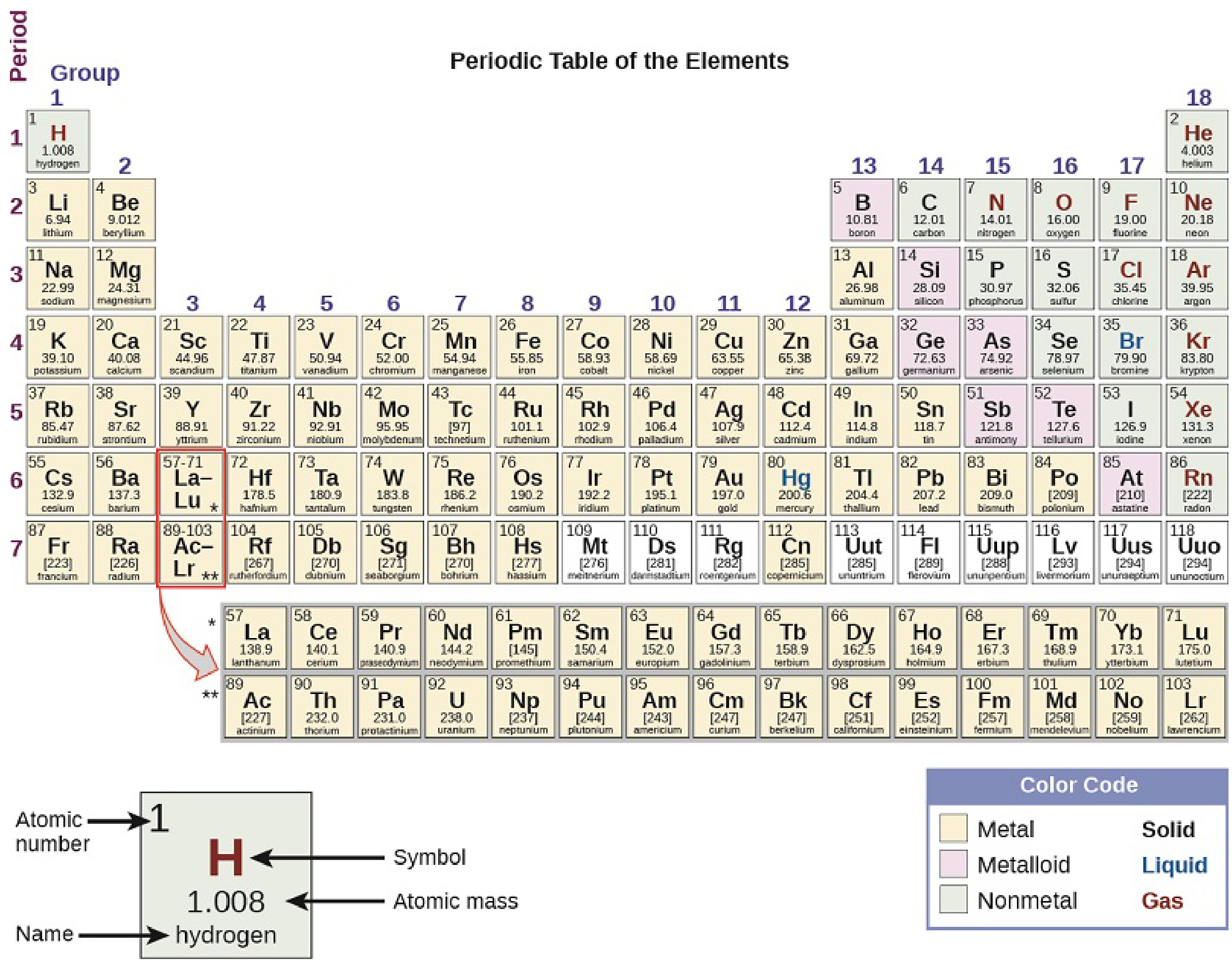


Figure 2.5.2: Elements in the periodic table are organized according to their properties.

Many elements differ dramatically in their chemical and physical properties, but some elements are similar in their behaviors. For example, many elements appear shiny, are malleable (able to be deformed without breaking) and ductile (can be drawn into wires) and conduct heat and electricity well. Other elements are not shiny, malleable, or ductile, and are poor conductors of heat and electricity. We can sort the elements into large classes with common properties:

- metals (elements that are shiny, malleable, good conductors of heat and electricity—shaded yellow);
- nonmetals (elements that appear dull, poor conductors of heat and electricity—shaded green); and
- metalloids (elements that conduct heat and electricity moderately well and possess some properties of metals and some properties of nonmetals—shaded purple).

The elements can also be classified into:

- the main-group elements (or representative elements) in the columns labeled 1, 2, and 13–18;
- the transition metals in the columns labeled 3–12; and
- inner transition metals in the two rows at the bottom of the table (the top-row elements are called lanthanides and the bottom-row elements are actinides (Figure 2.5.3).

Elements can be subdivided further by more specific properties, such as the composition of the compounds they form. For example:

- Elements in group 1 (the first column) form compounds that consist of one atom of the element and one atom of hydrogen. These elements (except hydrogen) are known as alkali metals, and they all have similar chemical properties.
- Elements in group 2 (the second column) form compounds consisting of one atom of the element and two atoms of hydrogen: These are called alkaline earth metals, with similar properties among members of that group.
- Other groups with specific names are the pnictogens (group 15),
- chalcogens (group 16),
- halogens (group 17), and
- the noble gases (group 18, also known as inert gases).

The groups can also be referred to by the first element of the group: For example, chalcogens can be called the oxygen group or oxygen family. Hydrogen is a unique, nonmetallic element with properties like both group 1 and group 17 elements. For that reason, hydrogen may be shown at the top of both groups, and by itself.

