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Anatomy and Physiology Preparatory Course Textbook (2nd Edition)

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Anatomy & Physiology

Preparatory Course Textbook

2nd Edition | 2021

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About Anatomy and Physiology Preparatory Textbook

The goal of this preparatory textbook is to give students a chance to become familiar with some terms and some basic concepts they will find later on in the Anatomy and Physiology course, especially during the first few weeks of the course.

Organization and functioning of the human organism are generally presented starting from the simplest building blocks, and then moving into levels of increasing complexity. This textbook follows the same presentation. It begins introducing the concept of homeostasis, then covers the chemical level, and later on a basic introduction to cellular level, organ level, and organ system level. This second edition incorporates a module on protein synthesis, and a complementary base pairing learning objective as requested by many students. This edition incorporates links to audios for all learning objectives, and many learning objectives have online videos associated to them. Icons for audio by Kieselli and for video by Satheesh Sankaran, both from Pixabay. The illustration on the cover is by Elisa Riva retrieved from Pixabay.

The textbook is organized in five **UNITS**, divided into sixteen **MODULES** covering a total of fifty-three **Learning Objectives**. Each learning objective has a short self-assessment at the end.

Learning Objectives Content

1. The list of **Learning Objectives (LO)** is a derivative work of the Learning Outcomes Guidelines by The Human Anatomy and Physiology Society (HAPS).
2. Important **terms** associated with each LO are shown in **Arial Bold**.
3. **Etymology** of some new terms is shown between brackets next to the term. The sources are The Free Dictionary by Farlex, and The Online Etymology Dictionary.
4. **Illustrations** are under Creative Commons licenses, or in the Public Domain. Their sources are cited next to them.
5. **Tables** compare terms, facts or concepts easier to visualize in a table format.
6. There are links to **simulations**, **interactive activities** and **videos** added to many learning objectives for this second edition. They serve to summarize, and also to show some descriptions from the text in a different way.

Assessment Content

1. **Review Questions** address terms, concepts and facts discussed within each learning objective. Most questions are knowledge questions (Bloom's taxonomy first level).
2. **Tests** are written in the format that students usually find in college exams (mostly multiple-choice questions, with some true/false, and some fill in the blank). Test questions are a mix of knowledge, comprehension and application questions (Bloom's taxonomy first three levels).

Acknowledgments

Dr. Maureen Gannon contributed with the editing of the first edition and with the development of the question bank. First online version the Preparatory Course was possible thanks to **Bronx Community College Library Open Education Resources Project.**

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MODULE 1: *Levels of Organization of The Human Organism*

Learning Objective 1: Describe, in order from simplest to most complex, the major levels of organization in the human organism.

Listen to Learning Objective 1

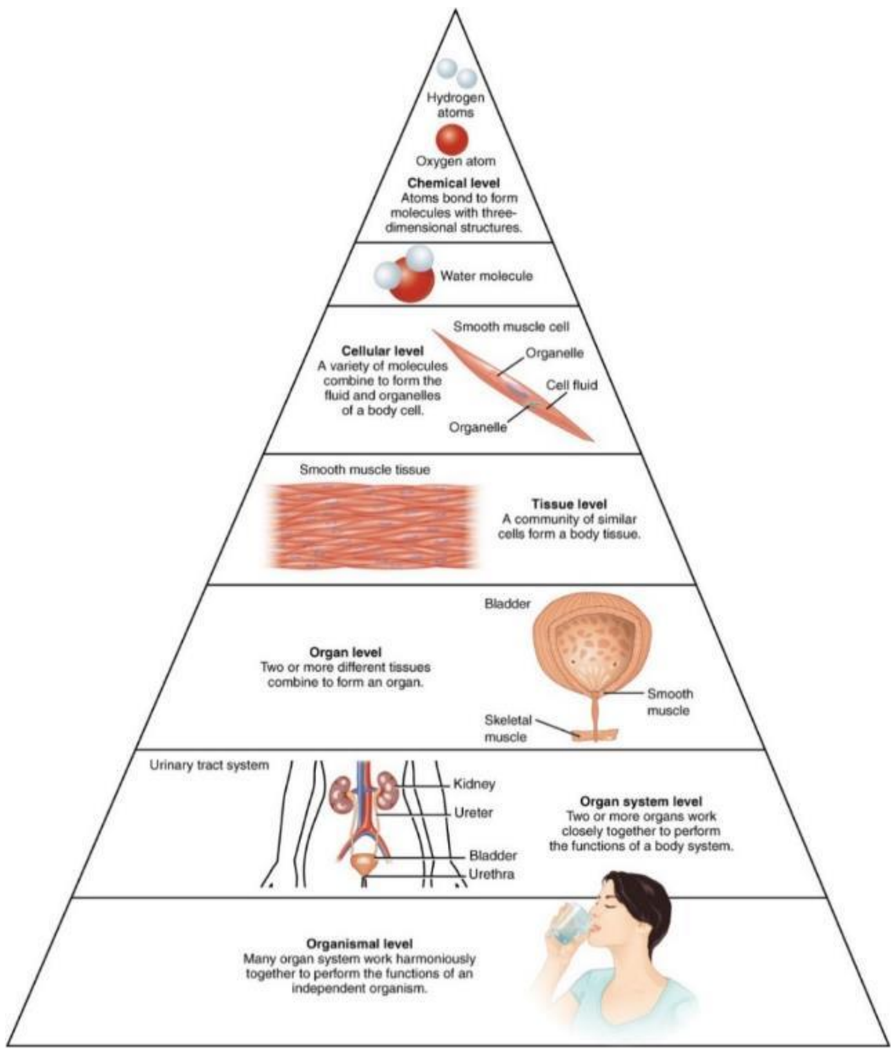
All living and non-living things are made of one or more unique substances called **elements**, the smallest unit of which is the **atom,** (for example, the element oxygen (O) is made of O atoms, carbon (C) is made of C atoms and hydrogen (H) is made of H atoms. Atoms combine to form **molecules**. Molecules can be small (for example, O_2, oxygen gas, which has 2 atoms of the element O; CO_2, carbon dioxide, which has 1 atom of C and 2 of O), medium (for example, $C_6H_{12}O_6$, glucose, which has 6 atoms of C, 12 of H, and 6 of O); or large (for example molecules called proteins are made of hundreds of atoms of C, H, and O with other elements such as nitrogen (N). Molecules are the building blocks to all structures in the human body.

All living structures are made of **cells**, which are made of many different molecules. Cells are the smallest independent living thing in the human body. The body is made of many different cell types, each with a particular function, (for example muscle cells contract to move something, and red blood cells carry oxygen). All human cells are made of a cell membrane (thin outer layer) that encloses a jelly-like cellular fluid containing tiny organ-like structures called **organelles**. There are many types of organelles, each with a particular function (for example, organelles called mitochondrion provides energy to a cell). Different types of cells contain different amounts and types of organelles, depending on their function, (for example muscle cells use a lot of energy and therefore have many mitochondria while skin cells do not and have few mitochondria).

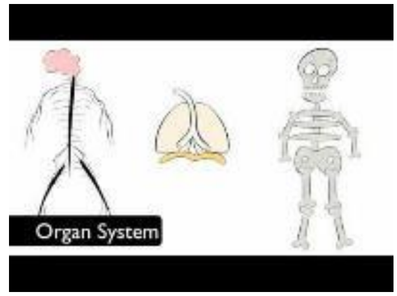
As in other multicellular organisms, cells in the human body are organized into tissues. A **tissue** is a group of similar cells that work together to perform a specific function. There are four main tissue types in humans (muscular, epithelial, nervous and connective). An **organ** is an identifiable structure of the body composed of two or more tissues types (for example, the stomach contains *muscular tissue* made of muscle cells, which allows it to change its shape, *epithelial tissue* which lines both the inner and outer surface of the stomach, *nervous tissue* which sends and receives signals to and from the stomach and the central nervous system, and *connective tissue* which binds everything together). Organs often perform a specific physiological function (for example, the stomach helps digest food). An **organ system** is a group of organs that work together to perform a specific function (for example, the stomach, small and large intestines are all organs of the digestive system, that work together to digest foodstuff, move nutrients into the blood and get rid of waste). The most complex level of organization, the human **organism** is composed of many organ systems that work together to perform the functions of an independent individual.

Summarizing:
The major levels of organization in the body, from the simplest to the most complex are: atoms, molecules, organelles, cells, tissues, organs, organ systems and the human organism. See below Figure 1.1.

Figure 1.1
Hierarchical levels of organization of the human body from the smallest chemical level to the largest organismal level. Read the description, and examples for each level in the pyramid: Chemical level, Cellular level, Tissue level, Organ level, Organ system level, and Organismal level.
Art by OpenStax College CC-BY



Watch this video to review levels of organization**:** https://youtu.be/ZRFykdf4kDc



Review Questions for Learning Objective 1

Write your answer in a sentence form. (Do not answer using loose words)

1. What is an element?
2. What is an atom?
3. What is a molecule?
4. What is a cell?
5. What is an organelle?
6. What is a tissue?
7. What is an organ?
8. What is an organ system?
9. What is an organism?
10. What are the levels of organization in the human organism (list them from the smallest to the largest)?

Test for Learning Objective 1

1. This is the correct order of the major levels of organization:
    a. Atom, molecule, cell, tissue, organ, organelle, organ system, organism
    b. Atom, molecule, organelle, cell, tissue, organ, organ system, organism
    c. Atom, molecule, cell, tissue, organelle, organ, organ system, organism
    d. Atom, molecule, cell, tissue, organism, organ, organelle, organ system

2. This is the correct order of examples of the major levels of organization (from most complex to least complex):
    a. Human body, digestive system, muscular tissue, stomach, muscle cell, mitochondrion, protein molecule, carbon atom
    b. Human body, digestive system, stomach, muscle cell, muscular tissue, mitochondrion, protein molecule, carbon atom
    c. Human body, digestive system, stomach, muscular tissue, muscle cell, mitochondrion, protein molecule, carbon atom
    d. Human body, digestive system, stomach, muscular tissue, muscle cell, mitochondrion, carbon atom, protein molecule

3. A group of similar cells that work together to perform a specific function is called a(an) ___.
    a. Organ
    b. Tissue
    c. Organelle
    d. Organ system

4. An ___ is an identifiable structure of the body composed of two or more tissues.
    a. Organism
    b. Organelle
    c. Organ system
    d. Organ

5. ___ are the smallest independent living things in the human body.
    a. Molecules
    b. Organelles
    c. Cells
    d. Organs

MODULE 2: *What Is Human Anatomy, What Is Human Physiology*

Learning Objective 2: Define the terms anatomy and physiology, and give specific examples to show the interrelationship between anatomy and physiology.

Listen to Learning Objective 2

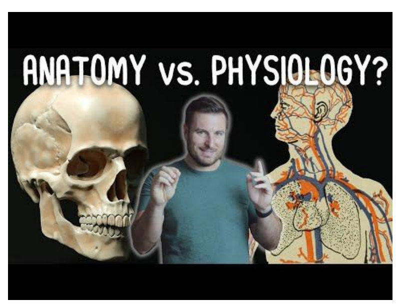
Human **Anatomy** (ana- = “up”, tome = “to cut”) is often defined as the study of structures in the human body. Anatomy focuses on the description of *form*, or how body structures at different levels *look*. **Gross anatomy** studies macroscopic structures (for example, the body, organs, and organ systems), and **histology** studies microscopic structures (for example, tissues, cells, and organelles).

Human **Physiology** (physio = “nature”; -logy = “study”) studies the “nature” of the human body, nature in the sense of how structures at different levels work. Physiology focuses on *function*, or how structures at different levels *work*.

Anatomy and physiology are intimately related. A hand is able to grab things (function) because the length, shape, and mobility of the fingers (form) determine what things a hand can grab (function). A muscle contracts and brings bones together (function) due to the arrangement of muscles and bones, and the arrangement of organelles inside of muscle cells (form) determines how much and for how long a muscle can contract (function).

Body structure functions depend on their form. The way structures work depends on the way they are organized. So, understanding Physiology requires an understanding of Anatomy, and vice versa.

Watch this video to review what physiology means and what anatomy means: https://youtu.be/fuw2UyTj14o



Review Questions for Learning Objective 2

Write your answer in a sentence form. (Do not answer using loose words)

1. What is anatomy?

2. What is gross anatomy?

3. What is histology?
4. What is physiology?

Test for Learning Objective 2

1. ___ studies how human structures at different levels work, so it focuses on function.
    a. Anatomy
    b. Gross anatomy
    c. Physiology
    d. Histology
2. ___ is the discipline that describes macroscopic stomach features.
    a. Biology
    b. Gross Anatomy
    c. Physiology
    d. Histology

3. ___ studies the microscopic features of the stomach.
    a. Physiology
    b. Anatomy
    c. Histology
    d. Gross anatomy

Learning Objective 3: Define homeostasis.

Listen to Learning Objective 3

Homeostasis (homeo- = "like, resembling, of the same kind"; stasis = "standing still") means to maintain body functions within specific livable ranges, adjusting to internal and external changes. Temperature, nutrient concentration, acidity, water, sodium, calcium, oxygen, as well as blood pressure, heart rate, and respiratory rate are some of the internal body variables that must remain within a certain range. When the body fails to maintain internal body variables within a certain range, normal function is interrupted, and disease or illness may result.

Review Questions for Learning Objective 3

Write your answer in a sentence form. (Do not answer using loose words)

1. Which are some of the internal body variables that must remain within a certain range?
2. What happens when internal body variables are out of a certain range?
3. What is homeostasis?

Test for Learning Objective 3

1. Homeostasis means to maintain body functions ___
    a. normal for any given age and gender
    b. at least at the minimum needed to be able to reproduce
    c. within specific livable ranges, adjusting to internal and external changes
    d. within a strict control and prevent any changes at all

Learning Objective 4: Define control system and describe its components.

Listen to Learning Objective 4

Anything that must be maintained in the body within a normal range must have a **control system**. A control system consists of four components:

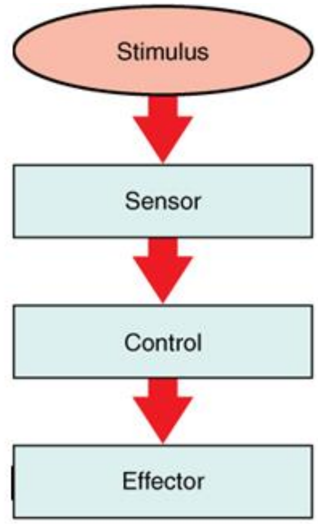
Stimulus, or physiological variable that changes, is the item to be regulated. *Variable* in the broad sense is a value that varies or changes. Two examples of variables that change are body temperature and blood glucose. Anything that can be measured and varies is a variable.

Sensor, or sensory receptor, is the cell, tissue, or organ that senses the change in the stimulus or physiological variable. For example, sensory nerve cell endings in the skin sense a raise of body temperature, and specialized cells in the pancreas sense a drop in blood glucose. The sensory receptor or sensor provides input to the control center.

Control center is the body structure that determines the normal range of the variable, or **set point**. For example, an area of the brain called the hypothalamus determines the set point for body temperature (around 37°C, or 98.6°F), and specialized cells in the pancreas determine the set point for blood glucose (around 70-100mg/dL). To maintain homeostasis, the control center responds to the changes in the stimulus received from the sensor by sending signals to effectors.

Effector is the cell, tissue, or organ that responds to signals from the control center, thus providing a response to the stimulus (physiological variable that changed) in order to maintain homeostasis. For example, sweat glands (effectors) throughout the body release sweat to lower body temperature; and cells of the liver (effectors) release glucose to raise blood glucose levels. See the four components of a control system in below Figure 1.2 below.

Figure 1.2
Components of a Control System: stimulus or physiological variable that changes, sensor or sensory receptor, control center, and effector.
Art derivative of OpenStax College – CC-BY



Review Questions for Learning Objective 4

Write your answer in a sentence form. (Do not answer using loose words)

1. What are the four components of a control system?
2. Define stimulus using two examples
3. What is a sensor (or sensory receptor)?
4. What is a control center?
5. What is a set point?
6. What is an effector?

Test for Learning Objective 4

1. This sequence shows the components of a control system in order:
    a. Stimulus, sensory receptor, control center, effector
    b. Stimulus, sensory receptor, effector, control center
    c. Sensory receptor, stimulus, control center, effector
    d. Sensory receptor, stimulus, effector control, center

2. Control center is ___.
    a. the physiological variable that is adjusted
    b. the structure in the body where a change takes place
    c. the body structure that determines the normal range of the physiological variable
    d. the organ or tissue that provides a response to influence the physiological variable

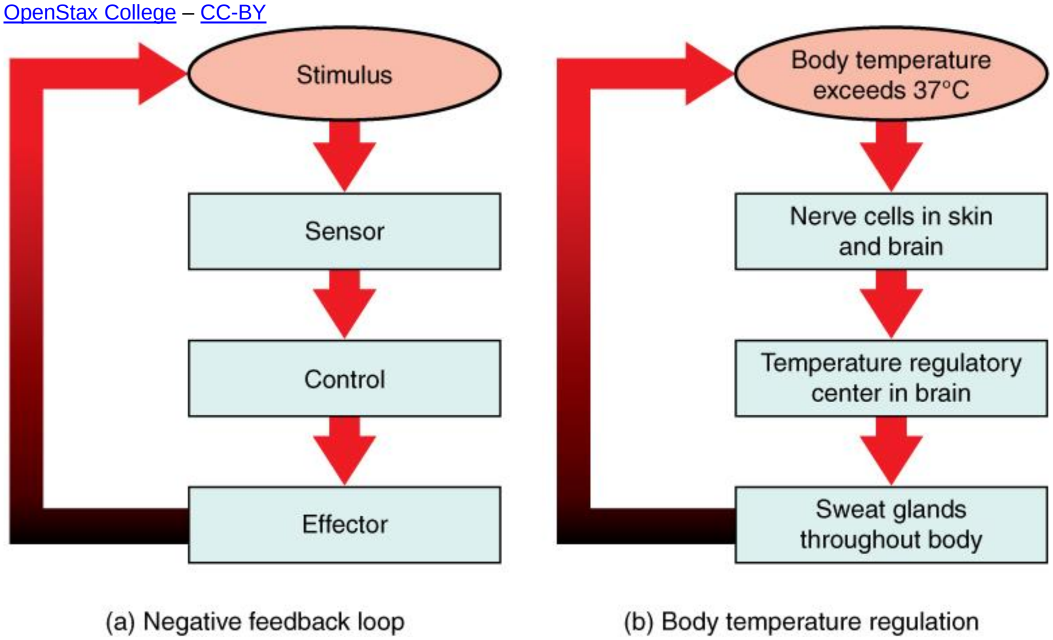
3. The cell, tissue, or organ that provides a response to a stimulus is called the___
    a. Sensory receptor
    b. Effector
    c. Set point
    d. Control center

Learning Objective 5: Define negative feedback and give one example using body temperature.

[Listen to Learning Objective 5](#)

Most control systems maintain homeostasis by a process called **negative feedback**. Negative feedback prevents a physiological variable or a body function from going beyond the normal range. It does this by reversing a physiological variable change (stimulus) once the normal range is exceeded. The components of a negative feedback are the sensor (or sensory receptor), the control center (where the set point is), and the effector. See figure 1.3 below.

Figure 1.3
In a negative feedback loop, a stimulus—a deviation from a set point—is resisted through a physiological process that returns the body to homeostasis. (a) A negative feedback loop has four basic parts. (b) Body temperature is regulated by negative feedback.



Review Questions for Learning Objective 5

Write your answer in a sentence form. (Do not answer using loose words)

1. What is negative feedback?

Test for Learning Objective 5

1. Negative feedback ___.

   a. Is the mechanism that intensifies a change of body function
   b. Is the mechanism that restores normal ranges of body function
   c. Intensifies a change in a physiological condition
   d. Accelerates a change until in a physiological condition is completed

Learning Objective 6: Define positive feedback and give one example; also, compare and contrast positive and negative feedback in terms of the relationship between response and result.

Listen to Learning Objective 6

Positive feedback is a mechanism that intensifies a change in the body's physiological condition rather than reversing it (as a negative feedback mechanism does). A deviation from the normal range results in more change, and the system moves farther away from the normal range. Positive feedback in the body is normal only when there is a definite end point.

Childbirth is one example of a positive feedback loop that is normal but is activated only when needed. The first contractions of labor (stimulus) push the baby toward the cervix (the lowest part of the uterus). The cervix contains stretch-sensitive cells (sensors) that monitor the degree of stretching. These nerve cells send messages to the brain (control center), which in turn causes the pituitary gland at the base of the brain to release the hormone oxytocin into the bloodstream. Oxytocin causes stronger contractions of the smooth muscles (effectors) in the uterus, pushing the baby further down the birth canal. This causes even greater stretching of the cervix. The cycle of stretching, oxytocin release, and increasingly more forceful contractions stops only when the baby is born. At this point, the stretching of the cervix halts, stopping the release of oxytocin. The end result in a positive feedback loop is to reach an *end* point (delivery) as opposed to reach a *set* point as in negative feedback. See figure 1.4 below for an example, and table 1.1 for a comparison between negative feedback and positive feedback.

Figure 1.4
Normal childbirth is driven by a positive feedback loop. A positive feedback loop results in a change in the body's status, rather than a return to a set point.
Art derivative of [OpenStax College](#) – [CC-BY](#)

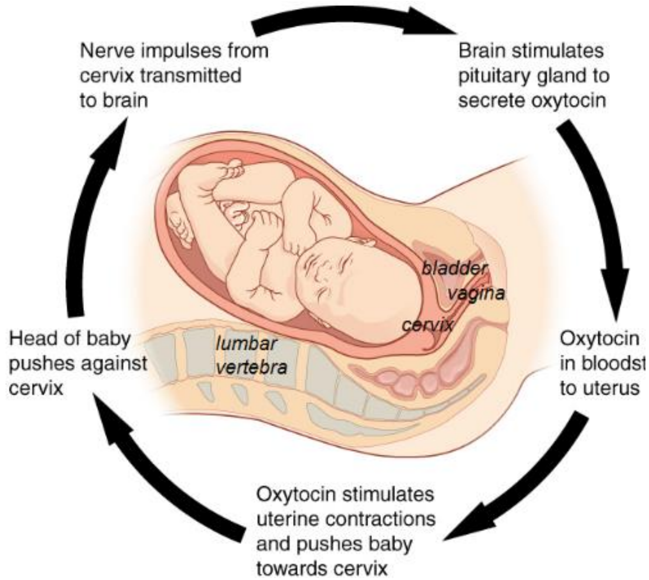
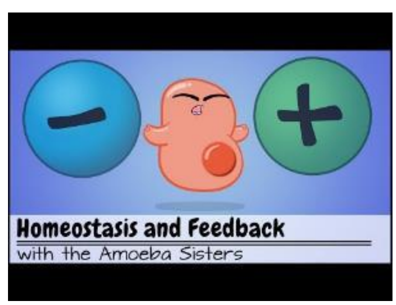


Table 1.1
Comparison between negative feedback and positive feedback

	Negative Feedback	Positive Feedback
Example	Regulation of body temperature or blood glucose	Normal childbirth
Response	***Reverses*** a change in a physiological condition	***Intensifies*** a change in physiological condition
Result	Return to a ***set point***	Reach an ***end point***
Overall	Provides ***stability***	***Accelerates a process*** to completion

Watch this video to review homeostasis, negative feedback, and positive feedback: https://youtu.be/Iz0Q9nTZCw4



Review Questions for Learning Objective 6

Write your answer in a sentence form. (Do not answer using loose words)

1. What is positive feedback?
2. How are negative and positive feedback different (Compare response, result, and overall)

Test for Learning Objective 6

1. Positive feedback ___
   a. Provides stable conditions
   b. Accelerates a process to completion
   c. Reverses a change in a physiological condition
   d. Returns a physiological variable to a set point

MODULE 4: *Atoms*

Learning Objective 7: Define the term atom and describe its structure in terms of location and charge of its subatomic particles.

Listen to Learning Objective 7

Matter is anything that has mass and takes up space. All things in the universe (i.e. living and non-living things) are considered to be matter. The smallest component of matter normally found is the **atom**. Then, all things in the universe (including humans) are made of atoms.

Atoms themselves are composed of even smaller **subatomic particles** (extremely tiny things) called neutrons, protons, and electrons. **Protons** have a positive electrical charge (+), **electrons** have a negative electrical charge (-), and **neutrons** are electrically neutral, meaning they have no charge.

Each one of the different types of atoms in the universe has the same number of protons and electrons. Then, all and every atom in the universe is **electrically neutral**. For example, one atom of sodium has 11 electrons (-) and 11 protons (+). The 11 positive protons cancel out the 11 negative electrons, and the overall charge of the atom is zero.

Protons and neutrons each weigh one atomic mass unit (amu), and are located at the core of the atom, or **nucleus.** Electrons move within orbital clouds around the nucleus in **orbital shells**. Electrons are so small that their mass is considered zero. See figure 2.1 and 2.2 below, and do activities 2.1 and 2.2 below.

Figure 2.1
Representation of an atom. This atom in particular has five electrons and five protons; it is neutral as all atoms are. Electrons' masses are extremely small compared with protons' and neutrons' masses.
Art by Berkeley Lab; Public Domain

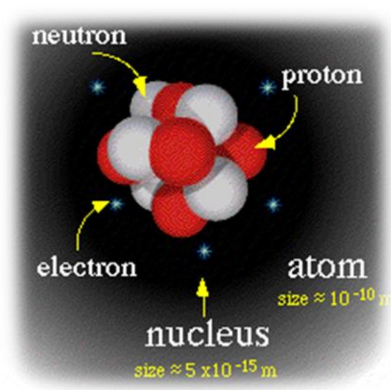
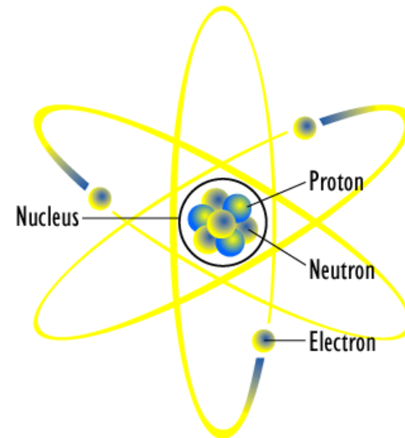
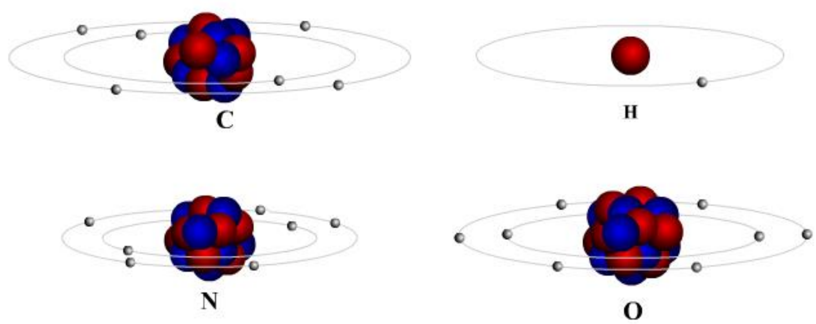


Figure 2.2
Typical planetary representation of an atom highlighting orbital shells. This atom has three protons and three electrons; then, it is **neutral**, as all atoms are. Electrons are represented much bigger than what they really are, only so they can be clearly seen. Art by Fastfission CC-BY-SA



Activity 2.1
Count the number of protons and electrons in the Carbon, Hydrogen, Oxygen, and Nitrogen atoms shown below. Protons are red and neutrons are blue. Each atom should have the same number of protons as electrons.
Art By University of Maryland University College CC-BY-NC



Review Questions for Learning Objective 7

Write your answer in a sentence form. (Do not answer using loose words)

1. What is an atom?
2. What is a subatomic particle?
3. How many different types of subatomic particles are there in an atom?
4. Where are the different subatomic particles located in an atom?
5. Which subatomic particle is positive?
6. Which subatomic particle is negative?
7. Which subatomic particle is neutral?
8. What is the *overall* charge of an atom (positive, negative, neutral)?
9. What is an orbital shell?

Test for Learning Objective 7

1. All things in the universe are made of atoms: T/F
2. The human body is made of atoms: T/F
3. All the organs and cells in the body are made of atoms: T/F
4. An atom is the smallest component of matter: T/F
5. Subatomic particles are tiny things forming atoms T/F
6. All subatomic particles are neutral T/F
7. Orbital shells are at the core of an atom T/F
8. The subatomic particle that has a positive electrical charge is the ___.
9. The subatomic particle that has a negative electrical charge is the ___.
10. The ___ is an electrically neutral subatomic particle.
11. If one atom of carbon has six electrons, then it has ___ protons.
12. If one atom of oxygen has eight protons, then it has ___ electrons.

13. This is the best definition of atom:
    a. The atom is the smallest component of the subatomic particles
    b. The atom is the smallest component of matter normally found
    c. Atoms are small particles found in the nucleus of all matter
    d. Atoms are particles found moving around orbital shells

14. Which of the following lists all subatomic particles?
    a. Molecule, atom and electron
    b. Proton, neutron and electron
    c. Nucleus, proton and electron
    d. Atom, neutron and proton

15. Which subatomic particles are located in the nucleus of an atom?
    a. Protons and electrons
    b. Protons and neutrons
    c. Neutrons and electrons
    d. Protons, neutrons, and electrons

Learning Objective 8: Define the term element and distinguish between atom and element.

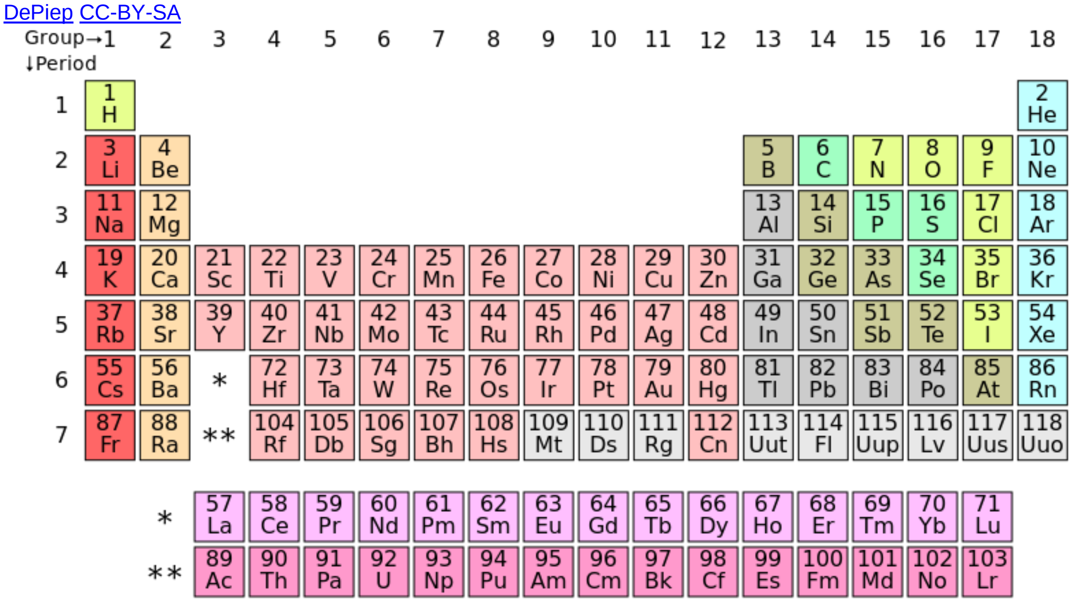
Listen to Learning Objective 8

While all atoms are made of subatomic particles (protons, neutrons, and electrons) not all atoms are the same. There are 118 different types of atoms, called **elements**. Each element has unique physical and chemical properties. For example, the element carbon and the element oxygen have different melting points, different densities, and different colors. An atom is the smallest unit of an element that retains the properties of that element. We can also define an **element** as a substance that is made of a single type of atom. See figure 2.3 below.

Figure 2.3
From left to right, images of the elements sodium (solid), nitrogen (liquid), and oxygen (colorless gas bubbles in the pale blue liquid). The element sodium is made of sodium atoms, the element nitrogen is made of nitrogen atoms, and the element oxygen is made of oxygen atoms.
Art by Dnn87 CC BY-SA 3.0 (Sodium), Cory Doctorow CC BY-SA 2.0 (Nitrogen), and Dr. Warwick Hillier GPL (Oxygen)

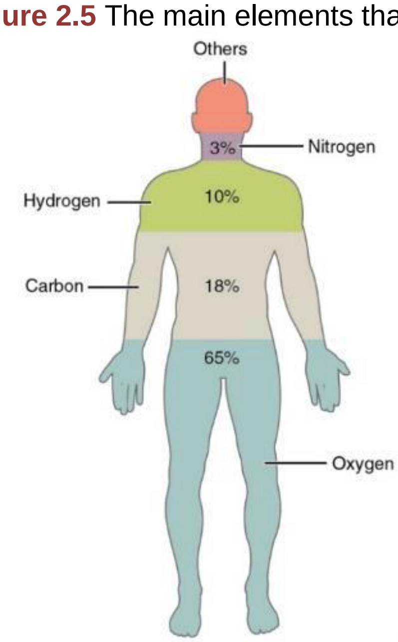
All known elements in the universe are organized in a chart called the **Periodic Table of Elements.** The table arranges elements according to their chemical properties, their number of protons, and the way electrons are organized in orbital shells. Elements are symbolized by a **chemical symbol** (one- or two-letter abbreviation). See figure 2.4 below.

Figure 2.4
A standard 18-column form of the Periodic Table of Elements. This figure shows the simplest representation of the table with basic information.
Art by DePiep CC-BY-SA



The human body is composed of many different elements as shown in figure 2.5 below. For example, carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorous (P), and calcium (Ca), make up 98.5% of the human body weight. Other important elements are potassium (K), sulfur (S), sodium (Na), chlorine (Cl), and magnesium (Mg).

Figure 2.5 The main elements that compose the human body. Art by OpenStax College – CC-BY



Element	Symbol	Percentage in Body
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.2
Calcium	Ca	1.5
Phosphorus	P	1.0
Potassium	K	0.4
Sulfur	S	0.3
Sodium	Na	0.2
Chlorine	Cl	0.2
Magnesium	Mg	0.1
Trace elements include boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).		less than 1.0

Review Questions for Learning Objective 8

Write your answer in a sentence form. (Do not answer using loose words)

1. What is an element?
2. What is the difference between an atom and an element?
3. What is a chemical symbol?
4. What is the Periodic Table of Elements?

Test for Learning Objective 8

1. Different types of atoms are referred to as elements T/F
2. Carbon, hydrogen, oxygen and nitrogen are some examples of elements T/F
3. All elements have the same physical and chemical properties T/F
4. All atoms of the same element have the same physical and chemical properties T/F
5. An element is a substance that is made of a single type of atom T/F
6. A chemical symbol is a one- or two-letter abbreviation that symbolizes an element T/F

7. Which of the following elements is not among the most abundant (in percentage) in the human body?
   a. Carbon
   b. Oxygen
   c. Hydrogen
   d. Sodium

8. This is the correct sorting of major elements in the human body from the most abundant (in percentage) to the least abundant: ___
   a. Oxygen, carbon, hydrogen, nitrogen
   b. Oxygen, hydrogen, carbon, nitrogen
   c. Carbon, oxygen, hydrogen, nitrogen
   d. Carbon, hydrogen, oxygen, nitrogen

9. The periodic table of elements shows all the known elements in ___.
   a. an organism
   b. the universe
   c. a cell
   d. an atom

Learning Objective 9: Distinguish between the terms atomic number and mass number.

Listen to Learning Objective 9

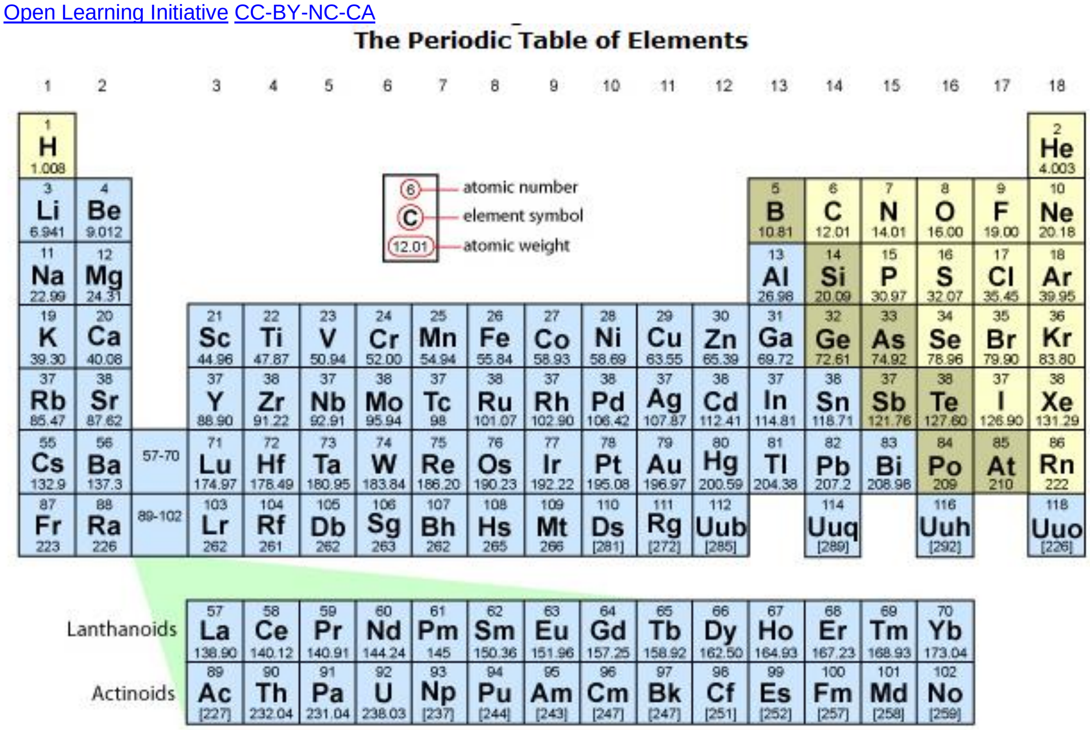
All elements differ in their physical and chemical properties. These properties are given by the number of subatomic particles (protons, electrons and neutrons) they carry. The number of protons an atom carries in its nucleus determines which element it is. For example, one atom of the element carbon (C) always has six protons in its nucleus; and one atom of the element oxygen (O) always has eight protons in its nucleus. In short, all atoms with a particular number of protons belong to the same element.

The number of protons in an atom is denoted by the **atomic number**, which is shown as a number in the periodic table, usually shown above the chemical symbol of the element. Then, the atomic numbers above each element in the periodic table show the number of protons of each element.

Since atoms are electrically neutral (they carry the same number of protons as electrons); then, the number of protons tells us the number of electrons an element has. For example, nitrogen (N) has an atomic number of 7 (see the periodic table below). Then, nitrogen must have seven protons, and it must also have seven electrons. Sodium (Na) has an atomic number of is 11; then, sodium must have eleven protons, and it must also have eleven electrons. The same applies to all elements in the periodic table. See figure 2.6 below.

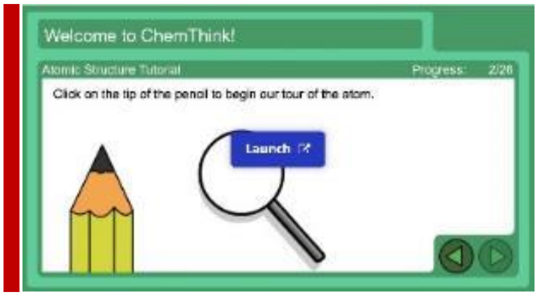
Figure 2.6

Periodic Table of Elements showing symbols, atomic numbers and mass numbers. The relative atomic mass is also referred to as the atomic weight. Then, we approximate atomic weight and mass number as the same.



The atomic mass of an atom is mostly the mass of its neutrons and its protons (since electrons have a negligible mass). For example, the atomic mass of carbon (C) is 12.01. This comes from adding the number of protons (6) plus the number of neutrons (6), each of which weighs 1 amu. We will see where the decimal point comes from in the next learning objective. The atomic mass for an atom of each element is shown as a decimal number called the atomic **mass number** in the periodic table, usually shown below the chemical symbol of the element.

Summarizing:
Atomic Number = Number of protons = Number of electrons
Mass Number = Number of protons + Number of neutrons



Activity 2.2 Follow this link to review atomic structure. By Chris Bruce/PBS LearningMedia
View simulation at http://tiny.cc/atomstr

Review Questions for Learning Objective 9

Write your answer in a sentence form. (Do not answer using loose words)

1. What is the atomic number of an element?
2. What is the mass number of an element?
3. How are atomic number, number of protons and number of electron related?
4. How are mass number, number of protons and number of neutrons related?