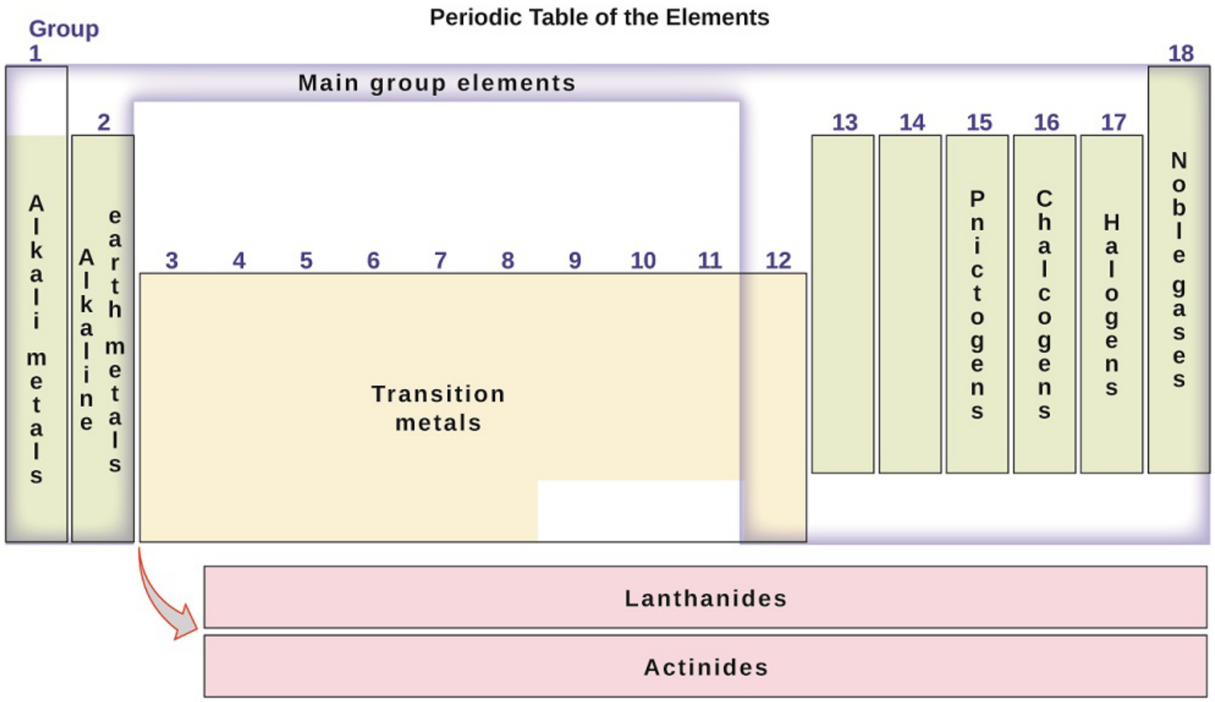


Figure 2.5.3: The periodic table organizes elements with similar properties into groups.

Chemistry of Life

Hydrocarbons are organic molecules consisting entirely of carbon and hydrogen, such as methane (CH_4). We often use hydrocarbons in our daily lives as fuels—like propane in a gas grill or the butane in a lighter. The many covalent bonds between the atoms in hydrocarbons store a great amount of energy, which is released when these molecules are burned (oxidized). Methane, an excellent fuel, is the simplest hydrocarbon molecule, with a central carbon atom bonded to four different hydrogen atoms, as illustrated in Figure 1.2.

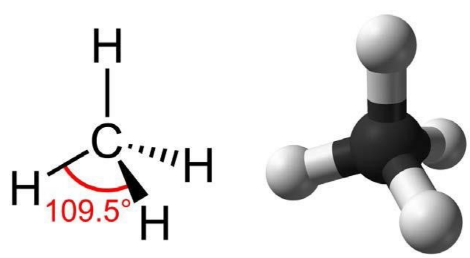


Figure 1.2. Methane (CH_4) has a tetrahedral geometry, with each of the four hydrogen atoms spaced 109.5° apart.

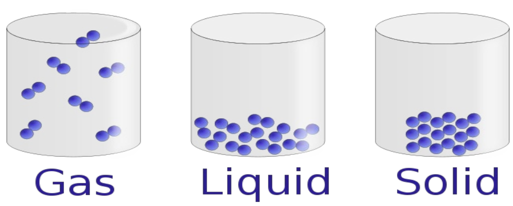
As the backbone of the large molecules of living things, hydrocarbons may exist as linear carbon chains, carbon rings, or combinations of both. This three-dimensional shape or conformation of the large molecules of life (macromolecules) is critical to how they function.

Matter and Its States

Matter typically exists in one of three states: **solid**, **liquid**, or **gas**. The state a given substance exhibits is also a physical property. Some substances exist as gases at room temperature (oxygen and carbon dioxide), while others, like water and mercury metal, exist as liquids. Most metals exist as solids at room temperature. All substances can exist in any of these three states.

- **Solids** are rigid and have fixed shapes and volumes. A rock, for example, is a solid.
- **Liquids** have fixed volumes but flow to assume the shape of their containers, such as a beverage in a can.
- **Gases**, such as air in an automobile tire, have neither fixed shapes nor fixed volumes and expand to completely fill their containers.

Whereas the volume of gases strongly depends on their temperature and **pressure** (the amount of force exerted on a given area), the volumes of liquids and solids are virtually independent of temperature and pressure. Matter can often change from one physical state to another in a process called a **physical change**. For example, liquid water can be heated to form a gas called steam, or steam can be cooled to form liquid water. However, such changes of state do not affect the chemical composition of the substance.