Test for Learning Objective 9

1. The atomic number of an element is the same as its number of protons (T/F)
2. The mass number of an element is the number of protons plus the number of neutrons of the element (T/F)
3. Oxygen has eight protons. Its atomic number is ___
   a. 4
   b. 8
   c. 16
   d. 64
4. Carbon has six protons and six neutrons. Its mass number is ___
   a. 3
   b. 6
   c. 12
   d. 36
5. Nitrogen has a mass number of 14, and an atomic number of 7. Nitrogen has ___
   a. 14 neutrons and an unknown number of protons
   b. 14 protons and 14 neutrons
   c. 7 protons and an unknown number of neutrons
   d. 7 protons and 7 neutrons

Learning Objective 10: Define isotope.

[Listen to Learning Objective 10](#)

All the elements in the periodic table have two or more variants. As we mentioned before, an atom's proton number is characteristic of each element. For example, an atom with six protons is an atom of carbon. However, there are three variants of the carbon atom. One has six protons and six neutrons, another one has six protons and seven neutrons, and yet another one has six protons and eight neutrons; so, they have different atomic mass numbers: 12, 13 and, 14, respectively. These different types of an atom that have the same number of protons (same atomic number) but different number of neutrons (different atomic masses) are called **isotopes**. Some isotopes are unstable, and may spontaneously break down releasing energy (radioisotopes). This property of isotopes is used as a tool in medical laboratory technology.

From the previous learning objective, we can add that the atomic mass we see in the periodic table (for example 12.01 for carbon, or 1.008 for hydrogen) is the weighted average of the atomic masses of the different isotopes of an element. See isotopes of carbon and hydrogen in figure 2.7 below.

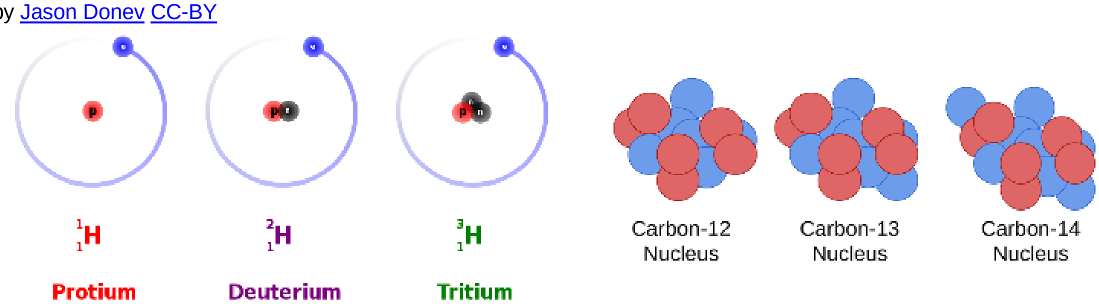
Figure 2.7

Left: The three naturally-occurring isotopes of hydrogen. The fact that each isotope has one proton makes them all variants of hydrogen: the identity of the isotope is given by the number of protons and neutrons. From left to right, the isotopes are protium (^{1}H) with zero neutrons, deuterium (^{2}H) with one neutron, and tritium (^{3}H) with two neutrons.

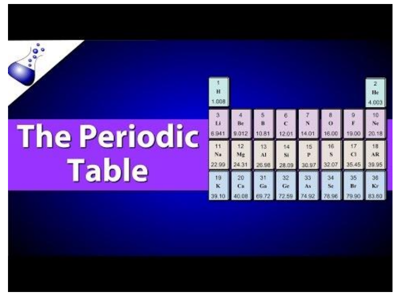
Art by Dirk Hünniger CC BY-SA 3.0

Right: Three isotopes of carbon (nuclei only, electrons not shown). Carbon-12 has six protons and six neutrons (^{12}C), carbon-13 has six protons and seven neutrons (^{13}C), carbon-14 has six protons and eight neutrons (^{14}C).

Art by Jason Donev CC-BY



Watch this video to review atomic number, atomic mass and, isotopes: https://youtu.be/YKZv9bsFD3w



Review Questions for Learning Objective 10

Write your answer in a sentence form. (Do not answer using loose words)

1. What is an isotope?

Learning Objective 11: Describe the arrangement of electrons in atoms, define valence electrons, and explain the octet rule.

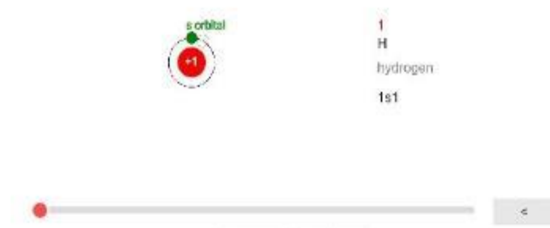
Listen to Learning Objective 11

Electrons are arranged in orbital shells (layers) surrounding the atom's nucleus. The first shell can carry up to two electrons, the second shell can carry up to eight electrons, and the third shell [can carry up to eighteen electrons but] is usually filled with up to eight electrons for what we cover in A&P. For example, the atomic number of nitrogen is 7. This means that nitrogen has seven protons, and therefore has seven electrons. Two electrons fill the first orbital shell, and five electrons go to the second orbital shell. Hydrogen's atomic number is 1. This means that hydrogen has one proton, and also one electron, which goes to the first shell. Sodium's atomic number is 11, so sodium has eleven protons and eleven electrons. The first two fill the first orbital shell, eight more fill the second orbital shell, and the last electron goes to the third orbital shell. Practice this doing activity 2.3 below.

Activity 2.3

Follow this link to see atomic structure and electron distribution in orbital shells. You can ***try with up to 20 electrons*** by sliding the red dot at eth bottom of the atom. It is not a goal of this learning objective to describe what happens after 20 electrons, as it becomes more complex.

By JavaLab View simulation at https://javalab.org/en/electron_configuration_en/



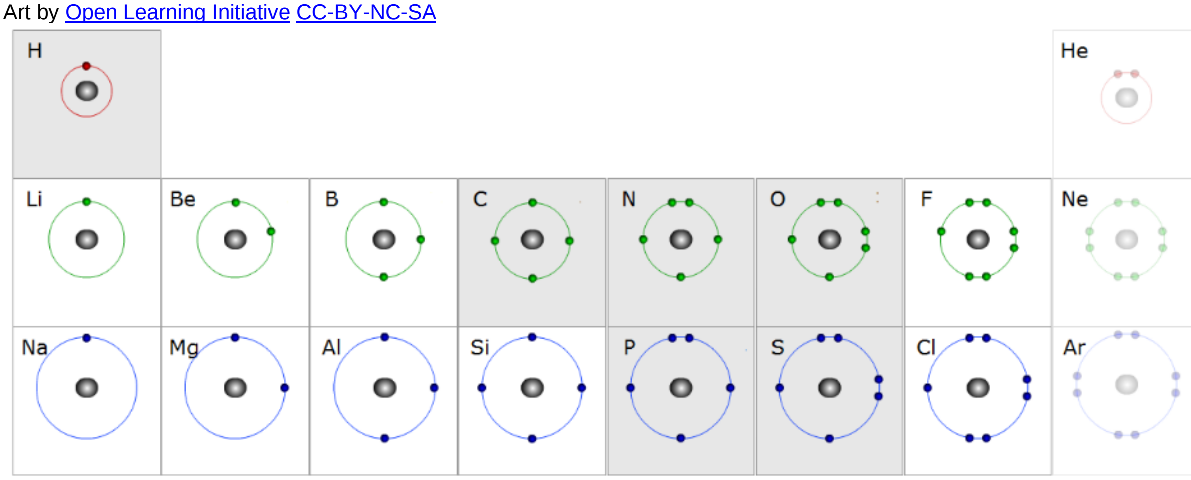
Single atoms by themselves are unstable and chemically reactive (unless their outermost electron shell is already filled with electrons). This means that they tend to react and bond with other atoms until they become non-reactive, or stable. As it is stated by the **Octet Rule** (oct- = eight), many elements become stable when they have eight electrons in their outermost orbital shell (except hydrogen, which becomes stable having two). For example, nitrogen has five electrons in its second and outermost shell, and completes eight by sharing three electrons with other atom(s). This makes nitrogen stable, which means that by completing an octet it does not need to react with any other atom. We will explore this rule further in a following learning objective.

The number of electrons in the outermost shell of atoms determines the type of bonding that occurs between atoms of the same, or different elements. The electrons found in the outermost shell, and involved in chemical bonding, are called **valence electrons**. Do activity 2.4 below.

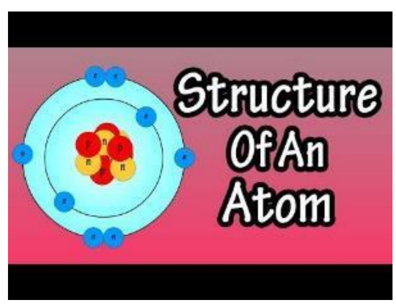
Activity 2.4

Valence electrons for some of first elements in the Periodic Table. Count the electrons for each element. Note that the first shell has up to two electrons, the second shell up to eight, and the third up to eight too. Electrons in the outermost shell are valence electrons.

Art by [Open Learning Initiative](#) [CC-BY-NC-SA](#)



Watch this video to review atomic structure, and valence electrons, and octet rule: https://youtu.be/TYEYEIuTmGQ



Review Questions for Learning Objective 11

Write your answer in a sentence form. (Do not answer using loose words)

1. What does the octet rule say?
2. What are valence electrons?

Test for Learning Objective 11

1. Electrons found ___ are called valence electrons.
    a. in the innermost shell of an atom
    b. in the outermost shell of an atom
    c. throughout an atom
    d. in the nucleus of an atom

2. Which of following statements about carbon is correct? (Carbon has six electrons)
    a. Carbon has two electrons in the first shell and four in the second shell
    b. Carbon has three electrons in the first shell and three in the second shell
    c. Carbon has four electrons in the first shell and two in the second shell
    d. Carbon has six electrons in the first shell

3. Which of following statements about oxygen is correct? (Oxygen has eight electrons)
    a. Oxygen has 2 valence electrons
    b. Oxygen has 4 valence electrons
    c. Oxygen has 6 valence electrons
    d. Oxygen has 8 valence electrons

Learning Objective 12: Define the terms ion, cation, anion, and electrolyte.

Listen to Learning Objective 12

In order to follow the octet rule and end up with eight electrons in the valence shell (the outermost shell) usually atoms with one or two valence electrons tend to give them away to atoms with six or seven valence electrons that need one or two more electrons to complete eight.

For example, sodium (Na) has a total of eleven electrons: two electrons in the first shell, eight electrons in the second, and one more in the third. By giving up this last electron to an atom of another element, the second shell becomes the outermost, and sodium has eight electrons in its (new) valence shell. Initially, sodium had eleven positive charges from its eleven protons, and eleven negative charges from its eleven electrons, with an overall charge equal to zero. Now that sodium lost one negative charge (the electron), it has an extra positive charge and becomes a **cation**, a positively charged particle.

In contrast, chlorine (Cl) has a total of seventeen electrons: two electrons in the first shell, eight electrons in the second shell, and seven more in the third (valence shell). By taking up one electron from an atom of other element, its third shell completes eight electrons. Initially, chlorine had seventeen positive charges from its seventeen protons, and seventeen negative charges from its seventeen electrons, with an overall charge equal to zero. Now that chlorine gained one negative charge (the electron), it has an extra negative charge and becomes an **anion**, a negatively charged particle.

Positively or negatively charged particles are called **ions**. In the two examples above, the *element sodium* becomes a *sodium ion* (Na^+), a **cation**; and the *element chlorine* becomes a *chloride ion* Cl^-, an **anion**.

Cations are represented with a superscripted plus sign (+) for each electron lost, and anions are represented with a superscripted minus sign (-) for each electron gained. A single atom can form an ion like in K^+, Cl^-, F^-; Mg^{2+}, Al^{3+}; and also, a group of atoms, or parts of a molecule, can form ions like in OH^-, HPO_4^-, NH_4^+, SO_4^{2-}.

Electrically charged particles, such as ions, are also called **electrolytes**. For example, all the ions listed in the previous paragraph are electrolytes. Electrolytes usually dissolve well in water, and a mixture of water and electrolytes can conduct electrical currents.

Review Questions for Learning Objective 12

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a cation?
2. What is an anion?
3. What is an ion?
4. What is the difference between an element and an ion?
5. What is an electrolyte?

Test for Learning Objective 12

1. A positively charged particle is called ___
2. A negatively charged particle is called ___
3. When the element Y gains one electron, it becomes ___
   a. Y
   b. Y^+
   c. Y^-
   d. Y^{2-}
4. When the element X loses two electrons it becomes ___
   a. X
   b. X^+
   c. X^{2+}
   d. X^{2-}
5. Which of the following symbols represents a cation?
   a. Ca
   b. Na
   c. K^+
   d. F^-
6. Which of the following symbols represents an anion?
   a. Mg
   b. N
   c. Na^+
   d. Br^-
7. Which of the following symbols represents an element, and *not* an ion?
   a. K^+
   b. Na
   c. Ca^{2+}
   d. Cl^-

MODULE 5: *Chemical Bonds*

Learning Objective 13: Define chemical bonding, molecules, salts and compounds; and list three types of chemical bonds important for the study of human physiology.

Listen to Learning Objective 13

Atoms and ions can combine by chemical bonds. A **chemical bond** is an interaction between atoms or ions that stabilizes their outer shells. The interaction happens among the valence electrons (the ones in the outermost orbital shell). As a product of this interaction, participating atoms complete eight electrons in their outermost shells, form a chemical bond, and become stable.

Chemical bonding is responsible for the formation of molecules and salts. **Molecules** are substances composed of two or more ***atoms*** held together by a chemical bond. For example, in a molecule of carbon dioxide (CO_2) the atom of carbon and the two atoms of oxygen are held together by chemical bonds. **Salts** are substances composed of ***ions*** held together by a chemical bond. For example, in a crystal of NaCl, table salt, Na^+ and Cl^- are held together by a chemical bond.

Salts and molecules made up of two or more atoms of different elements are called **compounds**. For example, CO_2, H_2O, and NaCl are compounds, whereas O_2 or H_2 are not.

There are three types of chemical bonds important for the study of the human physiology. These are **ionic bonds**, **covalent bonds**, and **hydrogen bonds**.

Ionic bonds occur between ions with opposite charges (between anions and cations); **covalent bonds** occur between atoms of the same molecule; and **hydrogen bonds** occur between atoms in different molecules (one of them being hydrogen), or different parts of the same molecule.

Review Questions for Learning Objective 13

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a chemical bond?
2. What subatomic particles participate in a chemical bond?
3. What is a molecule?
4. What is a salt?
5. What is a compound?
6. What is an ionic bond?
7. What is a covalent bond?
8. What is a hydrogen bond?

Test for Learning Objective 13

1. A chemical bond is an interaction between atoms (T/F)
2. Electrons are the subatomic particles participating in a chemical bond (T/F)
3. Salts are compounds (T/F)
4. Compounds are made up of two or more different elements (T/F)

5. Covalent bonds occur between ___
   a. ions with opposite charges
   b. atoms of the same molecule
   c. molecules of the same atoms
   d. atoms in different molecules

6. Ionic bonds occur between ions with___
   a. Either same or opposite charges
   b. Same charges and similar sizes
   c. Opposite charges
   d. Same charges

7. Molecules are composed of ___
   a. two or more atoms held together by a covalent bond
   b. two or more atoms held together by a hydrogen bond
   c. two or more ions held together by a covalent bond
   d. two or more ions held together by a hydrogen bond

Learning Objective 14: Define ionic bonds and describe how they form, and define salts.

Listen to Learning Objective 14

Ionic bonds are formed by the electrical attraction between ions of opposite charges. The attraction between a cation and an anion forms an ionic bond.

Ions form when atoms take on or give up electrons following the octet rule. Do activity 2.5 below. .

Activity 2.5

Follow this link to review ions and ionic bonds.

By Chris Bruce/PBS LearningMedia

View simulation at http://tiny.cc/ionbond

Salts are a class of compounds formed by ionic bonds between ions. For example, NaCl, table salt, forms when Na^+ forms an ionic bond with Cl^-. See the structure of NaCl in figure 2.8 below.

When a salt crystal is placed in water –as you can observe by placing table salt crystals in a glass of water-, it dissociates (separates) into its forming ions, or electrolytes, in a way that we will explore in an upcoming learning objective.

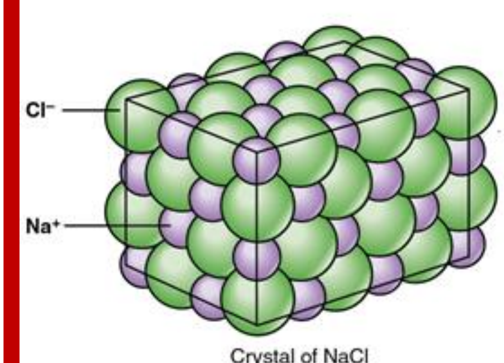


Figure 2.8

The structure of a NaCl crystal is given by the interaction of its forming ions, Na^+ and Cl^-, which are linked by ionic bonds

Review Questions for Learning Objective 14

Write your answer in a sentence form. (Do not answer using loose words)

1. What is an ionic bond?
2. What is a salt?

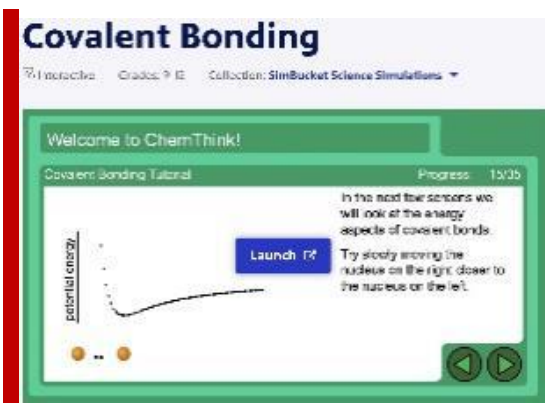
Test for Learning Objective 14

1. Which one of the following pairs will form an ionic bond?
   a. Na ; Cl
   b. Na^+ ; K^+
   c. Cl ; K^+
   d. Br^- ; K^+
2. A(n) ___ forms by ionic bonds between ions.
   a. Molecule
   b. Compound
   c. Salt
   d. Electrolyte

Learning Objective 15: Define covalent bonds and describe how they form, and differentiate between the two types of covalent bond.

[Listen to Learning Objective 15]

Instead of taking on or giving up electrons completely as happens in ionic bonding, atoms with four or more valence electrons may share pairs of electrons so both atoms' outer shells complete eight electrons (or two for the case of hydrogen). Each pair of shared electrons moves in an orbital cloud around the nuclei of the *two* atoms. This sharing of electrons between atoms is called a **covalent bond** (co-= "together, mutually, in common", valent = relative to the valence electron). See how covalent bond are formed. below in activity 2.6.

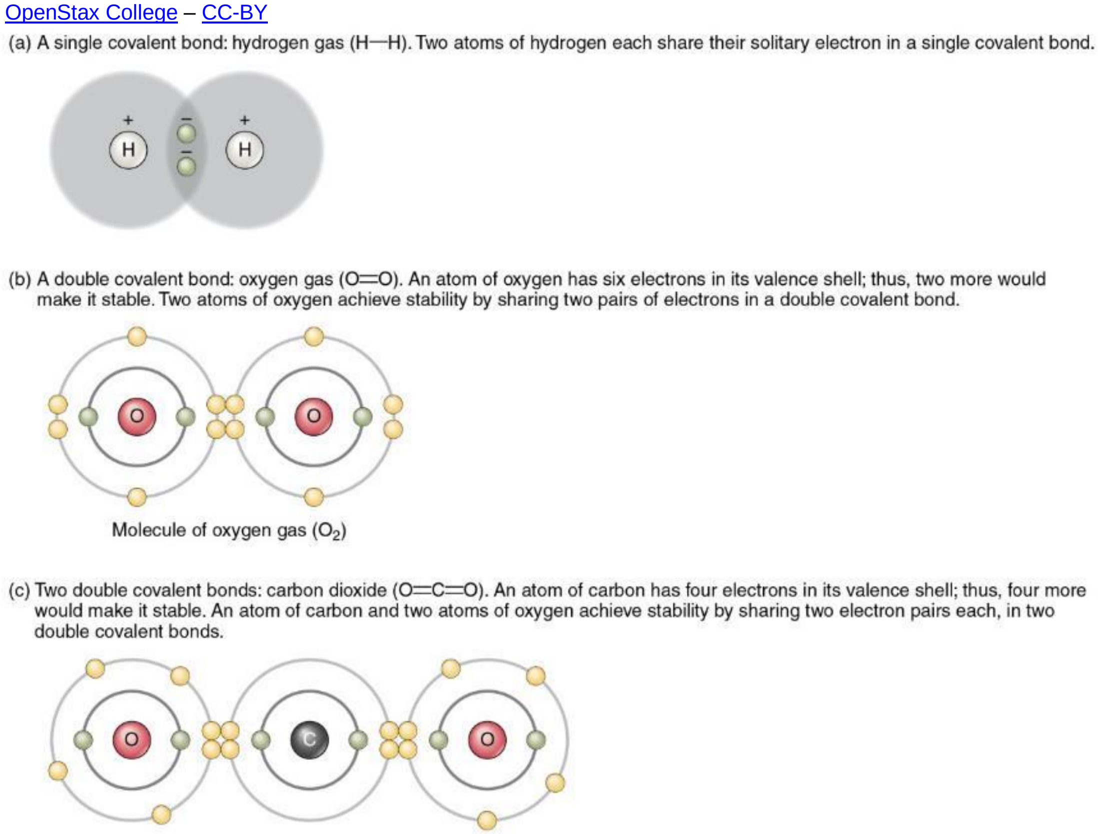


Activity 2.6
Covalent bonds simulation review. View [here]. Simulation by [Chris Bruce/PBS LerningMedia]
Link: [http://tiny.cc/covbond]

In a **single covalent bond**, a pair of electrons is shared between two atoms, while in a **double covalent bond**, two pairs of electrons are shared between two atoms.