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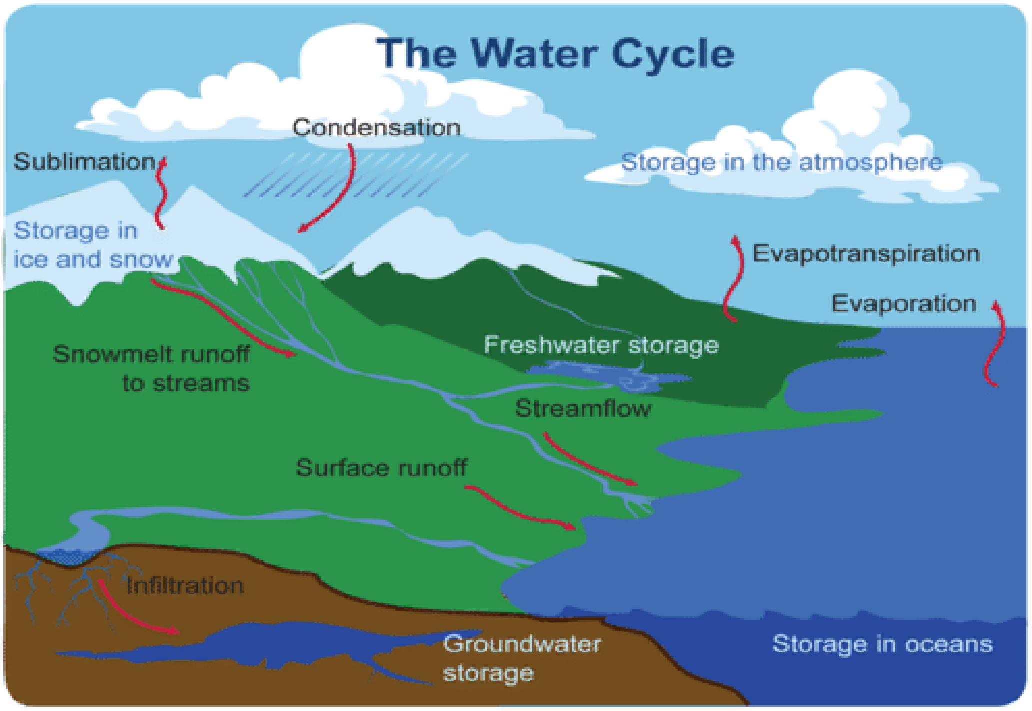
The Water Cycle

The chemical elements and water that are needed by organisms continuously recycle in ecosystems. They pass through biotic and abiotic components of the biosphere. That's why their cycles are called **biogeochemical cycles**. For example, a chemical might move from organisms (*bio*) to the atmosphere or ocean (*geo*) and back to organisms again. Elements or water may be held for various periods of time in different parts of a cycle.

1. Part of a cycle that holds an element or water for a short period of time is called an **exchange pool**. For example, the atmosphere is an exchange pool for water. It usually holds water (in the form of water vapor) for just a few days.
2. Part of a cycle that holds an element or water for a long period of time is called a **reservoir**. The ocean is a reservoir for water. The deep ocean may hold water for thousands of years.

Water on Earth is billions of years old. However, individual water molecules keep moving through the water cycle. The **water cycle** is a global cycle. It takes place on, above, and below Earth's surface, as shown in figure below.



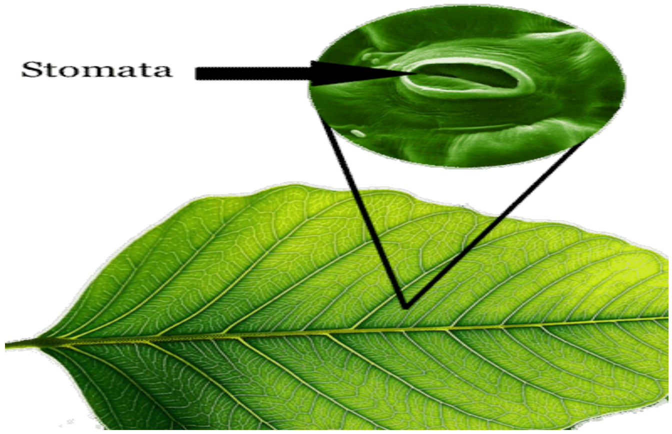
Like other biogeochemical cycles, there is no beginning or end to the water cycle. It just keeps repeating.

During the water cycle, water occurs in three different states: gas (water vapor), liquid (water), and solid (ice). Many processes are involved as water changes state in the water cycle.

Evaporation, Sublimation, and Transpiration

Water changes to a gas by three different processes:

3. **Evaporation** occurs when water on the surface changes to water vapor. The sun heats the water and gives water molecules enough energy to escape into the atmosphere.
4. **Sublimation** occurs when ice and snow change directly to water vapor. This also happens because of heat from the sun.
5. **Transpiration** occurs when plants release water vapor through leaf pores called stomata (see **Figure** below).



Plant leaves have many tiny stomata. They release water vapor into the air.

Condensation and Precipitation

Rising air currents carry water vapor into the atmosphere. As the water vapor rises in the atmosphere, it cools and condenses. **Condensation** is the process in which water vapor changes to tiny droplets of liquid water. The water droplets may form clouds. If the droplets get big enough, they fall as **precipitation**—rain, snow, sleet, hail, or freezing rain. Most precipitation falls into the ocean. Eventually, this water evaporates again and repeats the water cycle. Some frozen precipitation becomes part of ice caps and glaciers. These masses of ice can store frozen water for hundreds of years or longer.

Groundwater and Runoff

Precipitation that falls on land may flow over the surface of the ground. This water is called **runoff**. It may eventually flow into a body of water. Some precipitation that falls on land may soak into the ground, becoming **groundwater**. Groundwater may seep out of the ground at a spring or into a body of water such as the ocean. Some groundwater may be taken up by plant roots. Some may flow deeper underground to an **aquifer**. This is an underground layer of rock that stores water, sometimes for thousands of years.

Changes

Balancing Chemical Equations

The little boy on this seesaw weighs more than the little girl on the other side. That's why his side of the seesaw is on the ground and her side is up in the air. For a seesaw to balance, the two riders must be the same weight. A chemical equation that represents a chemical reaction is a little bit like a seesaw. For a chemical equation to balance, there must be the same number for each type of atom on both sides of the equation.

Writing Chemical Equations

A chemical equation represents the changes that occur during a chemical reaction. A chemical equation has the general form:

Reactants → Products

An example of a simple chemical reaction is the reaction in which hydrogen (H_2) and oxygen (O_2) combine to produce water (H_2O). In this reaction, the reactants are hydrogen and oxygen, and the product is water. To write the chemical equation for this reaction, you would start by writing the reactants on the left and the product on the right, with an arrow between them to show the direction in which the reaction occurs:

Equation 1:

$H_2 + O_2 \rightarrow H_2O$

Q: Look closely at equation 1. There is something wrong with it. What is it?

A: All chemical equations must be balanced. This means that there must be the same number for each type of atom on both sides of the arrow. That is because mass is always conserved in chemical reactions. Count the number of hydrogen and oxygen atoms on each side of the arrow. There are two hydrogen atoms in both reactants and products. There are two oxygen atoms in the reactants but only one in the product. Therefore, equation 1 is not balanced.

Balancing Chemical Equations

Coefficients are used to balance chemical equations. A coefficient is a number placed in front of a chemical symbol or formula. It shows how many atoms or molecules of the substance are involved in the reaction. For example, two molecules of hydrogen would be written as 2 H_2, and two molecules of water would be written 2 H_2O. A coefficient of 1 usually is not written. Coefficients can be used to balance equation 1 (above) as follows:

Equation 2:

$2\ H_2 + O_2 \rightarrow 2\ H_2O$

Equation 2 shows that two molecules of hydrogen react with one molecule of oxygen to produce two molecules of water. The two molecules of hydrogen each contain two hydrogen atoms and so do the two molecules of water. Therefore, there are now four hydrogen atoms in both reactants and products.

Q: Is equation 2 balanced?

A: Count the oxygen atoms to find out. There are two oxygen atoms in one molecule of oxygen in the reactants. There are also two oxygen atoms in the products, one in each of the two water molecules. Therefore, equation 2 is balanced.

Steps in Balancing a Chemical Equation

Balancing a chemical equation involves a certain amount of trial and error. In general, however, you should follow these steps:

1. Count each type of atom in reactants and products. Does the same number of each atom appear on both sides of the arrow? If not, the equation is not balanced, and you need to go to step 2.

2. Place coefficients, as needed, in front of the symbols or formulas to increase the number of atoms or molecules of the substances. Use the smallest coefficients possible. Warning! Never change the subscripts in chemical formulas. Changing subscripts changes the substances involved in the reaction. Change only the coefficients.

3. Repeat steps 1 and 2 until the equation is balanced.

Also, you could watch this video from Khan Academy: Balancing chemical equations

Balance this chemical equation for the reaction in which nitrogen (N_2) and hydrogen (H_2) combine to form ammonia (NH_3):

$N_2 + H_2 \rightarrow NH_3$

1. First count the nitrogen atoms on both sides of the arrow. There are two nitrogen atoms in the reactants so there must be two in the products as well. Place the coefficient 2 in front of NH_3 to balance nitrogen:

   $N_2 + H_2 \rightarrow 2\ NH_3$

2. Now count the hydrogen atoms on both sides of the arrow. There are six hydrogen atoms in the products so there must also be six in the reactants. Place the coefficient 3 in front of H_2 to balance hydrogen:

   $N_2 + 3\ H_2 \rightarrow 2\ NH_3$

Practice Activity

1. What holds an element or water for a brief period?
   A. Exchange pool
   B. Reservoir
   C. Aquifer

2. What is an example of a water reservoir?
   A. An ocean
   B. A glacier
   C. The atmosphere
   D. A and B

3. Glaciers can store water for long periods. What role do glaciers play in the water cycle?
   A. Exchange pool
   B. Reservoir
   C. Transpiration
   D. Biotic factor

4. When the water frozen in an Austrian glacier change directly to water vapor, this process is called?
   A. Transpiration
   B. Evaporation
   C. Sublimation
   D. Fixation

5. The process by which water vapor changes to tiny droplets of liquid water is called?
   A. Evaporation
   B. Sublimation
   C. Condensation
   D. Precipitation

6. Which of the following reservoirs holds the least water?
    A. The atmosphere
    B. All freshwater systems and groundwater combined
    C. Glaciers and polar ice caps
    D. The ocean

7. Sublimation occurs when ice and snow change directly to water vapor.
    A. True
    B. False

8. Through transpiration, water is released back into the atmosphere through the plant's stomata.
    A. True
    B. False

9. Evaporation occurs when water on the surface changes to water vapor (gas).
    A. False
    B. True

10. The atmosphere is an example of an exchange pool for water.
    A. True
    B. False

11. Which coefficient placed before HCI will balance the following equation?
    $Zn + HCl \text{-->} ZnCl_2 + H_2$
    A. 2
    B. 3
    C. 4
    D. *None* of the above

12. Which of the following is the general form of a chemical equation?
    A. Products + Reactants = 100%
    B. Reactants --> Products
    C. Reactants = Products
    D. Products --> Reactants

13. A chemical equation is balanced when the number of each type of atom is the same on both sides of the equation.
    A. True
    B. False

14. A chemical equation is a written method of representing the changes that occur in a chemical reaction.

A. True
B. False

15. Which of the following rules should you follow to balance chemical equations?
    A. Change only the subscripts
    B. Use the smallest possible subscripts
    C. Add coefficients as needed
    D. Two of the above