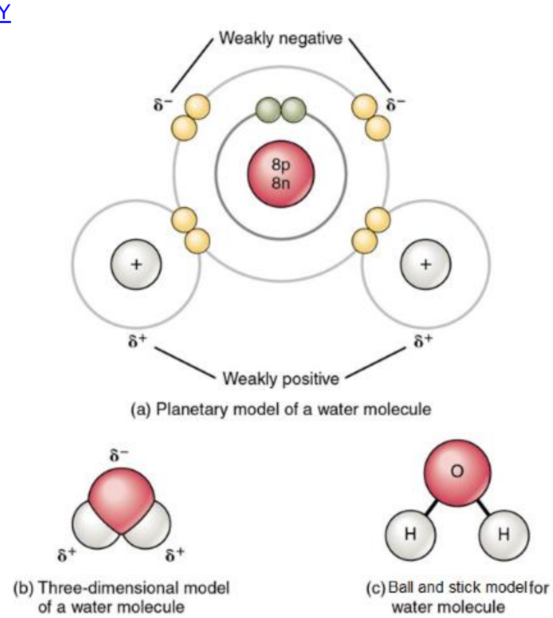
Figure 2.9 below shows in (a) that a *molecule* of hydrogen has two atoms of the element hydrogen. This can be represented by either a **molecular formula**, H_2, which shows how many atoms of each different type of element form a molecule or a **structural formula,** H-H, which shows the single covalent bond involved as one line, representing the pair of shared electrons. The oxygen *molecule* is formed by two *atoms* of the element oxygen as shown in (b). The *molecular* formula of the gas oxygen is O_2, while the *structural* formula of this molecule is O=O, where the double line shows a double covalent bond indicating two pairs of shared electrons. A molecule of carbon dioxide is shown in (c) and has a *molecular* formula of CO_2, showing that it is made of one atom of the element carbon and two atoms of the element oxygen. The *structural* formula of carbon dioxide in O=C=O, shows that the molecule has two double covalent bonds.

Figure 2.9
The examples shown above show sharing of electrons between atoms with similar a number of electrons (carbon and oxygen have six and eight, respectively). In these cases, the shared electrons spend about the same time moving around each one of the nuclei of both atoms. This type of covalent bond where electrons are ***equally*** shared is called a **non-polar covalent bond.** Nonpolar covalent bonds do not have a charge and are electrically neutral.
Art by OpenStax College – CC-BY



A second type of covalent bond occurs when electrons between atoms are shared in an ***unequal*** manner and is called a **polar covalent bond**. A polar covalent bond is common when either oxygen or nitrogen is sharing electrons with hydrogen. As shown in Figure 2.10 below, water (H_2O) is a polar covalent molecule, in which one oxygen atom is covalently bound to two hydrogen atoms. The oxygen atom has 8 protons (and 8 electrons) and the hydrogen atom has just one proton (and one electron). The eight protons in the oxygen atom draw the pair of shared electrons toward oxygen and away from hydrogen. This is because the eight protons in the nucleus of oxygen attract the shared electrons with a stronger force than the single proton in the nucleus of hydrogen. This unequal share of electrons results in the atom that attracts the electrons more, in this example oxygen, having a slightly negative charge density (noted as δ-) and the other atom, in this example hydrogen, having a slightly positive charge density (noted as δ+). Note that we refer to charge density, as opposed to net charge, because neither oxygen nor hydrogen gains or loses electrons.

Figure 2.10
Water: a polar covalent molecule (a) shows two polar covalent bonds in the water molecule. See the explanation in the paragraph above; (b) and (c) show two other ways to represent a water molecule, other than the molecular formula, H_2O, and the structural formula, H-O-H.
Art by OpenStax College – CC-BY



Summarizing:

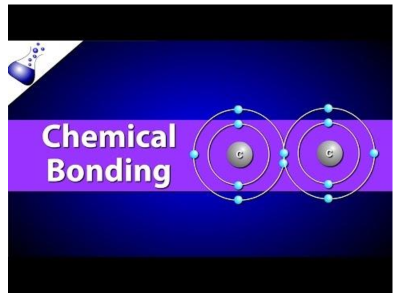
Covalent bonds are formed when atoms in a molecule **share electrons**. There are two types of covalent bonds. Molecules with **non-polar covalent bonds equally share electrons** between atoms and have an **even arrangement of charges**. Molecules with **polar covalent bonds share electrons unequally** between atoms and have an **uneven arrangement of changes**.

Review Questions for Learning Objective 15

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a covalent bond?
2. What is the difference between a single covalent bind and a double covalent bond?
3. What is the difference between a molecular formula and a structural formula?
4. What is a non-polar covalent bond? What is a polar covalent bond?

Watch this video to review atomic structure, valence electrons, octet rule, covalent bond, and ionic bond: https://youtu.be/OTgpN62ou24



Test for Learning Objective 15

1. The sharing of electrons between atoms is called ___ bond
2. Two atoms sharing *two* pairs of electrons form a ___ ___ bond
3. The equal sharing of electrons between two atoms forms a ___ ___ bond, as opposed to the non-equal sharing of electrons between two atoms, which forms a ___ ___ bond.

4. The structural formula of oxygen gas, O=O, shows that ___.

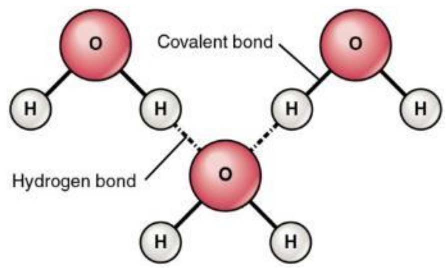
a. Two molecules of oxygen are held together by a double covalent bond
b. Two molecules of oxygen are held together by a single covalent bond
c. Two atoms of oxygen are held together by a double covalent bond
d. Two atoms of oxygen are held together by a single covalent bond

Learning Objective 16: Define hydrogen bonds and describe how they form.

Listen to Learning Objective 16

Atoms in the water molecule are held together by polar covalent bonds, as we saw in the previous learning objective. The unequal share of electrons in the O-H polar covalent bonds results in the oxygen atom having a slightly negative charge density (δ-) and hydrogen atom having a slightly positive charge (δ+). The slightly negative $O^{\delta-}$ in one water molecule is attracted to the slightly positive $H^{\delta+}$ of a neighboring water molecule as shown in figure 2.11 below.

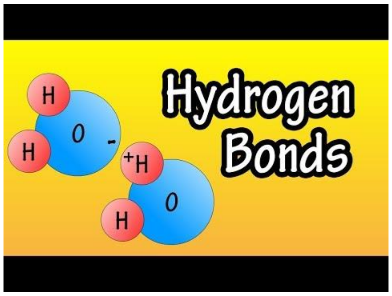
Figure 2.11
Hydrogen bonds are relatively weak. They occur between atoms of *different* molecules and are shown as a dotted line rather than a solid line. Covalent bonds are stronger, occur between atoms of the *same* molecule and are shown as solid lines.
Art by OpenStax College – CC-BY



The electrical attraction between $H^{\delta+}$ in one molecule and $O^{\delta-}$ in another molecule is called a **hydrogen bond**. (Hydrogen bond can also be formed between $H^{\delta+}$ in one molecule and $N^{\delta-}$ in another molecule). A hydrogen bond is a weaker type of attraction, but many hydrogen bonds add up. Hydrogen bonds explain many of the properties of water. Activity 2.7 below shows how hydrogen bonds form.

Activity 2.7 Adjust the lever (top right) in the interactive simulation here to speed up the motion of water molecules. Note that hydrogen atoms of a molecule and oxygen atoms of another molecule are always positioned in front of each other. Simulation by Chris Bruce/PBS LearningMedia
Watch the simulation here: https://ny.pbslearningmedia.org/resource/arct15-sci-water/water-simulation/

Watch this video to review hydrogen bonds, and polar and non-polar molecules: https://youtu.be/RSRiywp9v9w



Review Questions for Learning Objective 16

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a hydrogen bond?

Test for Learning Objective 16

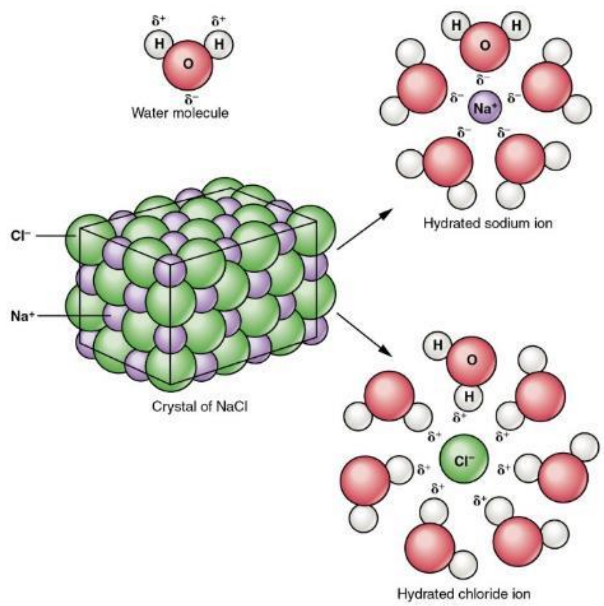
1. The attraction between the slightly negative end of one ___ to the slightly positive end of a neighboring ___ forms a hydrogen bond
   a. hydrogen atom; oxygen atom
   b. water molecule; water molecule
   c. hydrogen molecule; oxygen molecule
   d. oxygen atom; oxygen atom

Learning Objective 17: Describe the behavior of ionic compounds when placed in water.

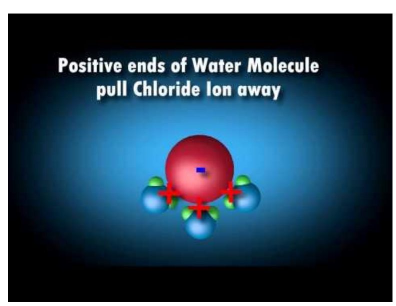
Listen to Learning Objective 17

When an ionic compound, or salt, (e.g., NaCl) is placed in water, its ionic components (e.g., Na^+ and Cl^-) **dissociate** (separate) and water molecules surround each ion. This is shown in figure 2.13 below. The small positive charges on hydrogen atoms in water molecules attract the anions (Cl^-), and the small negative charges on the oxygen atoms attract the cations (Na^+). Thus, because water is a polar covalent liquid, many salts and some polar covalent molecules (e.g., glucose) tend to 'dissolve' in water, while non-polar covalent molecules (e.g., fat) do not.

Figure 2.13
A sodium chloride crystal dissociates not into molecules of NaCl, but into Na^+ cations and Cl^- anions, each completely surrounded by water molecules.
Art by OpenStax College – CC-BY



Watch this video to review ionic compound dissociation in water:
https://youtu.be/JAWiJKhmbQc



Review Questions for Learning Objective 17

Write your answer in a sentence form. (Do not answer using loose words)

1. What happens to an ionic compound (salt) when placed in water?

Test for Learning Objective 17

1. When NaCl is placed in water: ___
    a. Na^+ and Cl^- dissociate (separate)
    b. Na^+ and Cl^- agglutinate (come together)
    c. Na^+ and Cl^- form an ionic bond
    d. Na^+ and Cl^- form a hydrogen bond

Learning Objective 18: Differentiate between hydrophobic and hydrophilic substances.

Listen to Learning Objective 18

Polar molecules are generally water soluble (they mix with water well), so they are referred to as **hydrophilic**, or "water-loving". (hydro = water; philia = loving, tendency toward). Alcohols, salts and some sugars are examples of hydrophilic substances. Nonpolar molecules do not interact with water, and they are not water soluble (they do not mix with water), so they are referred to as being **hydrophobic**, or "water-fearing" (phobos = fear). Oils, fats and waxes are examples of hydrophobic substances. See examples of hydrophobic and hydrophilic substances in figure 2.14 below.

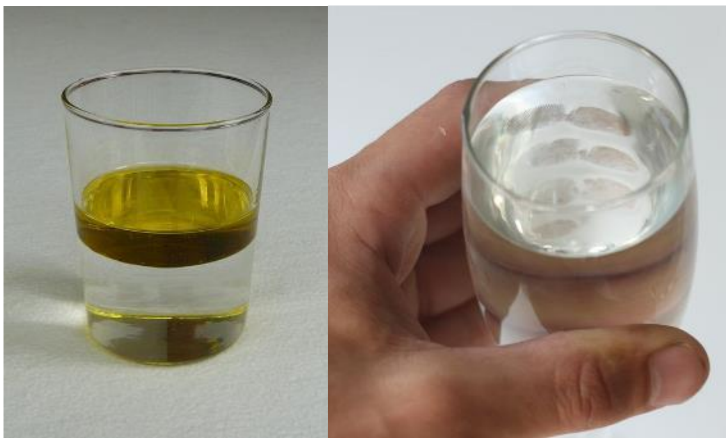
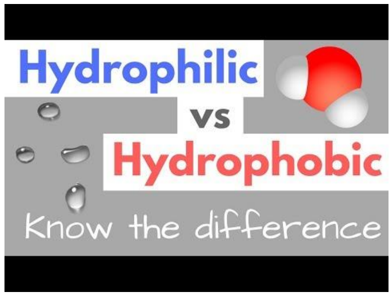


Figure 2.14
Sucrose (sugar table) molecules are hydrophilic and mix well with water, whereas unsaturated fats (mineral oils) are hydrophobic and do not mix well with water.
Art by Olli Niemitalo - Public Domain (left) and Victor Blacus - CC BY-SA (right)

Watch this video to review what hydrophilic and hydrophobic mean: https://youtu.be/JbaScpYu8Vs



Review Questions for Learning Objective 18

Write your answer in a sentence form. (Do not answer using loose words)

1. What does hydrophilic mean?
2. What does hydrophobic mean?

Test for Learning Objective 18

1. Which of the following substances is hydrophobic?
   a. Water
   b. Alcohol
   c. Oil
   d. Table Sugar

Learning Objective 19: Define the terms solution, solvent, and solute.

Listen to Learning Objective 19

A **mixture** is a combination of two or more substances, where each substance maintains its own properties. When we mix sucrose (table sugar) with water, we have a liquid mixture. Water molecules have not changed, and sucrose molecules have not changed either; they are mixed together. Each one maintains its own chemical properties.

A **solution** is a type of liquid mixture that consists of a **solvent** that dissolves a substance called a **solute**. A "sugary water" solution consists of water (solvent) that dissolves sucrose, or table sugar (solute). A drop of ink is a solution of water (solvent) and tiny colorful particles (solute). See another example in figure 2.15 below.

Most chemical reactions that happen inside and outside our body occur among compounds dissolved in water. For this is reason water is considered the "universal solvent".

Figure 2.15 A saline water **solution** can be prepared by dissolving table salt (NaCl) in water. Salt is the **solute** and water the **solvent.** Photo by Chris 73 – CC- BY-SA

Watch this video to review what a solution is, and see some examples: https://youtu.be/fAjvEoNMpL8

Review Questions for Learning Objective 19

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a mixture?
2. What is a solution?
3. What is a solvent?
4. What is a solute?

Test for Learning Objective 19

1. When you pour sugar in a glass with water, you are preparing a solution, where: ___
   a. Sugar is the solvent and water is the solute
   b. Sugar is the solute and water is the solvent
   c. Sugar is the solute and sweetened water is the solvent
   d. Sugar is the solvent and sweetened water is the solute

Learning Objective 20: Define and differentiate the terms acid and base.

Listen to Learning Objective 20

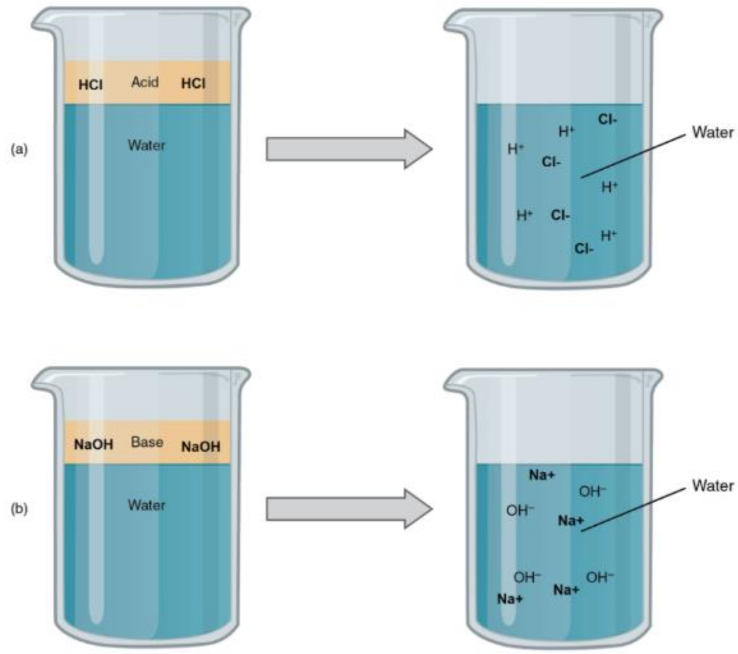
An **acid** is a substance or compound that releases hydrogen ions (H^+) when in solution. In a strong acid, such as hydrochloric acid (HCl), all hydrogen ions (H^+), and chloride ions (Cl^-) dissociate (separate) when placed in water and these ions are no longer held together by ionic bonding. In a weak acid, such as carbonic acid (H_2CO_3), only some of the ions dissociate into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-), while others are still held together by ionic bonding.

A **base** is a substance that releases hydroxyl ions (OH^-) when in solution. The hydroxyl ions (OH^-) released will combine with any hydrogen ions (H^+) in the solution to form water molecules ($OH^- + H^+ = H_2O$), so we can also define a **base** as a substance that takes or accepts hydrogen ions (H^+) already present in the solution.

Sodium hydroxide (NaOH) is a strong base because when placed in water, it dissociates completely into sodium ions (Na^+) and hydroxyl ions (OH^-), all of which are now released and dissolved in water.

Acids, bases and salts, dissociate (separate) into ***electrolytes*** (ions) when placed in water. Acids dissociate into H^+ and an anion, bases dissociate into OH^- and a cation, and salts dissociate into a cation (that is not H^+) and an anion (that is not OH^-).

Figure 2.16 (a) In aqueous (watery) solution, an acid dissociates into hydrogen ions (H^+) and anions. Every molecule of a strong acid dissociates, producing a high concentration of H^+. (b) In aqueous solution, a base dissociates into hydroxyl ions (OH^-) and cations. Every molecule of a strong base dissociates, producing a high concentration of OH^-. Art derivative of [OpenStax College](#)–[CC-BY](#)



When an acid and a base react (combine) releasing equal quantities of H^+ ions and OH^- ions, **neutralization** results. H^+ ions and OH^- ions combine (neutralize each other) to regenerate water.

Review Questions for Learning Objective 20

Write your answer in a sentence form. (Do not answer using loose words)

1. What is an acid?
2. What is a base?

Test for Learning Objective 20

1. A(n) ___ is a substance that releases hydrogen ions when is solution.
   a. Electrolyte
   b. Acid
   c. Base
   d. Salt

Learning Objective 21: Define the terms pH, neutral, acidic, and basic (or alkaline).

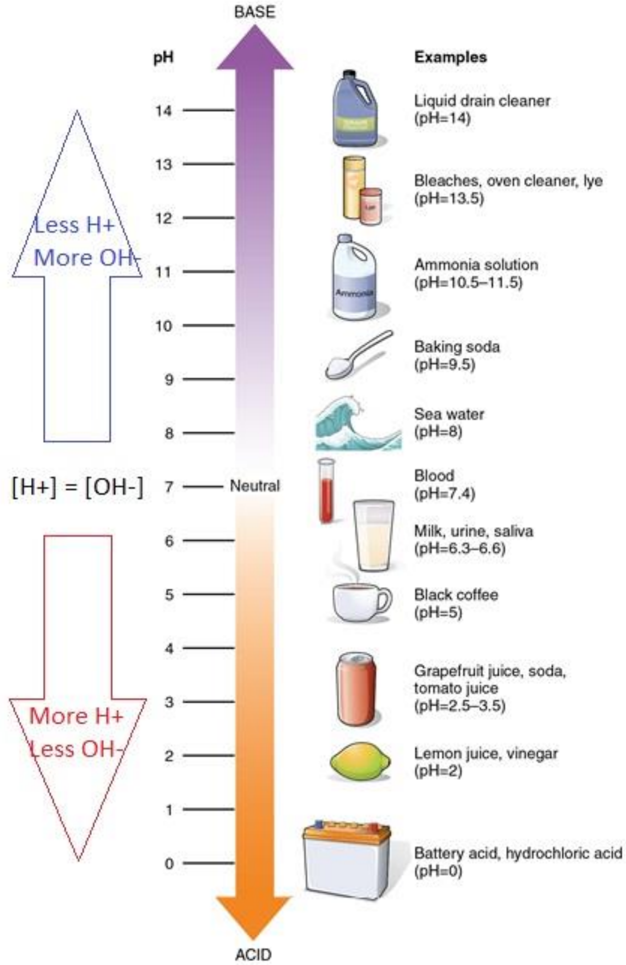
Listen to Learning Objective 21

pH is a unit of measurement of the concentration of hydrogen ions (H^+) and hydroxyl ions (OH^-) in an aqueous (water) solution. Pure water is said to be **neutral with a pH of 7**, because there are very few H^+ and OH^- ions in equal concentrations (only 1 in 10,000,000 water molecules dissociate to H^+ and OH^-, which gives a pH of 7). Adding equal amounts of H^+ and OH^- to water will also be neutral with a pH of 7, because most of these ions combine to form water molecules and the remaining H^+ and OH^- ion concentration is equal and very low.

When H^+ concentration is higher than OH^- concentration, the solution is **acidic**, and the pH of the solution is indicated with a number *below* 7. Saliva, coffee, lemon juice, tomato juice, and the acid in a battery are all acidic, so in all of them the concentration of H^+ is higher than the concentration of OH^-. The more H^+ in a solution the more acidic and the lower is its pH (See Figure 2. 17 below).

When H^+ concentration is lower than OH^- concentration, the solution is **basic** or **alkaline**, and the pH of the solution is indicated with a number *above* 7. Blood, baking soda, ammonia and bleaches are all basic, so in all of them the concentration of H^+ is lower than the concentration of OH^-.

Figure 2.17
pH of various solutions. The lower the pH, the more hydrogen ions (H^+) the solutions has. The higher the pH, the less hydrogen ions the solution has.
Art derivative of [OpenStax College](#)–[CC-BY](#)



Watch this video to review acid, base, and pH scale: https://youtu.be/t5eUOXm-wiE

Review Questions for Learning Objective 21

Write your answer in a sentence form. (Do not answer using loose words)

1. What is pH?
2. What is a neutral solution?
3. What is an acidic solution?
4. What is a basic (or alkaline) solution?

✍ Test for Learning Objective 21

1. A pH of 9 indicates a(n) ___ solution
   A pH of 6 indicates a(n) ___ solution
   A pH of 7 indicates a(n) ___ solution
   A pH of 5 indicates a(n) ___ solution
   A pH of 12 indicates a(n)___ solution

2. Lemon juice has an acidic pH. Which of the following pHs could be lemon juice's pH?
   a. 12.4
   b. 10.8
   c. 7.1
   d. 2.4

3. Which of the following is the most acidic pH?
   a. 2.5
   b. 1.9
   c. 6.2
   d. 3.5

4. Which of the following is the most alkaline pH?
   a. 4.5
   b. 11.9
   c. 7.2
   d. 3.5

Learning Objective 22: Define the term buffer, and compare the response of a regular solution with a buffer solution to the addition of acid or base.

Listen to Learning Objective 22

Chemical reactions in the body, the food we eat, medication we take, and the effects of some diseases can add or remove hydrogen or hydroxyl ions in or from our body fluids. Levels of these ions, especially H^+ since body cells are constantly producing H^+ as a waste product of cell activity, must be maintained within a normal range (slightly alkaline pH between 7.35 and 7.45,). Then, all cells in our body depend on homeostatic regulation of acid-base balance to maintain pH within optimal living conditions.

There are several homeostatic mechanisms to maintain pH within optimal conditions. pH can be regulated by the internal availability of substances (chemicals) by adjusting breathing rate, and by eliminating chemicals in urine.

Chemical buffers in the body are substances that resist changes in pH. For example, during exercise muscle cells may produce excess lactic acid, which increases hydrogen ions (acids release hydrogen ions). These hydrogen ions tend to make our body fluids more acidic, but chemical buffers in the body absorb those hydrogen ions preventing a pH change. Bicarbonate, phosphates, and proteins work as chemical buffers in our body fluids. They absorb extra hydrogen ions or extra hydroxyl ions released from the things we make or eat.

See below a table comparing what happens when acid or base are added to a solution without buffering properties, or to a solution that absorbs hydrogen ions or hydroxyl ions (with buffering properties).

Table 2.2
Comparison between a regular solution without buffering properties and a buffer solution with buffering properties

	Regular solution (*without* buffering properties)	**Buffer solution (*with* buffering properties)**
When acid is added, it releases hydrogen ions and …	the pH drops and the solution becomes more acidic	the pH does not drop
When base is added, it absorbs hydrogen ions (or releases hydroxyl ions) and …	the pH rises and the solution become more basic (alkaline)	the pH does not drop

Review Questions for Learning Objective 22

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a buffer?
2. What happens to the pH of a plain solution when acid is added to it?
3. What happens to the pH of a buffer solution when acid is added to it?

Test for Learning Objective 22

1. A substance, or a system, that can absorb extra hydrogen ions or extra hydroxide ions, preventing a change in pH is called ___.
   a. Acid
   b. Buffer
   c. Base
   d. Alkaline solution

2. When we add a base to an unbuffered solution, its pH ___
   a. Increases
   b. Decreases
   c. Stays the same
   d. First increases and then decreases

3. When we add a base to a buffered solution, its pH ___
   a. Increases
   b. Decreases
   c. Stays the same
   d. First decreases and then increases

UNIT 3 • *Molecular Level: Biomolecules, the Organic Compounds Associated with Living Organisms*

MODULE 8: *Organic Compounds*

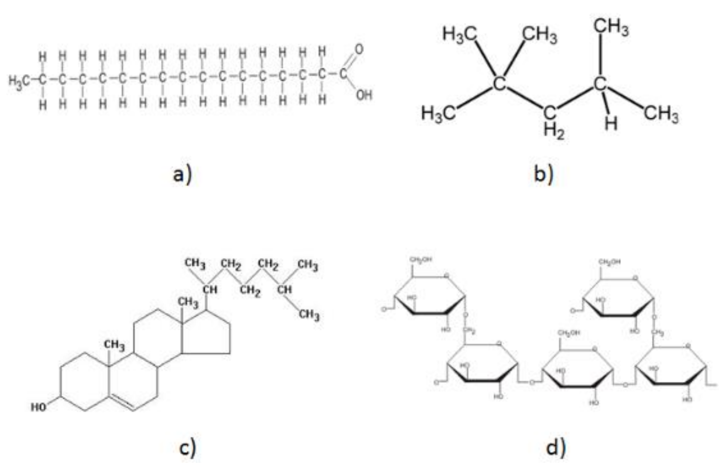
Learning Objective 23: Define the terms organic compound and macromolecule, and list the four groups of organic compounds found in living matter.

Listen to Learning Objective 23

Animal tissues, plant tissues, bacteria, and fungi contain organic molecules; horns and nails, fallen leaves, eggs, fruits and vegetables contain organic compounds; wood, milk, paper, petroleum and gasoline contain organic compounds. In summary, all living matter, parts or products of living matter and remains of living matter contain organic compounds. Organic molecules associated with living organisms are also called **biomolecules**.

Organic compounds are molecules that contain carbon atoms covalently bonded to hydrogen atoms (C-H bonds). Many organic compounds are formed from chains of covalently-linked carbon atoms with hydrogen atoms attached to the chain (a hydrocarbon backbone). This means that all organic compounds have in common the presence of carbon atoms *and* hydrogen atoms. In addition, different organic compounds may contain oxygen, nitrogen, phosphorous, and other elements. Carbon dioxide (CO_2) does not have hydrogen; then, it is not an organic compound. Water (H_2O) has no carbon; then, it is not an organic compound. Sodium chloride has neither carbon nor hydrogen; then, it is not an organic compound. Generally, gases, and mineral salts (inorganic substances found in soil, or bodies of water or watercourses) are not organic.

Figure 3.1 Organic molecules have a diversity of shapes and sizes due to carbon's ability to form four covalent bonds. Carbon can form long chains (such as the fatty acid seen in a); branched chains (as seen in b); rings (such as the cholesterol seen in c); or branched chains of rings (as the seen in d). Art by Art by Open Learning Initiative CC-BY-NC-SA



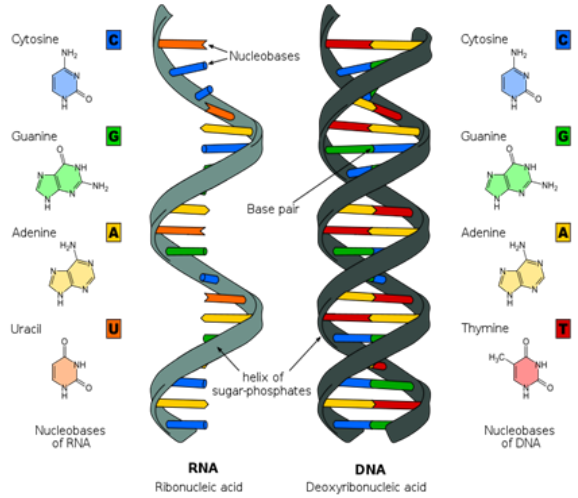
Most organic compounds making up our cells and body belong to one of four classes: **carbohydrates, lipids, proteins, and nucleic acids**. These molecules are incorporated into our bodies with the food we eat. In general, molecules in these four classes are very large, and we often call large molecules **macromolecules** (macro- = "very large", or "on a large scale").

Figure 3.2
Carbohydrate-rich food.
Art by HealthClub

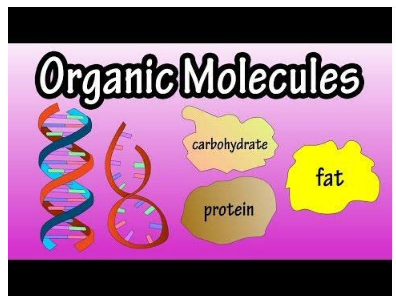
Figure 3.3
Protein-rich food.
Art by Gooddietplan

Figure 3.4
Lipid-rich food.
Art by NationalCancerInstitute – Public Domain

Figure 3.5
Two types of nucleic acids, RNA and DNA.
Art by Art by [Open Learning Initiative](#) [CC-BY-NC-SA](#)



Watch this video to review what an organic compound is, and preview some characteristics of the four groups of organic compounds: https://youtu.be/MqO3_270X-s



Review Questions for Learning Objective 23

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a biomolecule?
2. What is an organic compound?
3. What is a macromolecule?
4. What are the four classes of biomolecules found in living things?

Test for Learning Objective 23

1.
2. What substance is *not* organic?
   a. The horn of a bull
   b. The bark of a tree
   c. A boulder
   d. A rat
3. What substance is organic?
   a. A fatty acid
   b. A mineral
   c. CO_2
   d. H_2O

4. This substance is *not* an organic compound: ___
   a. CH_4
   b. $C_6H_{12}O_6$
   c. NaOH
   d. $C_{257}H_{383}N_{65}O_{77}S_6$

5. The classes of biomolecules associated with living things are:___
   a. Lipids and carbohydrates
   b. Lipids, carbohydrates, and water
   c. Lipids, carbohydrates, proteins, and nucleic acids
   d. Lipids, carbohydrates, proteins, nucleic acids, and water

Learning Objective 24: Define functional groups and give examples.

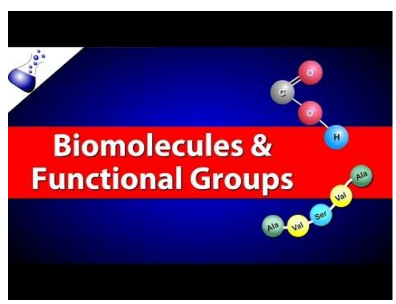
Listen to Learning Objective 24

Number of carbons that form the backbone of an organic compound, and shape of it (long chain, branched chain, ring) are not the only features that determine organic compounds properties. Groups of atoms of other elements associated to the carbon backbone give unique properties to the millions of different types of organic molecules. A specific group of atoms linked by strong covalent bonds is called a **functional group**. There are many important functional groups in human physiology. Some of them are hydroxyl, carboxyl, amino, methyl and phosphate groups.

Table 3.1
Functional groups important in human physiology.
Derivative of OpenStaxCollege – CC-BY

Functional group	Molecular Formula	Importance
Hydroxyl	-OH	Hydroxyl groups are polar. They are especially common in carbohydrates
Carboxyl (Acid)	-COOH	Carboxyl groups are polar. They are found within fatty acids, amino acids (building blocks of proteins), and many other organic acids.
Amino	$-NH_2$	Amino groups are polar. They are found within amino acids (building blocks of proteins).
Methyl	$-CH_3$	Methyl groups are not polar. They are found in many organic compounds.
Phosphate	$-PO_4^{2-}$	Phosphate groups are polar. They are found within phospholipids (building blocks of cell membranes), nucleotides (building blocks of nucleic acids), and many proteins.

Watch this video to review biomolecules (organic compounds) and functional groups: https://youtu.be/OGD3q1eQ1TE



Review Questions for Learning Objective 24

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a functional group?

Test for Learning Objective 24

1. The molecular formula .–OH is the formula of the function group ___.
2. The molecular formula -COOH is the formula of the function group ___.
3. The molecular formula $-NH_2$ is the formula of the function group ___.
4. The molecular formula $-PO_4^{2-}$ is the formula of the function group ___.

Learning Objective 25: Differentiate between substrate and product, and define chemical equation.

Listen to Learning Objective 25

Chemical reactions begin with one or more substances that enter into the reaction. The substances in our cells and body tissues that enter into the reaction are called **substrates**. The one or more substances produced by a chemical reaction are called **products**.

Chemical reactions are represented by **chemical equations** by placing the substrate(s) on the left and the product(s) on the right. Substrate(s) and product(s) are separated by an arrow (→) which indicates the direction and type of the reaction. For example, lactose, the sugar found in milk, is broken down by our digestive system into two smaller sugars, glucose and galactose. In this reaction, lactose is the substrate, and glucose and galactose are the products. The chemical equation for this reaction is:

Lactose → Glucose + Galactose

Review Questions for Learning Objective 25

Write your answer in a sentence form. (Do not answer using loose words)

1. What is the difference between a substrate and a product?
2. What is a chemical equation?

Test for Learning Objective 25

1. In the chemical reaction A + B → AB, A and B are the ___.
2. In the chemical reaction XW → X + W, X and W are the ___.

Learning Objective 26: Define metabolism, synthesis (anabolic), decomposition (catabolic), and exchange reactions.

Listen to Learning Objective 26

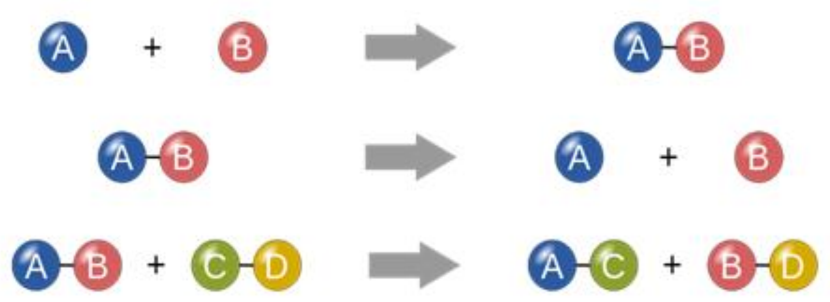
Metabolism refers to the sum of all chemical reactions happening in a living organism. There are three main types of chemical reactions important in human physiology, synthesis (anabolic), decomposition (catabolic) and exchange.

In a **synthesis reaction** (syn- = together; -thesis = "put, place, set"), two or more substrate molecules covalently bond to form a larger product molecule. Synthesis reactions ***require*** energy to form the bond(s). A synthesis reaction is often symbolized as **A + B → AB**, where A and B are the substrates, and AB is the product. Synthesis reactions can also be called **anabolic** or constructive activities in a cell.

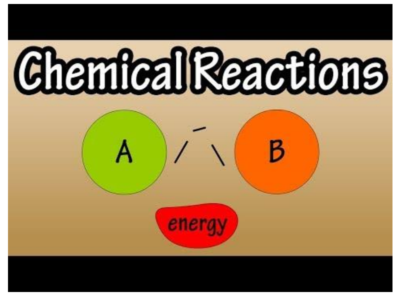
In a **decomposition reaction** (de- off, away= -composition = "putting together, arranging"), covalent bonds between components of a larger substrate molecule are broken down to form smaller product molecules. Decomposition reactions ***release*** energy when covalent bonds in the substrate are broken down. A decomposition reaction is often symbolized as **AB → A + B**; where AB is the substrate, and A and B are the products. Different types of decomposition reactions may also be referred to as digestion, hydrolysis, breakdown, and degradation reactions. Decomposition reactions are the basis of all **catabolic**, or breakdown activities in a cell.

In an exchange reaction, covalent bonds are both broken down and then reformed in a way that the components of the substrates are rearranged to make different products. An exchange reaction is often symbolized as **AB + CD → AC + BD.** In this exchange reaction, the covalent bonds between A and B, and between C and D were broken; and new covalent bonds between A and C, and B and D were formed.

Figure 3.6
Representation of three types of chemical reactions. From top to bottom: synthesis, decomposition, and exchange.
Derivative of Aushulz – CC-BY-SA



Watch this video to review chemical reactions: https://youtu.be/7BYkPWwNE00



Review Questions for Learning Objective 26

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a synthesis reaction?
2. How can a synthesis reaction be represented by using letters?
3. What is an anabolic reaction?
4. What is a decomposition reaction?
5. How can a decomposition reaction be represented by using letters?
6. What is a catabolic reaction?
7. What is an exchange reaction?
8. How can an exchange reaction be represented by using letters?
9. What is a metabolism reaction?
10. What is metabolism?

Test for Learning Objective 26

1. Which of the following represents a decomposition reaction?
   a. XY → XY + X + Y
   b. XY + X → XY + Y
   c. XY → X + Y
   d. X + Y → XY
2. Which of the following represents a synthesis reaction?
   a. XZ + X → XZ + Z
   b. YZ → YZ + Y + Z
   c. X + Z → XZ
   d. XZ → X + Z
3. Which of the following represents an exchange reaction?
   a. WZ → W + Z
   b. W + Z → WZ
   c. XY + WZ → XW + YZ
   d. XY + WZ → YZ + XW
4. Which reactions refer to all chemical reactions happening in the body?
   a. anabolic reactions
   b. synthesis reactions
   c. metabolic reactions
   d. catabolic reactions

Learning Objective 27: Differentiate between reversible reactions and irreversible reactions.

Listen to Learning Objective 27

Some metabolic reactions are called **irreversible reactions.** This means that the product(s) cannot be changed or "reversed" back into substrates. These reactions are represented with a single arrow as in A+B→C.

For example:

Glucose + Oxygen→ Carbon dioxide + Water

Note: This is a type of catabolic reaction (the larger glucose molecule is broken down to smaller carbon dioxide molecules) related to cellular energy production. In animal cells, such as humans, this is an irreversible reaction.

Other metabolic reactions are called **reversible reactions**. This means that the reaction can proceed from substrates to product(s) or from product(s) back to substrates. The product(s) can be changed back into or "reversed" into substrates. They are represented with a double arrow as in A+B⇔C+D.

For example:

Glycogen + Water ⇔Glucose

Note: When cells need energy, glycogen (a larger molecule used as an energy store in some cells) can be catabolized to smaller glucose molecules, which can then be further catabolized to provide energy for cell functions. When cells do not need as much energy, or when glucose levels are very high, glycogen is synthesized from the smaller glucose molecules. For example, muscle cells synthesize glycogen when resting and catabolize glycogen when contracting. Which way this reversible reaction proceeds depends on body needs.