16. Numbers called subscripts are used to balance chemical equations.
    A. True
    B. False

17. Which of the following equations is balanced?
    A. $CH_4 + O_2 \text{-->} CO_2 + H_2O$
    B. $CH_4 + O_2 \text{-->} CO_2 + 2H_2O$
    C. $CH_4 + 2O_2 \text{-->} CO_2 + 2H_2$
    D. $CH_4 + 2O_2 \text{-->} CO + 2H_2O$

18. Sam was given the following equation to balance: $H_2O \text{-->} H_2 + O_2$. She balanced it as follows: $2HO \text{-->} H_2 + O_2$. Is this correct?
    A. Yes
    B. No

19. $C + O_2 \text{-->} CO_2$ In this chemical reaction, the coefficient of oxygen is 2.
    A. True
    B. False

20. $3Fe + 2O_2 \text{-->} Fe_3O_4$ In this chemical reaction, the coefficient and subscript of O_2 are both 2.
    A. True
    B. False

Answers:

1. A
2. D
3. B
4. C
5. C
6. A
7. A
8. A
9. B

10. A
11. A
12. B
13. A
14. A
15. C
16. B
17. C
18. B
19. B
20. A

Attributions:

Chapter 5: Physics

Physics tells us that organized systems, such as living organisms, tend to disorder without a constant input of energy. Think, as an example, that after a week of living in your house it becomes a mess, and you must spend energy to return it to its previous, ordered state.

Physics also tells us that, although energy can be captured or transformed, it inevitably degrades, becoming heat, a less useful form of energy. Therefore, organisms require a constant input of energy; the work they must do uses up the energy they take in. Energy, unlike materials, cannot be recycled. The story of life is a story of energy flow – its capture, transformation, use for work, and loss as heat.

Some concepts:

- ✓ **Distance**: The length traveled by an object moving in any direction or even changing direction.
- ✓ **Position**: The location of an object in a frame of reference. For straight-line motion, positions can be shown using a number line.
- ✓ **Displacement**: The separation between original and final position.

In ordinary language, the words speed and velocity both refer to how fast an object is moving and are often used interchangeably. In physics, however, they are fundamentally different.

- **Speed** is the magnitude of an object's motion, with no regard for the direction.
- **Velocity**, on the other hand, includes direction. It is a vector, and thus must have a magnitude and a direction.

✓ Average speed is distance divided by time.
✓ Average velocity is displacement divided by time.
✓ An object whose velocity is changing is said to be accelerating. **Average acceleration** is defined as the rate of change of velocity, or the change in velocity per unit time. The units of acceleration are distance divided by time squared.

Newton's first law

If a bowling ball and a ping-pong ball are each moving with a velocity of 5 mph, you intuitively understand that it will require more effort to stop the bowling ball than the ping pong ball because of the greater mass of the bowling ball. Similarly, if you have two bowling balls, one moving at 5 mph and the other moving at 10 mph, you know it will take more effort to stop the ball with the greater speed. Both the mass and the velocity of a moving object contribute to what is necessary to change the motion of the moving object.

Momentum is the product of the mass and velocity of an object**.** Momentum is a vector quantity that has the same direction as the velocity of the object and is represented by a lowercase letter *p*.

$$\text{Momentum} = p = m*v$$

The momentum of a 0.500 kg ball moving with a velocity of 15.0 m/s will be

$p=m*v= (0.500\text{ kg})(15.0\text{ m/s}) = 7.50\text{ kg}*\text{m/s}$

P is momentum; v is velocity; m is mass; kg is kilograms; m/s is meters over seconds.

According to **Newton's first law**, the velocity of an object cannot change unless force is applied. If we wish to change the momentum of a body, we must apply force. The longer the force is applied, the greater the change in momentum. A common misconception is that when two objects collide, the smaller object is hit harder or experiences more force than the larger object.

A **force** is a push or a pull on an object. When you place a book on a table, the book pushes downward on the table and the table pushes upward on the book. The two forces are equal and there is no resulting motion of the book. If, on the other hand, you hold the book in the air and let go, the force of gravity will pull the book to the ground.

If you slide a book across the floor or a table, the book will experience a frictional force, which acts in the opposite direction of the motion. This force will slow down the motion of the book and eventually bring it to rest. A smoother surface has a smaller force of friction, which will allow the book to slide further before coming to rest. If a perfectly smooth floor could be created, there would be no friction and the book would slide forever at constant speed.

Inertia is the tendency of an object to resist change in its state of motion. In the absence of any force, an object will continue to move at the same constant speed and in the same straight line. If the object is at rest, in the absence of any force, it will remain at rest. Newton's First Law states that an object with no force acting on it moves with constant velocity.

Impulse is the quantity defined as the force multiplied by the time it is applied. It is a vector quantity that has the same direction as the force.

$$\text{Impulse} = F*t = m*\Delta v$$

F is force; t is time; Δ is change; Δv is change in velocity

The units for impulse are N*s = kg* m/s

Newtons (N) are $kg*m/s^2$ and so $N*s = (kg*m/s^2)(s) = kg*m/s$.

Impulse and momentum have the same units; when an impulse is applied to an object, the momentum of the object changes and the **change of momentum is equal to the impulse**.
$Ft=\Delta mv$

Newton's Second Law

The **mass** of an object is defined as the amount of matter in the object. The amount of mass an object has does not change.

The **weight** of an object is the force pulling the object downward. On Earth, this would be the gravitational force of the Earth on the object. On the moon, this would be the gravitational force of the moon on the object. The gravitational force of the moon is one-sixth the magnitude of the gravitational force of the Earth; the weight of the moon rock on the moon will be one-sixth the weight of the moon rock on the Earth's surface.