Review Questions for Learning Objective 27

Write your answer in a sentence form. (Do not answer using loose words)

1. What does it mean that a reaction is irreversible?
2. What does it mean that a reaction is reversible?

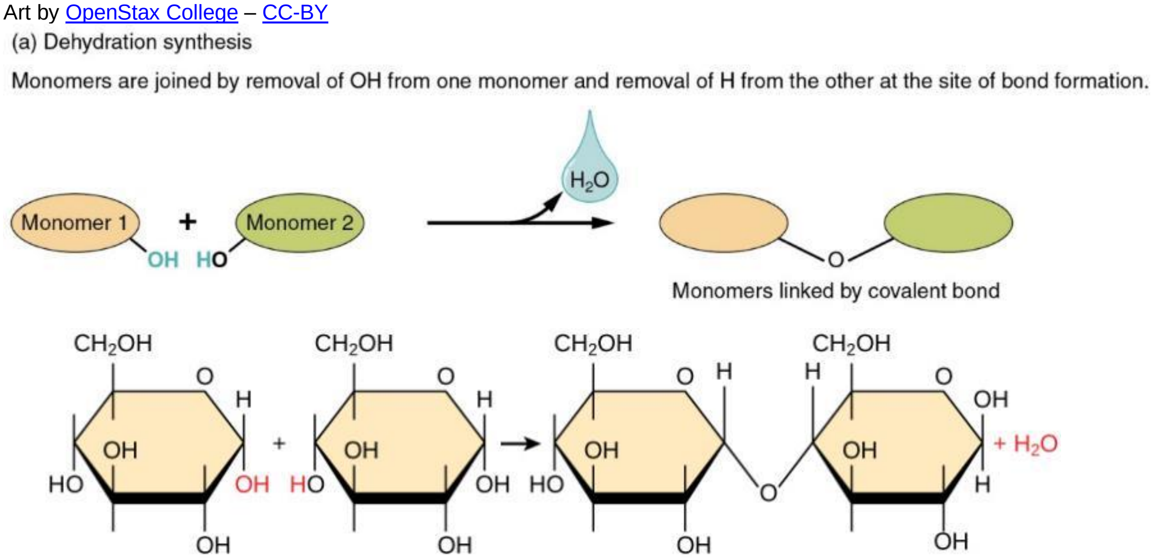
Learning Objective 28: Explain dehydration synthesis and hydrolysis reactions.

Listen to Learning Objective 28

In the body, synthesis reactions (smaller molecules to larger molecule, requires energy) and decomposition reactions (larger molecule to smaller molecules, releases energy) are often associated with the formation and breakdown of water molecules, respectively. A **dehydration synthesis** reaction is a type of synthesis reaction that **makes water** as a byproduct. A **hydrolysis** reaction is a type of decomposition reaction that **uses water**.

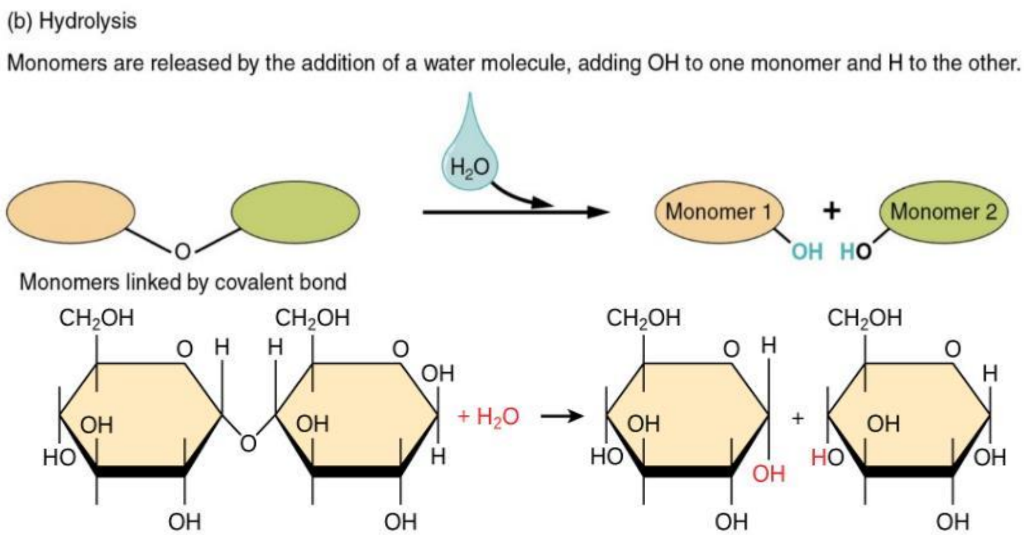
In the **dehydration synthesis** (de- = "off, remove"; hydrate = "water") shown in figure 3.7, two monomers are covalently bonded in a reaction in which one gives up a hydroxyl ion ($-OH^-$) and the other a hydrogen ion ($-H^+$). Monomer 1 and monomer 2 are the substrates on the left, and the "monomers linked by a covalent bond" is the product on the right. The product shown here is also called a dimer (di- = two, mer = part). OH^- and H^+ combine to *form a molecule of water*, which is released as a byproduct. This can be confusing because water is made during dehydration synthesis. The larger product has been dehydrated (lost the water).

Figure 3.7
Example of **dehydration synthesis**: two glucose molecules (substrates on the left of the arrow) form a covalent bond to form a maltose molecule (product on the right of the arrow). The OH^- and H^+ shown in red combine with each other to form H_2O (shown in red too).
Art by OpenStax College – CC-BY



In the **hydrolysis reaction** shown in figure 3.8, (hydro- = "water"; -lysis = "breaking-down, a loosening, a dissolution") the covalent bond between two monomers is split by the addition of a hydrogen ion (H^+) to one and a hydroxyl ion (OH^-) to the other. These two ions come from splitting a water molecule, H_2O, into H^+ and OH^-. The dimer (monomers linked by a covalent bond on the left) is the substrate, and monomer 1 and monomer 2 on the right are the products.

Figure 3.8
Example of **hydrolysis reaction**: a covalent bond (-O-) in a maltose molecule (substrate on the left of the arrow) is broken to form two glucose molecules (the products on the right of the arrow). The H_2O is used to add OH^- and H^+ (shown in red) to the two glucose molecules.
Art by OpenStax College – CC-BY



Review Questions for Learning Objective 28

Write your answer in a sentence form. (Do not answer using loose words).

1. What is a dehydration synthesis reaction?
2. What is a hydrolysis reaction?

Test for Learning Objective 28

1.
2. Hydrolysis reactions are associated with the formation of a water molecule (T/F)
3. Hydrolysis reactions are associated with synthesis reactions (T/F)
4. Dehydration synthesis is associated with the splitting of a covalent bond (T/F)
5. This chemical equation represents a dehydration reaction: ___

a. $C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11} + H_2O$
b. $C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$
c. $H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6 + C_{12}H_{22}O_{11}$
d. $H_2O + C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11}$

Learning Objective 29: Explain the relationship between monomers and polymers.

Listen to Learning Objective 29

Large molecules composed of hundreds or thousands of atoms are called macromolecules. Many macromolecules are composed of repetitive units of the same building block, similar to a pearl necklace that is composed of many pearls. **Polymers** (poly- = "many"; meros = "part") are long chain, large organic molecules (macromolecules) assembled from many covalently bonded smaller molecules called **monomers**. Polymers consist of many repeating monomer units in long chains, sometimes with branching or cross-linking between the chains.

Three of the four classes of organic molecules previously identified, i.e., carbohydrates, lipids, proteins, and nucleic acids are often polymers made of smaller monomer subunits (lipids are not). For example, proteins are polymers made of many covalently bonded smaller molecules, monomers, called amino acids. Each of these classes is considered in more detail below.

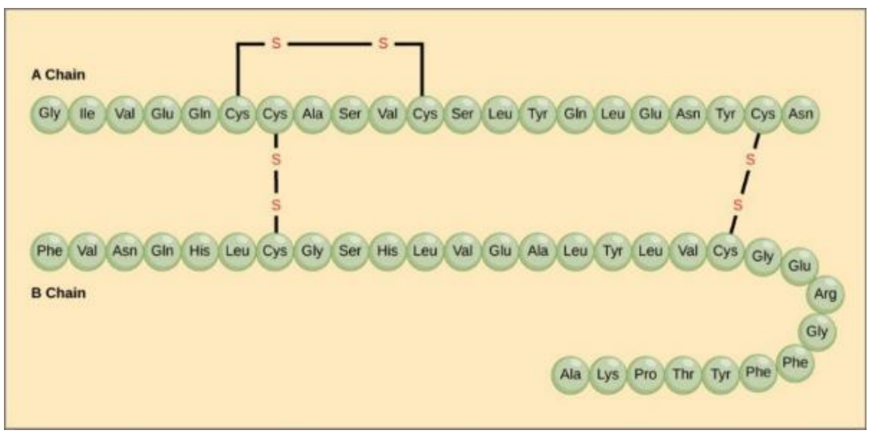
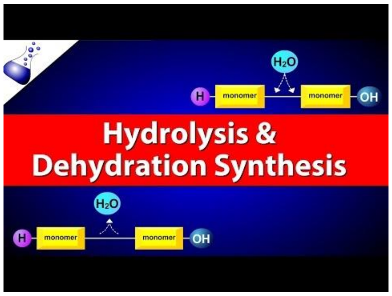


Figure 3.9
Two-dimensional view of the protein insulin. Insulin is a polymer made of covalently linked monomers called amino acids (shown as green balls).
Art by OpenStax College CC-BY

Watch this video to review monomers, polymers, and see how they relate with dehydration synthesis, and hydrolysis: https://youtu.be/ZMTeqZLXBSo



Review Questions for Learning Objective 29

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a polymer?
2. What is a monomer?

Test for Learning Objective 29

1. A polymer is a large size molecule (T/F)
2. A polymer is a macromolecule (T/F)
3. Polymers are the building blocks of monomers (T/F)

4. A polymer is a___
   a. monomer composed of many repetitive units linked together by covalent bonds
   b. macromolecule composed of many repetitive units linked together by covalent bonds
   c. monomer composed of many repetitive units linked together by ionic bonds
   d. macromolecule composed of many repetitive units linked together by ionic bonds

Learning Objective 30: Describe the general molecular structure of carbohydrates, and identify their monomers and polymers; list the three subtypes of carbohydrates, and describe their structure and function.

[Listen to Learning Objective 30]

Carbohydrates (carbo- = "carbon"; hydrate = "water") contain the elements carbon, hydrogen, and oxygen, and only those elements with a few exceptions.

The ratio of carbon to hydrogen to oxygen in carbohydrate molecules is 1:2:1. The component carbon (C, carbo-) and the component water (H_20, -hydrate) give the name to this group of organic molecules.

Carbohydrates are classified into three subtypes: **monosaccharides**, (mono- = "one", "alone"; saccharide = "sugar, sweet") **disaccharides** (di = "two"), and **polysaccharides**. (poly- = "many, much"). Monosaccharides and disaccharides are also called *simple* carbohydrates, and are generally referred to as sugars. Simple carbohydrates are small polar molecules, containing several –OH functional groups, which makes them *hydrophilic* (they dissolve well in water). Polysaccharides, also called *complex* carbohydrates, are large non polar molecules, and they are not hydrophilic.

The figure below shows the most common **monosaccharides**: glucose, fructose and galactose (six-carbon monosaccharides), and ribose and deoxyribose (five-carbon monosaccharides). Note that they are all named using the suffix ***–ose***, which means sugar. Carbohydrates are often named "something***ose***".

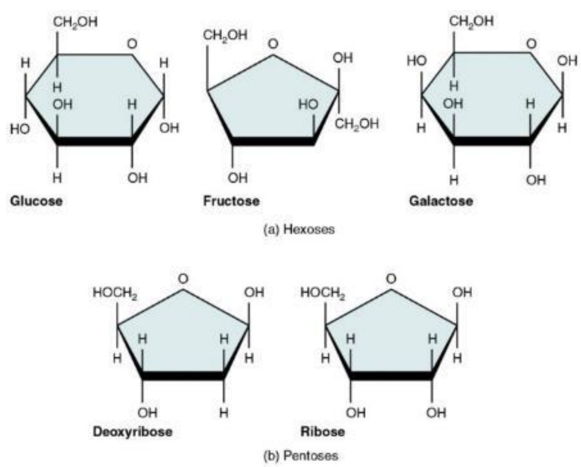
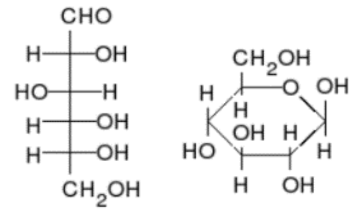


Figure 3.10
These monosaccharides respect the ration 1:2:1 mentioned above: glucose ($C_6H_{12}O_6$), fructose ($C_6H_{12}O_6$), galactose ($C_6H_{12}O_6$), ribose ($C_5H_{10}O_5$), deoxyribose ($C_5H_{10}O_4$, this one is missing an oxygen). Note that carbohydrates have lots of hydroxyl functional groups (-OH).
Art by OpenStax College – CC-BY

Figure 3.11
There are different ways to represent a glucose molecule ($C_6H_{12}O_6$). Two of the most common are straight-chain form (left) and ring form (right). Carbon atoms in the vertices are not shown.



Disaccharides form by a covalent bond between two monosaccharides. This type of bond between two monosaccharides is called a ***glycosidic*** bond, and energy is needed to form it.

Figure 3.12
The disaccharide sucrose is formed when a monomer of glucose and a monomer of fructose join in a dehydration synthesis reaction to form a glycosidic bond. In the process, a water molecule is lost (not shown in the figure). The lost water molecule is formed by -OH and -H shown in red. Oxygen forms covalent bonds with glucose on the left, and fructose on the right.

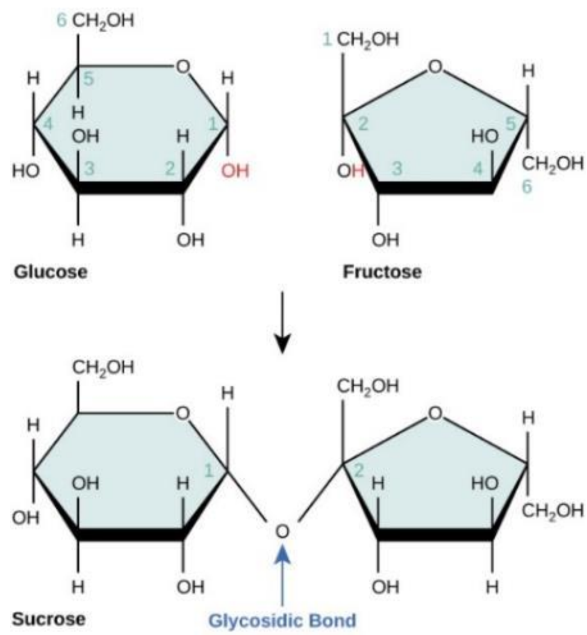
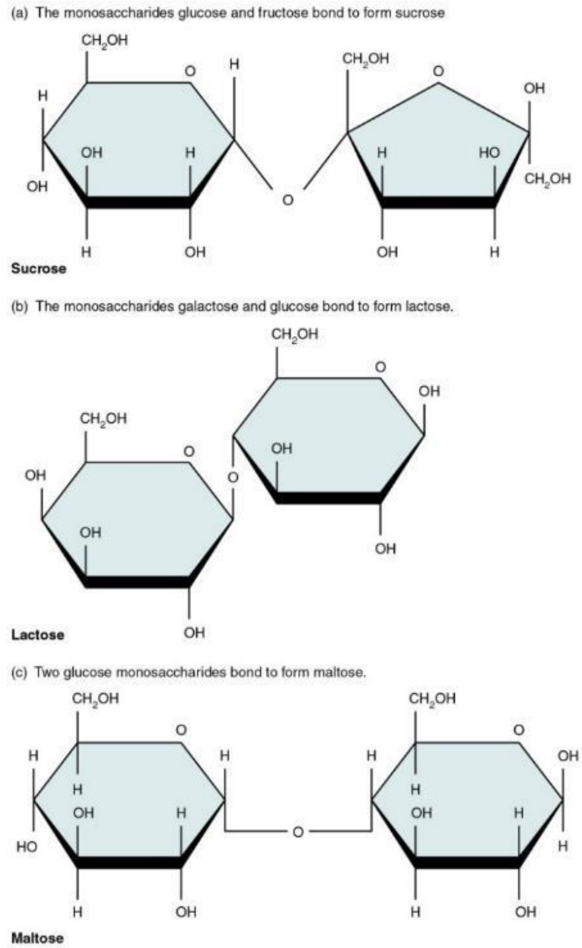


Figure 3.13 The most common disaccharides: sucrose ($C_{12}H_{22}O_{11}$), lactose ($C_{12}H_{22}O_{11}$), and maltose ($C_{12}H_{22}O_{11}$). Art by [OpenStax College](#) – [CC-BY](#)



Polysaccharides are macromolecules composed of repetitive units of the same building block, monosaccharides, similarly to a pearl necklace is composed of many pearls. We can also define polysaccharides as ***polymers*** assembled from many smaller covalently bonded ***monomers***. As shown in the Figures and Table below, three important polysaccharides in living organisms are glycogen, starch and cellulose. Glycogen and starch are used as energy stores in animal and plant cells respectively, while cellulose provides structural support in plants and fiber to our diets.

Figure 3.14
Amylose and amylopectin found in starch (a) are both polymers made of thousands of glucose molecules (the tiny clear blue hexagons in the figure) linked by covalent bonds. Glycogen (b) and cellulose (c) are also made of thousands of glucose molecules, but organized in a branched and straight pattern, respectively.

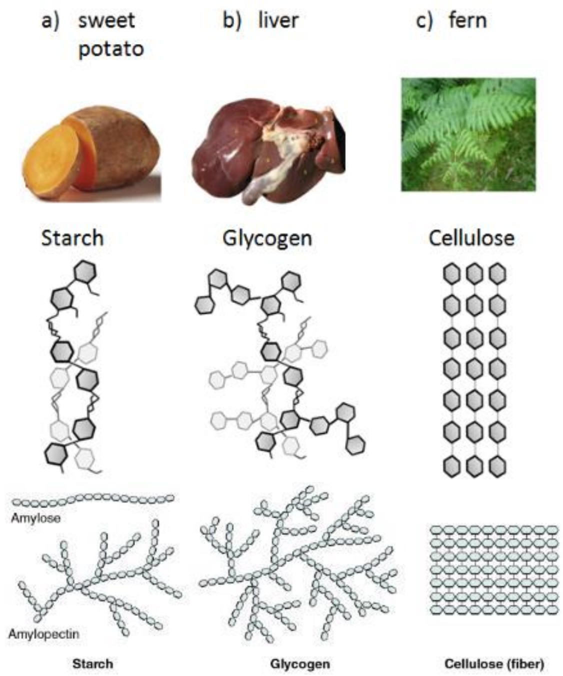
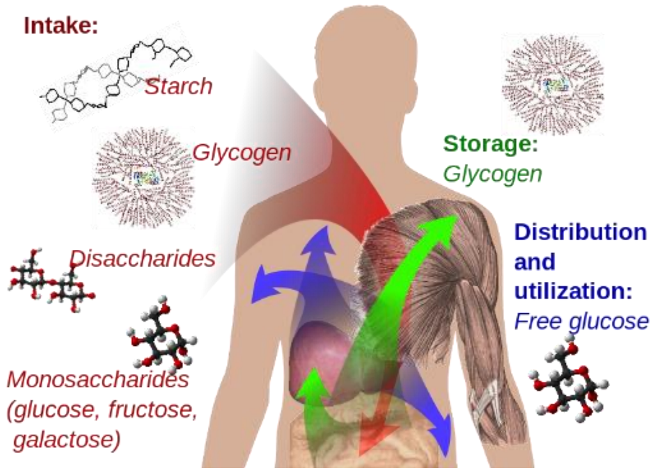


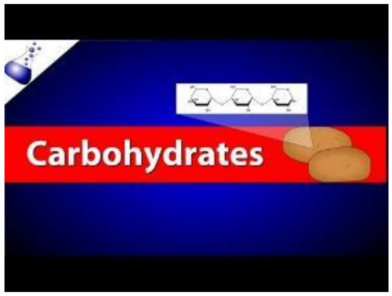
Table 3.2 Summary of types of carbohydrates, number of sugar (monosaccharide) subunits, functions, examples, and sources. Table derivative of University of Maryland University College CC-BY-NC

Type of Carbohydrates	No. of Sugar Subunits	Function	Examples and Sources
Monosaccharide (*simple sugars*)	1	Provide energy for cells	***Glucose***: many plants and fruits, honey, sport drinks; ***Fructose***: fruit, honey, sweetener in many processed foods (high-fructose corn syrup); ***Galactose***: dairy products (milk, butter, cheese, yogurt), beet; **Ribose and Deoxyribose**: nucleic acids
Disaccharide	2	Provide energy for cells	***Lactose***: dairy products; ***Sucrose***: "table sugar," sugarcane, sugar beets, candy; ***Maltose***: germinating seeds, beer
Polysaccharide (*complex carbohydrates*)	many to thousands	Store energy	***Starch***: plants, e.g., potatoes, corn, rice;
		Structural support	***Glycogen***: muscles and liver; ***Cellulose***: plants cell walls

Figure 3.15
How we use carbohydrates: we get carbohydrates in the diet as starch, glycogen, lactose, sucrose, maltose, glucose, fructose and galactose. Our blood carries glucose to most cells in our body, where it is used as a source of energy. Our body stores extra glucose as glycogen in muscles and liver.
Art by [Mikael Häggström](#) - [Public Domain](#)



Watch this video to review carbohydrates: https://youtu.be/LeOUIXbFyqk



Review Questions for Learning Objective 30

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a carbohydrate?
2. What elements are carbohydrates made of?
3. What suffix is used to name carbohydrates?
4. What is the difference in structure among monosaccharides, disaccharides, and polysaccharides?
5. List all the examples of monosaccharides, disaccharides, and polysaccharides described in the module
6. How does the body use monosaccharides, disaccharides, and polysaccharides (what is their function)?

Test for Learning Objective 30

1. A single carbohydrate unit is a ___.
2. Two carbohydrate units linked by covalent bonds form a ___.
3. Many covalently bound monosaccharides form a ___.
4. A polymer is to a monomer as glycogen is to ___.

5. Carbohydrates contain the following elements___
a. Carbon and hydrogen
b. Carbon and oxygen
c. Carbon, hydrogen, and oxygen
d. Carbon, hydrogen, oxygen, and nitrogen

6. This is a carbohydrate: ___.
a. C_6H_6
b. $C_6H_{12}O_6NS$
c. $C_5H_{10}O_5$
d. $C_2H_{12}O$

7. Which of the following is a carbohydrate?
a. Insulin
b. Adenine
c. Lactase
d. Lactose

8. This is *not* a monosaccharide: ___
a. Lactose
b. Galactose
c. Glucose
d. Fructose

9. This is *not* a disaccharide: ___
a. Galactose
b. Lactose
c. Sucrose
d. Maltose

10. These are *all* polysaccharides: ___
a. Glycogen, starch, and cellulose
b. Maltose, lactose, and sucrose
c. Fructose, galactose, and glucose
d. Glucose, sucrose, and glycogen

Learning Objective 31: Describe the general chemical structure of lipids, list three subtypes of lipids important in human functioning, and describe their structure and function.

Listen to Learning Objective 31

Lipids contain the same elements as carbohydrates: carbon, hydrogen and oxygen (C, H, and O). However, lipids are mainly made of hydrocarbon chains (or rings) and contain fewer polar hydroxyl groups (-OH). This makes most lipids nonpolar *hydrophobic* molecules (they do not dissolve well in water).

Lipids include a diverse group of organic compounds. We describe only three of them here: **triglycerides**, **phospholipids**, and **steroids**.

Triglycerides include fats and oils. They are the most common type of lipids found in our body fat tissues and, in our diet, and serve mostly as an energy store.

Triglycerides consist of one *glycerol molecule* and three *fatty acid molecules* (see Figure 3.16 below). Glycerol is an organic compound with three carbons, hydrogens, and hydroxyl (-OH) groups. Fatty acids are a long chain of carbons with hydrogens attached to them. A carboxyl (acid) (-COOH) group is attached to one end of the chain. The most common number of carbons in the fatty acid chain ranges from 12 to 18.

Figure 3.16
During triglyceride synthesis, glycerol gives up three hydrogen atoms, and the carboxyl groups on the fatty acids each give up a hydroxyl (-OH) group forming three water molecules. This is a *dehydration synthesis* reaction.

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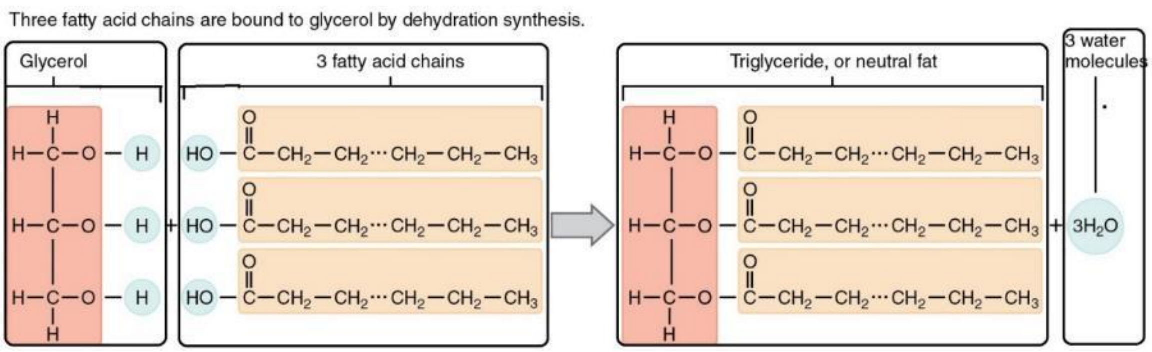

There are two classes of fatty acids: saturated and unsaturated (see Figure 3.17 below). **Saturated fatty acids** have all neighboring carbons in the hydrocarbon chain linked by single covalent bonds. This maximizes the number of hydrogen atoms attached to the carbon skeleton. Then, we say that carbons in the chain are *saturated* with hydrogens. **Unsaturated fatty acids** have at least two neighboring carbons in the hydrocarbon chain linked by double covalent bonds. This does *not* allow all carbons in the chain to maximize the number of hydrogen atoms attached to the carbon skeleton. Then, carbons in the chain are *unsaturated* (or not saturated) with hydrogens. Most triglycerides made of unsaturated fatty acids are liquid and are called oils. Triglycerides made of saturated fatty acids are semisolid at room temperature (e.g., fat in butter and meat).

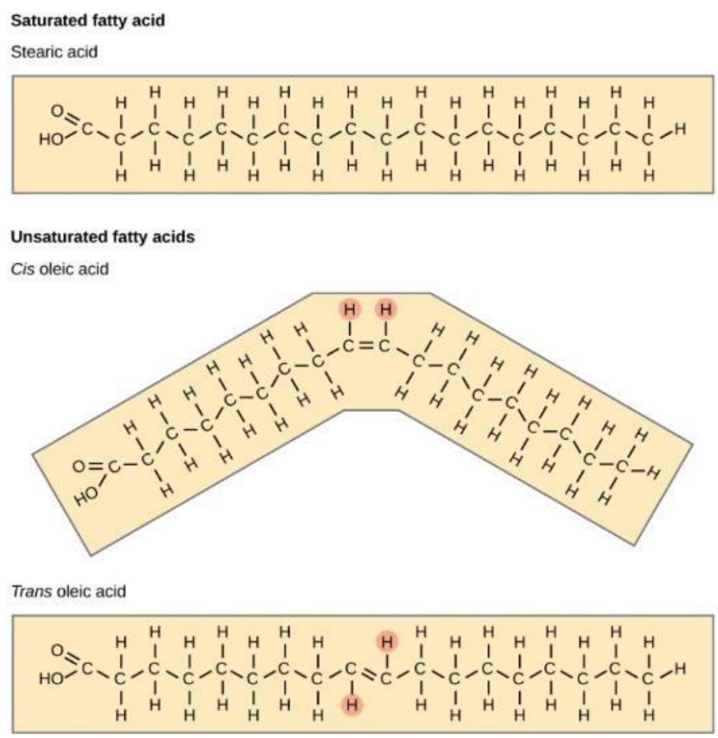

Figure 3.17
Saturated fatty acids have hydrocarbon chains connected by single bonds only. Unsaturated fatty acids have one or more double bonds. Each double bond may be in a cis or trans configuration. In the cis configuration, both hydrogens are on the same side of the hydrocarbon chain. In the trans configuration, the hydrogens are on opposite sides. A cis double bond causes a kink in the chain.

Phospholipids are the main components of cell membranes (the layer that separates inner content in a cell from the outside), and membranes inside cells (the enclosing layers that make up internal cell compartments). Phospholipids are composed of fatty acid chains attached to a glycerol backbone (see Figure 3.18 below). However, instead of three fatty acids attached as in triglycerides, they have two fatty acids. The third carbon of the glycerol backbone is bound to a modified phosphorous-containing group. The two fatty acid chains are nonpolar, so they don't interact with water, they are *hydrophobic*. The phosphorous-containing group is polar, so it does interact well with water, it is *hydrophilic*. Phospholipids are *amphipathic* molecules (amphi- = "both, both sides"; pathos = "suffering, feeling"), meaning they have a hydrophobic side and a hydrophilic side.

Figure 3.18
Phospholipids are composed of glycerol, two nonpolar hydrophobic "tails", and a polar hydrophilic "head". Phospholipids are *amphipathic* molecules.
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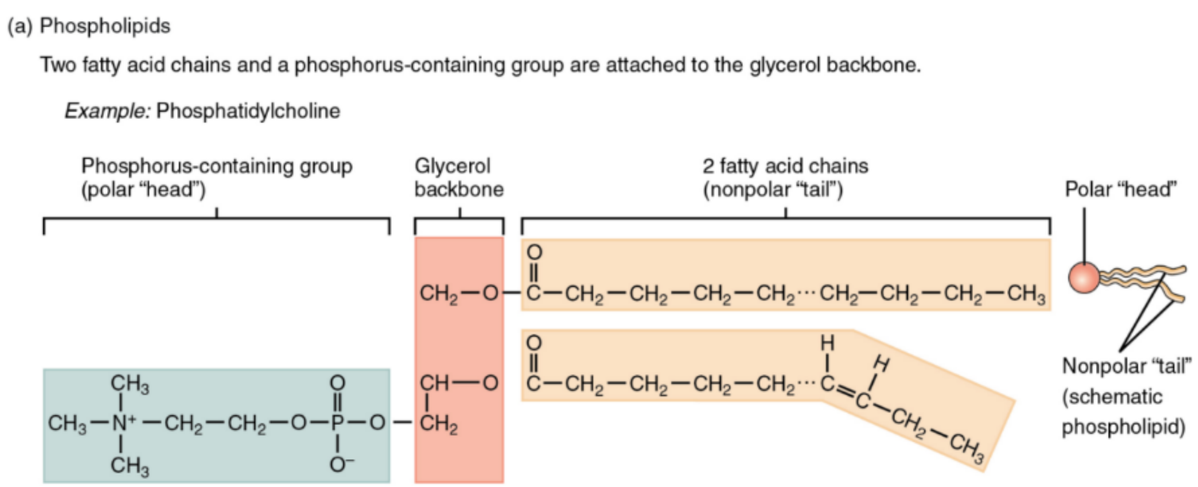

When phospholipid molecules are in an aqueous (water) solution they often form a bilayer (two layers) with the hydrophilic head groups of the phospholipids facing the aqueous solution and the hydrophobic tails in the middle of the bilayer (see Figure 3.19 below). Similarly, a phospholipid bilayer separates the internal and external aqueous environment of cells.

Figure 3.19
In a cell membrane (the surface surrounding a cell), a bilayer of phospholipids forms the basic structure. The hydrophobic fatty acid tails of phospholipids face each other, away from the water, whereas the hydrophilic phosphate groups face the outside surfaces, which are aqueous.
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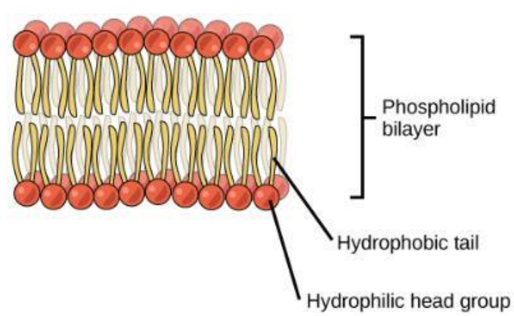
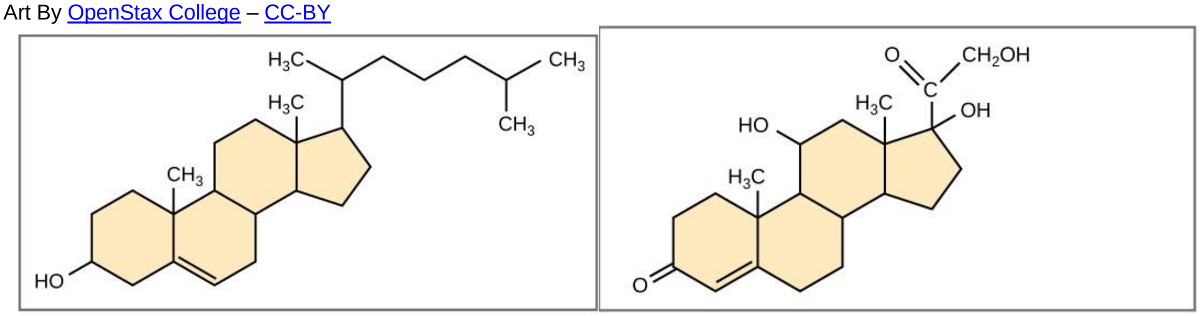


Steroids are small lipids where the hydrocarbon backbone has been linked into four rings with various functional groups attached to the rings. Steroids, like other lipids, are nonpolar and *hydrophobic. S*ee steroids structure in figure 3.20 below.

The most important steroid to human structure and function is cholesterol. Cholesterol helps provide structure to cell membranes and is a component of bile, which helps in the digestion of dietary fats. Cholesterol is also a substrate in the formation of many hormones, signaling molecules that the body releases to regulate processes at distant sites. As shown in Figure 3.20, cortisol is one of these hormones and regulates the stress response.

Figure 3.20

Structure of steroids. Cholesterol and cortisol share the same four-ring structure typical of steroids.



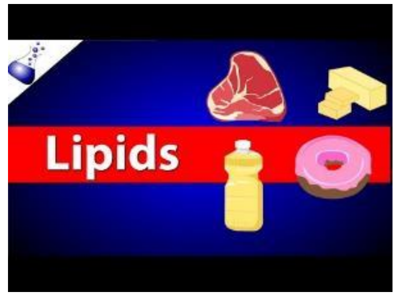
Cholesterol **Cortisol**

Table 3.3

Summary lipid's structure, functions, and examples.

Type of Lipid	Structure	General Function	Examples
Triglyceride (fats and oils)	Glycerol plus 3 Fatty acids	Stores energy for use at a later time.	Saturated fats, and unsaturated oils
Phospholipid	2 Fatty acids plus glycerol plus a phosphate group	Forms the cell membrane (layer that separates inner content in a cell from the outside), and membranes inside cells (the enclosing layers that make internal cell compartments)	Lipid bilayer membrane
Steroid	Small carbon ring molecules	Structural support of cell membranes; substrate for steroid hormone production;	Cholesterol
		steroid hormones regulate many developmental, and metabolic processes.	Cortisol, estrogen, testosterone

Watch this video to review lipids: https://youtu.be/5BBYBRWzsLA



Review Questions for Learning Objective 31

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a lipid?
2. What elements are lipids made of?
3. What are the three classes of lipids described in the module?
4. What is the difference in structure among triglycerides, phospholipids, and steroids (include a description of each one of them in your answer)?
5. What is the difference between saturated fatty acids and unsaturated fatty acids?
6. What does it mean that phospholipids are *amphipathic* molecules (include a description of a phospholipid molecule in your answer?
7. What are the functions of the different lipids?

Test for Learning Objective 31

1. Fatty acids are hydrophilic molecules (T/F)
2. Lipids are organic molecules (T/F)
3. Fats and oils are triglycerides (T/F)
4. Lipids contain carbon, hydrogen, and oxygen (T/F)
5. Saturated fatty acids have all neighboring carbons in the hydrocarbon chain linked by single covalent bonds, maximizing the number of hydrogen atoms attached to the carbon skeleton (T/F)

6. This is *not* a lipid: ___
   a. monosaccharide
   b. triglyceride
   c. phospholipid
   d. steroid

7. Triglycerides and phospholipids have these components in common ____
   a. Steroids
   b. Fatty acids
   c. Disaccharides
   d. Phosphorus-containing group

8. Triglycerides ___
   a. Provide structure to cell membranes
   b. Regulate metabolic processes
   c. Store energy for use at a later time
   d. Store water for use at a later time

9. Phospholipids ___.
   a. store energy
   b. store fat
   c. form the cell membrane
   d. form the skin

10. In phospholipids ___
a. The head is hydrophobic and the tail is hydrophilic
b. The head is hydrophilic and the tail is hydrophobic
c. Both head and tail are hydrophilic
d. Both head and tail are hydrophilic

11. Cholesterol and cortisol are examples of ___
a. Fatty acids
b. Triglycerides
c. Steroids
d. phospholipids

Learning Objective 32: Describe the general chemical structure of proteins and identify monomers and polymers; and list and explain functions proteins perform.

Listen to Learning Objective 32

Proteins contain the same elements as carbohydrates and lipids: carbon, hydrogen and oxygen; plus, nitrogen (C, H, O, and N). Proteins are usually much larger than polysaccharides and triglycerides. **Proteins** are macromolecules composed of repetitive units of the same building block, **amino acids**, similar to a pearl necklace that is composed of many pearls. We can also define proteins as ***polymers*** assembled from many smaller covalently bonded ***monomers***. The type of covalent bond linking neighboring amino acids is called **peptide bond,** as shown below in figure 3.23.

Proteins carry out most of the jobs in a cell and serve the most diverse range of functions of all the organic macromolecules in our cells and body. Different proteins form parts of cell and tissue structures; regulate physiological processes; contract to move cellular or body parts; or protect cells and the whole body; they may serve in transporting gases or other substances, or as important part of membranes; or they may be working as enzymes, which perform all chemical reactions happening in our cells and body.

Protein structures, like their functions, vary greatly. However, they are all made of combinations of twenty different amino acids available in nature, and all amino acids share the same basic structure as shown in figure 3.21 below.

Figure 3.21
All amino acids have a central α carbon covalently bound to a hydrogen, an ***amino functional group (-NH₂)***, a ***carboxyl (acid) functional group (-COOH),*** and ***a side chain R***. R represents any of the twenty different functional groups found in amino acids.
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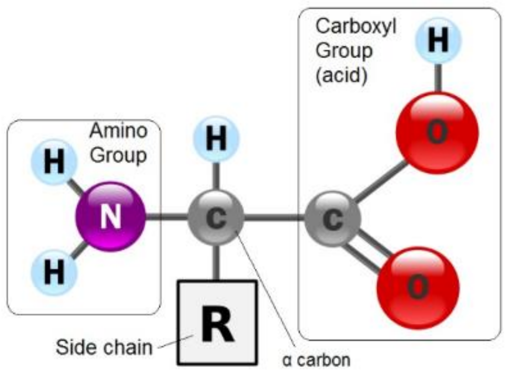

Figure 3.22
Six examples of amino acids. All amino acids have in common a central α carbon covalently bound to a hydrogen (shown on the right of the central carbon), an amino functional group (represented as $–NH_3^+$, shown on the left), a carboxyl (acid) functional group (shown on the top as $-COO^-$). Different amino acids have a different side chain R (shown on the bottom in blue)
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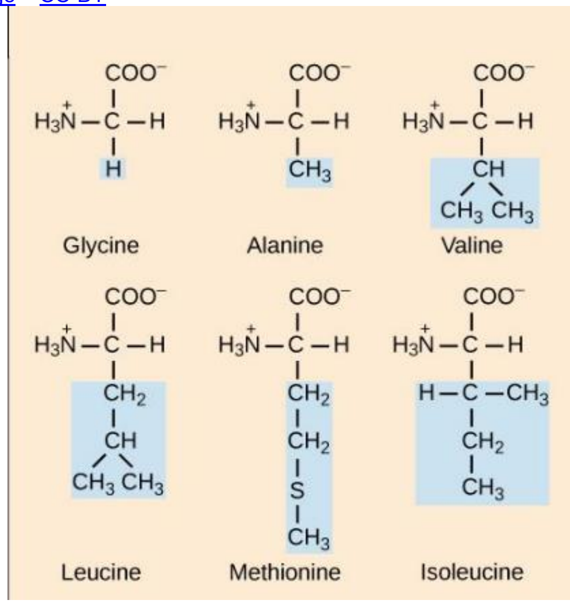

Depending on the amino acid side chain (R) different amino acids may be polar or nonpolar. The biological function of a particular protein is given by its shape, which in turn is given by the sequence and number of amino acids that form the polypeptide/s in that particular protein.