Newton's Second Law of Motion: "the acceleration (a) of an object is directly proportional to the net force on the object and inversely proportional to the mass of the object."

a=F/m or more commonly, F=ma

According to Newton's Second Law, a new force on an object causes it to accelerate. However, the larger the mass, the smaller the acceleration. A more massive object has greater inertia.

The gravitational force is derived from **Newton's Second Law**, $F = m*a$, where F is the force of gravity in Newtons, m is the mass of the object in kilograms, and a is the acceleration due to gravity on Earth, 9.81 m/s^2 .

When the formula is used specifically to solve for the weight of an object, it appears as *W*=*m***g*. Weight is always measured in force units Newtons, *m* is the mass of the object in kilograms, and *g* is the gravitational strength on the planet in N/kg or m/s^2 ($g_{Earth} = 9.81\ m/s^2$).

Newton's Third Law of Motion

It states that whenever one object exerts a force on a second object, the second object also exerts a force on the first object, equal in magnitude and opposite in direction. **"For every action, there is an equal and opposite reaction."** A key point to remember is that the two forces are on different objects—never on the same object. It is frequently the case that one of the objects moves because of the force applied but the motion of the other object in the opposite direction is not apparent.

Universal Law of Gravitational Attraction: Force of Gravity

In the mid-1600's, Newton wrote that the sight of a falling apple made him think of the problem of the motion of the planets. He recognized that the apple fell straight down because the earth attracted it and thought this same force of attraction might apply to the moon. It further occurred to him that the motion of the planets might be controlled by the gravity of the sun. He eventually proposed the **universal law of gravitational attraction** as

$$F = G.m_1m_2/d^2$$

m_1 and m_2 are the masses being attracted,

d is the distance between the centers of the masses,

G is the universal gravitational constant, and

F is the force of attraction.

The value for the universal gravitational constant, G, was determined by Henry Cavendish to be $6.67 \times 10^{-11}\ N \cdot m^2/kg^2$.

Energy

Figure 6.5.1

At what point does this diver have the most energy? This diver is going to jump from the end of the diving board. After he dives down and falls toward the water, he will have kinetic energy, or the energy of moving matter. But even as he is momentarily stopped high above the water, he has energy. Do you know why?

Stored Energy

The diver has energy because of his position high above the pool. The type of energy he has is called potential energy. **Potential energy** is energy that is stored in a person or object. Often, the person or object has potential energy because of its position or shape.

Q: What is it about the diver's position that gives him potential energy?

A: Because the diver is high above the water, he has the potential to fall toward Earth because of gravity. This gives him potential energy.

Gravitational Potential Energy

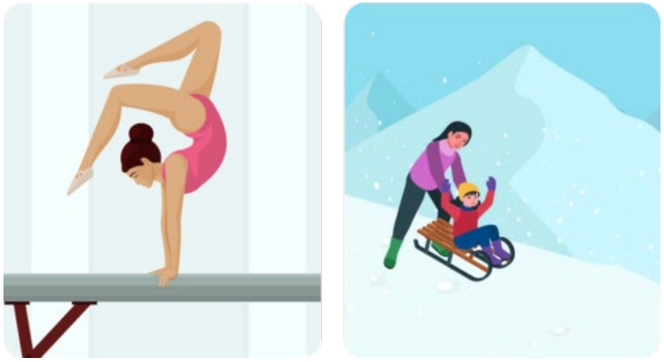


Figure 6.5.2

Potential energy due to the position of an object above Earth's surface is called *gravitational potential energy.* Like the diver on the diving board, anything that is raised up above Earth's surface has the potential to fall because of gravity. You can see another example of people with gravitational potential energy in the **Figure** above.

Elastic Potential Energy

Potential energy due to an object's shape is called *elastic potential energy*. This energy results when an elastic object is stretched or compressed. The farther the object is stretched or compressed, the greater its potential energy is. A point will be reached when the object cannot be stretched or compressed any more. Then it will forcefully return to its original shape.

Figure 6.5.3

Shooting an arrow from a bow, as shown in the image above, requires work done on the bow by the shooter's arm to bend the bow and thus produce potential energy. The release of the bow converts the **potential energy** of the bent bow into the **kinetic energy** of the flying arrow.

Other Forms of Potential Energy

If you hold two positive charges near each other, their ***electromagnetic potential energy*** pushes them apart when you let go. Potential energy is stored in **chemical bonds** (***chemical potential energy***). When these bonds are broken, the excess **energy** is seen as molecular motion and **heat**.

Calculating Potential Energy

If a cannon ball is fired straight up into the air, it begins with a high kinetic energy. As the cannon ball rises, it slows down due to the force of gravity pulling it toward the earth. As the ball rises, its gravitational potential energy increases, and its kinetic energy decreases. When the cannon ball reaches the top of its arc, its kinetic energy is zero and its potential energy is at the maximum. As gravity continues to pull the cannon ball toward the earth, the ball will fall downwards, causing its height to decrease and its speed to increase. The ball's potential energy decreases and its kinetic energy increases. When the ball returns to its original height, its kinetic energy will be the same as when it started upward.

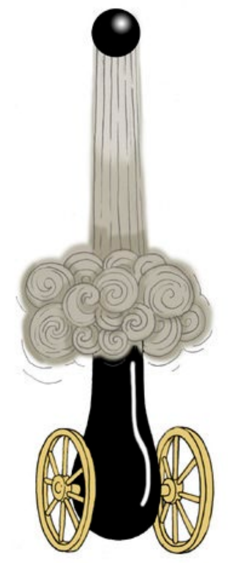


Figure 6.5.4

When work is done on an object, the work may be converted into either kinetic or potential energy. Work resulting in motion is caused when the work is converted into kinetic energy, while work resulting in a change of position is caused by a conversion into potential energy. Work is also spent overcoming friction and that work would be converted into heat, but we will consider primarily frictionless systems.

If we consider the potential energy of a bent stick or a stretched rubber band, the potential energy can be calculated by multiplying the force exerted by the stick or rubber band by the distance over which the force will be exerted. The formula for calculating this potential energy looks exactly like the formula for calculating work done: **W = F*d**. The only difference is:

- Work is calculated when the object moves and
- Potential energy is calculated when the system is still at rest, before any motion occurs.

Work

Work is the force exerted on an object multiplied by the distance the object moves due to that force.

$$W=F*d$$

In the scientific definition of the word, if you push against an automobile with a force of 200 N for 3 minutes but the automobile does not move, then you have done no work. Multiplying 200 N times 0 meters yields zero work. If you are holding an object in your arms, the upward force you are exerting is equal to the object's weight. If you hold the object until your arms become very tired, you have still done no work because you did not move the object in the direction of the force. <u>When you lift an object, you exert a force equal to the object's weight and the object moves due to that lifting force</u>. If an object weighs 200. N and you lift it 1.50 meters, then your work is W= F*d = (200. N) (1.50 m) = 300. N m.

One of the units you will see for work is shown above: the Newton meter (Nm). More often, however, units of work are given as the Joule (pronounced "jool") in honor of James Prescott Joule, a nineteenth century English physicist. **A Joule is a kg·m^2/s^2.**

Gravitational potential energy: the force exerted by the object is its weight, and the distance it can travel is its height above the earth.

Weight of an object is **W= m*g**, then

Gravitational potential energy is **PE= m*g*h**,

m is the mass of the object, g is the acceleration due to gravity, and *h* is the height the object will fall.

Kinetic Energy

Energy is the capacity of an object to do work, and like work, energy's unit is the joule (J). Energy exists in many different forms, but the one we think of most often when we think of energy is **kinetic energy**. Kinetic energy is often thought of as the energy of motion because it is used to describe objects that are moving. Remember, though, that energy is the ability of an object to do work. Any moving object has the capacity to cause another object to move if they collide. This ability is what we mean when we refer to an object's kinetic energy: the ability to change another object's motion or position simply by colliding with it. The equation of an object's kinetic energy depends on its mass and velocity:

$$KE = ½ * mv^2$$

The kinetic energy of a moving object is directly proportional to its mass and directly proportional to the square of its velocity. This means that an object with twice the mass and equal speed will have twice the kinetic energy while an object with equal mass and twice the speed will have quadruple the kinetic energy.

The kinetic energy of an object can be changed by doing work on the object. The work done on an object equals the kinetic energy gain or loss by the object.

This relationship is expressed in the work-energy theorem **W_{NET}=ΔKE**.

The net work done on a particle is equal to the change in the particle's kinetic energy:

$$W_{Net}=KE_B-KE_A$$

Conservation of Energy

The law of conservation of energy states that within a closed system, energy can change form, but the total amount of energy is constant. Another way of expressing the law of conservation of energy is to say that energy can neither be created nor destroyed. An important part of using the conservation of energy is selecting the system. Just as in conservation of momentum, energy is conserved only if the system is closed. In a closed system, objects may not enter or leave, and it is isolated from external forces so that no work can be done on the system.

In the analysis of the behavior of an object, you must make sure you have included everything in the system that is involved in the motion. For example, if you are considering a ball that is acted on by gravity, you must include the Earth in your system. If considered by itself, one can tell that the kinetic energy of the ball is increasing as it falls, but only by including the Earth in the system you can see that the increasing kinetic energy is balanced by an equivalent loss of potential energy.

Mechanical energy is the sum of the kinetic energy and the potential energy of an object.

Consider a box with a weight of 20.0 N sitting at rest on a shelf that is 2.00 m above the earth. The box has zero kinetic energy, but it has potential energy related to its weight and the distance to the earth's surface.

Potential Energy: PE=mgh=(20.0 N) (2.00 m) = 40.0 N = 40.0 J

If the box slides off the shelf, the only force acting on the box is the force of gravity and so the box falls. We can calculate the speed of the box when it strikes the ground by several methods:

I. We can calculate the speed directly using the formula $v^2=2ad$.

II. We can also find the final velocity by setting the kinetic energy at the bottom of the fall equal to the potential energy at the top

KE=PE, thus $½*mv^2=mgh$. When reduced, we see that $v^2=2gh$.

Note that these formulas are essentially the same; when gravity is the acceleration and the height is the distance, they are the same equation.

$v^2= (2)\ (9.81\ m/s^2)\ (2.00\ m)$

v =6.26 m/s

Machines

A machine is an object or mechanical device that receives an input amount of work and transfers the energy to an output amount of work. For an **ideal machine,** the input work and output work are always the same. Remember that work is force times distance (W=Fd); even though the *work* input and output are equal, the input *force* does not necessarily equal the output *force*, nor does the input *distance* necessarily equal the output *distance*.

Machines can be incredibly complex (think of robots or automobiles), or very simple, such as a can opener. A **simple machine** is a mechanical device that changes the magnitude or direction of the force. There are six simple machines that were first identified by Renaissance scientists:

- lever,
- pulley,
- inclined plane,
- screw,
- wedge, and
- wheel and axle.

These six simple machines can be combined to form **compound machines**.

We use simple machines because they give us a **mechanical advantage**. Mechanical advantage is a measurement of the force amplification of a machine. In ideal machines, where there is no friction, and the input work and output work are the same:

(Effort Force) * (Effort Distance) = (Resistance Force) * (Resistance Distance)

The **effort** is the work that you do. It is the amount of force you use times the distance over which you use it. The **resistance** is the work done on the object you are trying to move. Often, the resistance force is the force of gravity, and the resistance distance is how far you move the object.

The **ideal mechanical advantage** of a simple machine is the ratio between the distances:

IMA = effort distance/resistance distance

Again, the IMA assumes that there is no friction. The mechanical advantage is limited by friction; you must overcome the frictional forces in addition to the resistance force. Therefore, the **actual mechanical advantage** is the ratio of the forces:

AMA = resistance force/effort force

When simple machines are combined to form compound machines, the product of each simple machine's IMA gives the compound machine's IMA.

Power

Power is the rate at which work is done, or the rate at which energy is transformed.

- Power=Work/Time Power
- Power=Force * velocity

Power is measured in Joules per second, which is given a special name: the watt, W.

1.00 watt = 1.00 J/s

Another unit for power that is horsepower: 1.00 horsepower = 746 watts

Practice Activity

1. One of your things on your bucket list is skydiving. What law or theory explains what happens when you jump off a plane?
    A. Theory of relativity
    B. Law of Gravity
    C. Law of inertia
    D. Law of acceleration

Answer questions 2 and 3 with the following information:

A 0.15 kg baseball is thrown horizontally at 40. m/s and after it is struck by a bat, it is traveling at -40. m/s (The minus sign indicates that the impulse was in the opposite direction of the original throw).

2. What impulse did the bat deliver to the ball?
    A. (0.15 kg) (−40. m/s −40. m/s)
    B. (0.15 kg) (−40. m/s)
    C. (0.15 kg) (−40. m/s +40. m/s)
    D. (0.15 kg) (40. m/s −40. m/s)

3. If the contact time of the bat was 0.00080 seconds, what was the average force the bat exerted on the ball?
    A. (0.15 kg) (−40. m/s−40. m/s) / 0.00080 s
    B. (0.15 kg) (−40. m/s−40. m/s) * 0.00080 s
    C. (0.15 kg) (−40. m/s +40. m/s) / 0.00080 s
    D. (0.15 kg) (40. m/s −40. m/s) * 0.00080 s

4. A small car with a mass of 800 kg is moving at a velocity of 27.8 m/s. What is the momentum of the car?
    A. 800 kg / 27.8 m/s
    B. 800 Kg* 27.8 m/s * kg
    C. 27.8 * 800
    D. 800 Kg* 27.8 m/s

5. If a ball with mass 5.00 kg has a momentum of 5.25 kg*m/s, what is its velocity?
    A. 5.25 kg*m/s / 5.00 kg
    B. 5.25 kg*m/s * 5.00 kg
    C. 5.00 kg / 5.25 kg*m/s
    D. 5.00 kg * 5.25 kg*m/s

6. An object whose velocity is changing is said to be accelerating. Average acceleration is defined as the rate of change of velocity, or the change in velocity per unit time. The units of acceleration are distance over time squared. If a car accelerates along a straight road from rest to +60.0 km/h in 5.00 s. What is the magnitude of its average acceleration?
    A. (60 km/h) / 25 s
    B. (17 m/s) / (5 s)
    C. (60.0 km/h) / 5 s^2
    D. (17 m/s) / 5 s^2

7. Calculate the weight of an object on the Earth's surface if its mass is 44 kg.
    A. (9.81 m/s) * (44 kg^2)
    B. (44 kg) / (9.81 m/s^2)
    C. (44 kg) (9.81 m/s^2)
    D. (44 kg) (9.81 m/s)

8. Evaluate the mass of an object if its weight on the Earth is 2570 N.
    A. (2570 N) *(9.81 m/s2)
    B. (2570 N)/ (9.81 m/s2)
    C. (2570 N) *(9.81 m/s)
    D. (2570 N)/ (9.81 m)

The acceleration of an object is the result of an unbalanced force. If an object undergoes two forces, the motion of the object is determined by the net force. The magnitude of the acceleration is directly proportional to the magnitude of the unbalanced force. The direction of the acceleration is the same direction as the direction of the unbalanced force. The magnitude of the acceleration is inversely proportional to the mass of the object; the more massive the object, the smaller the acceleration produced by the same force.

9. A net force of 150 N is exerted on a rock. The rock has an acceleration of 20 m/s^2 due to this force. What is the mass of the rock?
    A. (150 N)/ (20 m/s^2)
    B. (150 N) *(20 m/s^2)
    C. (150 N) (20 m/s^2)
    D. (150 N)/ (20 m)

10. What force is required to accelerate a 2000 kg car at 2.000 m/s^2?
    A. (2000 kg) (2.000 m/s^2)
    B. (2000 kg)/ (2 m/s2)
    C. (200 kg) (2000 m/s2)
    D. (200 kg)/ (2000 m/s2)

11. A net force of 100 N is exerted on a ball. If the ball has a mass of 0.72 kg, what acceleration will it undergo?
    A. (100 N) *(0.72 kg)

B. (100 N) / (0.72 kg)
C. (10 N) *(0.72 kg)
D. (100 N)/ (72 kg)

12. Evaluate the kinetic energy of a 10,000 kg truck moving at 60 km/h
    A. (1/2) *(10,000 kg) *(16.67 m/s)^2
    B. (1/2) *(10,000 kg) *(16.67 m/s)
    C. (1/2) *(10,000 kg) * (60 km/h)^2
    D. (1/2) *(10,000 kg) *(60 m/s)^2

13. Evaluate the work done by a farmer who lifted a crate with produce that weighs 200 N. He lifted it at height of 1 m.
    A. (200 N)/ (1 m)
    B. (200 N) *(1 m)
    C. (200 N/m)
    D. 200 N * 200 m

Answers:

1. B
2. A
3. A
4. D
5. A
6. B
7. C
8. B
9. A
10. A
11. B
12. A
13. B

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Practice Exams

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