Two amino acids join to form a **dipeptide**, three amino acids form a **tripeptide**, a few amino acids form an **oligopeptide** (oligo- =few), and many amino acids form a **polypeptide**.

Figure 3.23
A dipeptide is formed when amino acid 1 and amino acid 2 are joined in a dehydration synthesis reaction to form a peptide bond. -OH from amino acid 1 and -H from amino acid 2, both shown in the red cloud, join to form a water molecule. This allows carbon of amino acid 1 on the left and nitrogen of amino acid 2 on the right to form a **peptide bond.**
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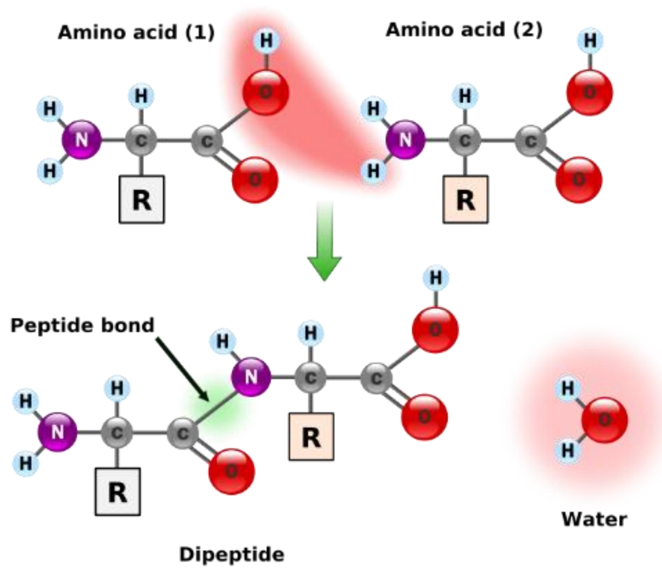

Figure 3.24
Each pearl represents an amino acid, and the whole pearl necklace represents a polypeptide. Polypeptides may have up to thousands of amino acids.
Art by National Human Genome Research Institute - Public Domain

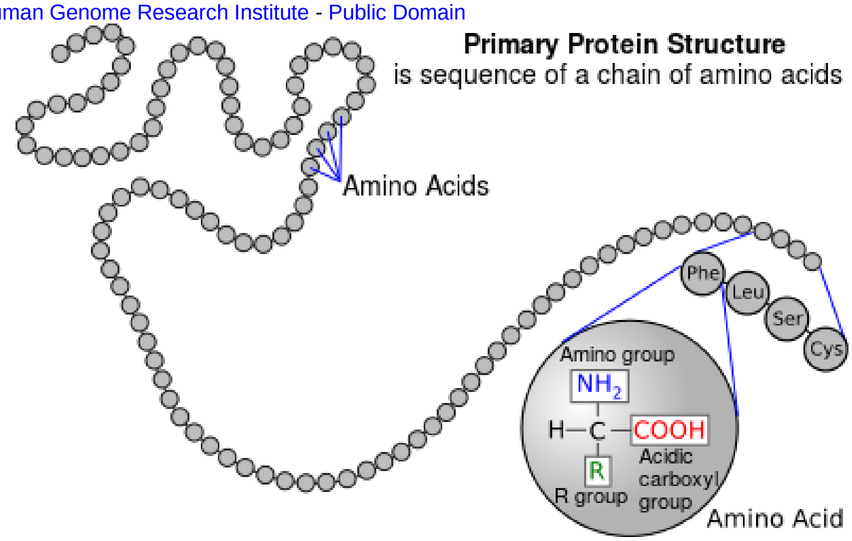

Figure 3.25
A computer generated three-dimensional representation of a protein (hexokinase) made of more than 400 amino acids. Each individual amino acid cannot be differentiated from the rest here. Each tiny ball represents an element (e.g., carbon is blue, oxygen is red, etc.).
Art by TimVickers - Public Domain

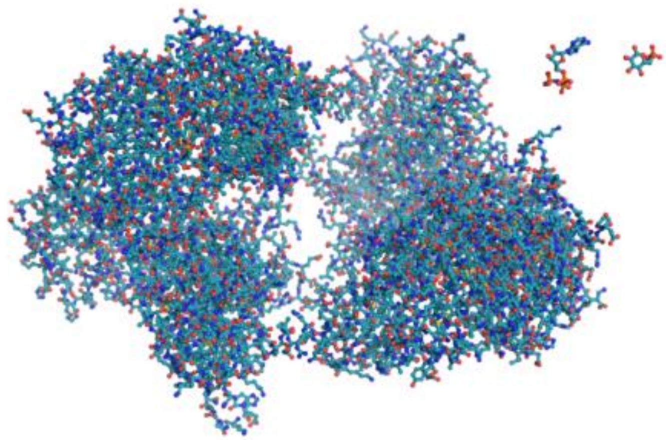

Figure 3.25B
A 3D spatial representation of the same protein shown above (hexokinase). The folding in the space of the polypeptide/s in a protein gives shape to it, and its shape determines its function.
3D model by PMID:10574795

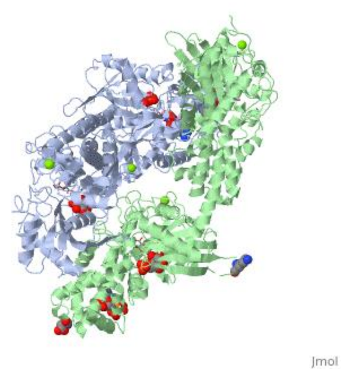

Table 3.4 Protein types, examples, and their functions
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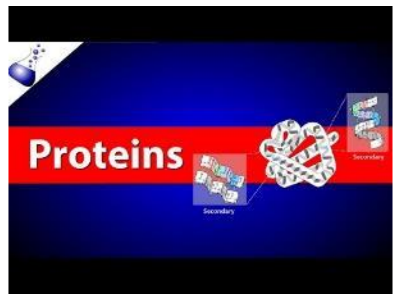
Type	Examples	Functions
Enzymes	Peptidase Lipase	Increase speed of chemical reactions in the body (all metabolic reactions)
Transport	Hemoglobin Albumin	Carry substances in the blood or lymph throughout the body

Structural	Collagen Tubulin	Provide structural support Construct different structures, like the cytoskeleton (inner skeleton in a cell)
Hormones	Insulin Oxytocin	Chemical messengers that coordinate the activity of different body systems
Defense	Immunoglobulins Complement	Protect the body from foreign pathogens
Contractile	Actin, Myosin	Participate in muscle contraction
Storage	Myoglobin Ferritin	Stores oxygen in muscle cells Stores iron in the liver

Watch this video to review proteins: https://youtu.be/AUMJwjLXh1M



Review Questions for Learning Objective 32

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a protein?
2. What elements are proteins made of?
3. What are the monomers (building blocks) of proteins?
4. What type of bond links neighboring amino acids in a protein?
5. What is the difference between the terms “polypeptide” and “protein”?
6. What are the functions of proteins listed in the module?

Test for Learning Objective 32

1.
2. What functional groups are found in all amino acids?
   a. Phosphate and Hydroxyl
   b. Carboxylic (acid) and amino
   c. Hydroxyl and carboxylic (acid)
   d. Hydroxyl and amino
3. A monomer is to a polymer as a(n) ___ is to a protein
   a. Monosaccharide
   b. Polypeptide
   c. Phospholipid
   d. Amino acid

4. Neighboring amino acids are linked by peptide bonds, which are types of ___

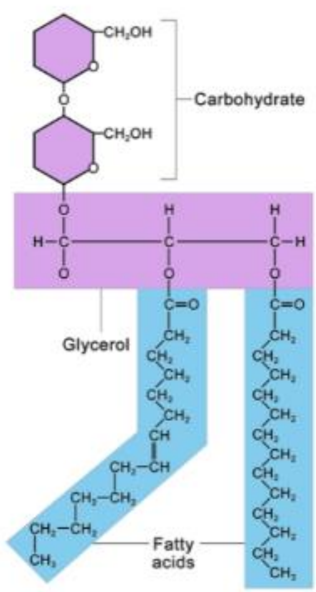
a. Ionic bonds
b. Hydrogen bonds
c. Covalent bonds
d. Weak bonds

Learning Objective 33: Define conjugated protein, lipoprotein, glycosylated molecule, glycoprotein, and glycolipid.

Listen to Learning Objective 33

Not all biomolecules are pure protein, pure carbohydrate, or pure lipid. **Conjugated proteins** are protein molecules combined with another kind of biomolecule. For example, proteins combine with lipids to form **lipoproteins**. Lipoproteins are found in in the blood, where they act as carriers for less soluble molecules, such as cholesterol. **Glycosylated molecules** are molecules to which a carbohydrate has been attached. Proteins combined with carbohydrates form **glycoproteins**. Lipids bound to carbohydrates become **glycolipids**. Glycoproteins and glycolipids, are important components of cell membranes. The second part of the name is always the largest part. For example, proteoglycans have more carbohydrate, while glycoproteins have more protein.

Figure 3.26
Lecithin, a glycolipid, is composed of a carbohydrate portion and a lipid portion (fatty acids plus glycerol part).
Art by BruceBlaus - CC BY 3.0



Review Questions for Learning Objective 33

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a conjugated protein?

2. What is a glycosylated molecule?

Test for Learning Objective 33

1. A glycolipid is made of ___
    a. A protein and a lipid
    b. A protein and a carbohydrate
    c. A lipid and a carbohydrate
    d. An amino acid and a lipid

2. This molecule is made of a protein with a carbohydrate attached to it: _____
    a. polypeptide
    b. lipoprotein
    c. glycoprotein
    d. glycolipid

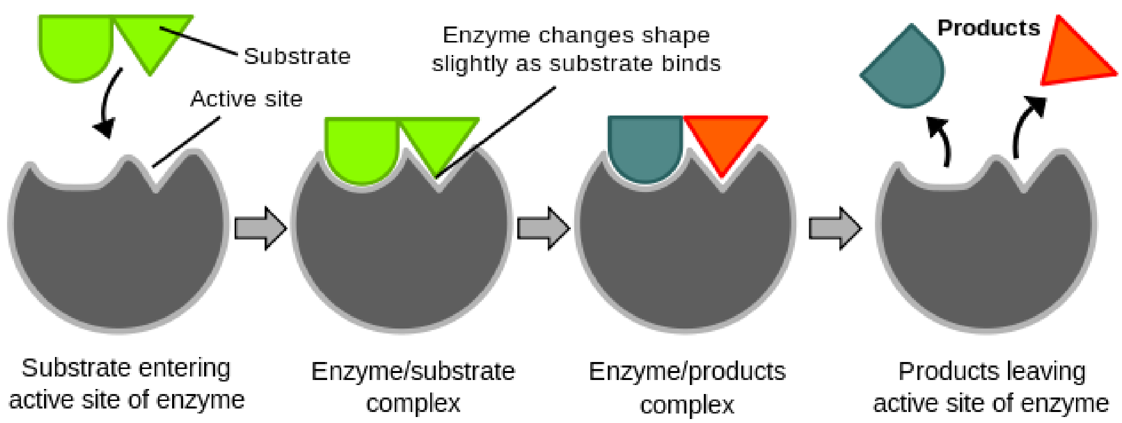
Learning Objective 34: Define enzyme, enzymatic reaction, substrate, product, and active site.

[Listen to Learning Objective 34](#)

While proteins have a diversity of important functions, many proteins work as enzymes. **Enzymes** speed up chemical reactions. We can define **enzymes** as organic catalysts (organic because proteins are organic compounds; catalyst = "substance which speeds a chemical reaction but itself remains unchanged"). Chemical reactions catalyzed by enzymes are called **enzymatic reactions**. All -or almost all- synthesis, decomposition, and exchange reactions occurring in our cells and body tissues are enzymatic reactions.

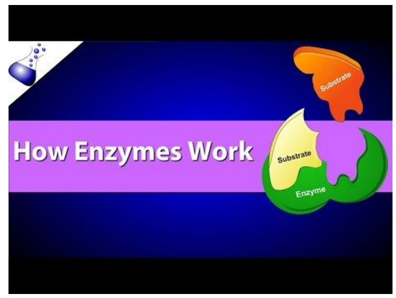
All enzymatic reactions begin with one or more substances that enter into the reaction. Substances in our cells and body tissues that enter into the reaction are called **substrates**. The one or more substances produced by an enzymatic reaction are called **products**. A substrate binds to its enzyme at the **active site** of the enzyme (a 3D space in the enzyme that matches the shape of the substrate). There is a very brief moment when an enzyme/*substrate* complex forms, which transitions into an enzyme/*product* complex. Then, once the reaction has finished, the product is released. The enzyme is not altered by the reaction, and once the product or products are released, the enzyme is ready to bind more substrate. See the mechanism of enzyme action in figure 3.27 below.

Figure 3.27
Mechanism of enzyme action. In this example, the green substrate is catalyzed by the gray pacman-like enzyme into blue and red products. This is a decomposition reaction, which would also require water (not shown).
Art by [TimVickers](#) - [Public Domain](#)



Enzymes are generally named using the suffix ***–ase***. The prefix (or the root of the word) provides information about the type of reaction a particular enzyme catalyzes. For example, lact***ase*** is an enzyme that breaks down the disaccharide lactose; prote***ase*** is an enzyme that breaks down proteins; and DNA polymer***ase*** is an enzyme involved in making DNA. Generally speaking, "something***ase***" is an enzyme that does something.

Watch this video to review enzyme, active site, substrates and products:
https://youtu.be/UVeoXYJlBtI



Review Questions for Learning Objective 34

Write your answer in a sentence form. (Do not answer using loose words)

1. What is an enzyme?
2. What is an enzymatic reaction?
3. What is an "active site" in an enzyme?
4. What is the difference between substrate and product?
5. What is the suffix used to name enzymes?

Test for Learning Objective 34

1. The reactant in a chemical reaction is to a product as a ___ in an enzymatic reaction is to product

2. In an enzymatic reaction, the substrate is ___
   a. The substance produced
   b. The substance that enters the reaction
   c. An organic catalyst
   d. An enzyme

3. Lact*ase* is an enzyme that breaks down lact*ose* into glucose and galactose. Then___
   a. Lact*ose* is the product
   b. Lact*ase* is the substrate
   c. Glucose and galactose are the products
   d. Glucose and galactose are the substrates

Learning Objective 35: Describe the general chemical structure of nucleic acids, identify monomers and polymers, and list the functions of RNA and DNA.

Listen to Learning Objective 35

Nucleic acids contain the same elements as proteins: carbon, hydrogen, oxygen, nitrogen; plus, phosphorous (C, H, O, N, and P). **Nucleic acids** are very large macromolecules composed of repetitive units of the same building blocks, **nucleotides,** similar to a pearl necklace made of many pearls. We can also define nucleic acids as ***polymers*** assembled from many smaller covalently bonded ***monomers***.

Nucleic acids are the molecules that function in encoding, transmitting and expressing genetic information in our cells.

All *nucleotides* are made of three subunits: one or more phosphate groups, a pentose sugar (five-carbon sugar, either deoxyribose or ribose), and a nitrogen-containing base (either adenine, cytosine, guanine, thymine, or uracil). See figure 3.28 below.

Figure 3.28
A nucleic acid short fragment made of five nucleotides is shown on the right; one nucleotide is enclosed in a red rectangle. Each nucleotide is made of one of the five nitrogenous bases, a pentose sugar (***ribose*** or ***deoxyribose***) and a phosphate group. Ribonucleic acid (RNA) has ribose for a pentose, whereas deoxyribonucleic acid (DNA) has deoxyribose. The five nitrogenous bases are classified as **pyrimidines** (cytosine, thymine, and uracil), which have a ring structure; and **purines** (adenine and guanine), which have a double-ring structure. RNA molecules may have up to a few-thousand nucleotides and are single-stranded, whereas DNA molecules have billions of nucleotides organized in two strings of nucleotides forming a helix. DNA, RNA, and proteins are related to each other as shown in table 3.5 below.

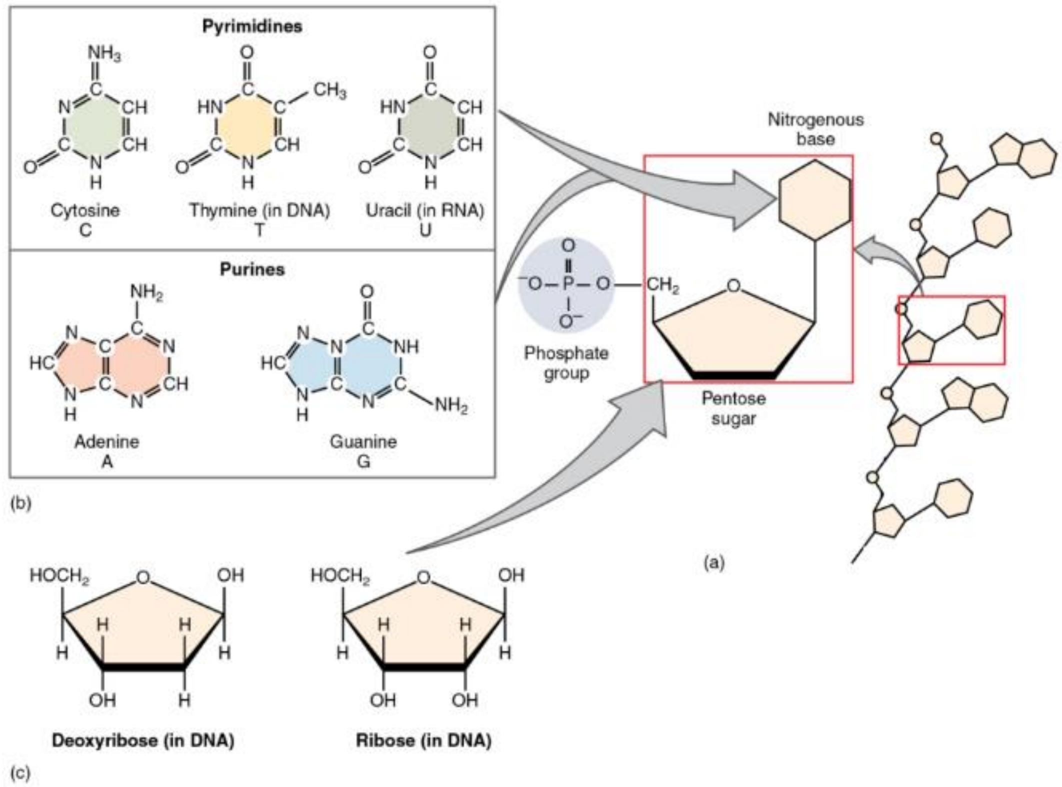


Table 3.5 DNA, RNA, and proteins relationship

DNA →	is used to synthesize	**RNA →**	which is used to synthesize	**Proteins**
Polymer of nucleotides		Polymer of nucleotides		Polymer of amino acids
Encodes amino acid sequence of proteins		Transmits and expresses information in DNA		Perform most cellular functions

Figure 3.29
DNA and RNA share three nucleotides in their composition (cytosine, guanine, and adenine), and **they differ in uracil** (found only in RNA) and thymine (found only in DNA). RNA is single strand, whereas DNA in double strand.
Art by [Open Learning Initiative](#) [CC-BY-NC-SA](#)

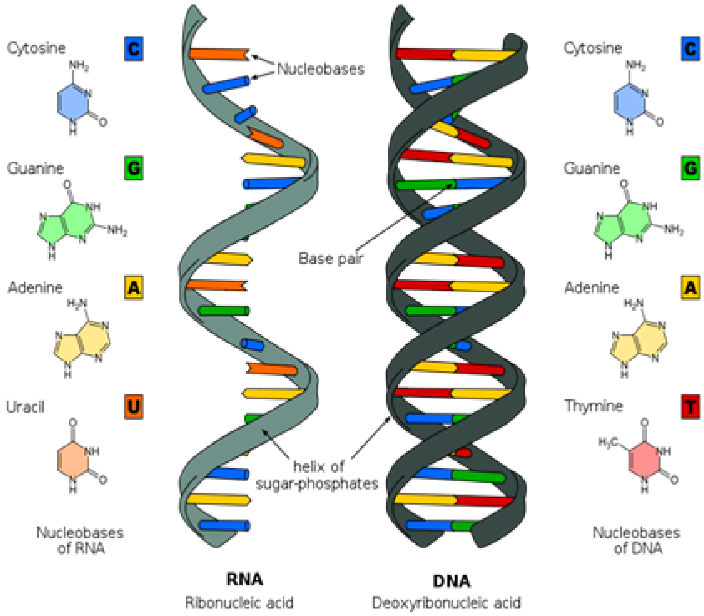
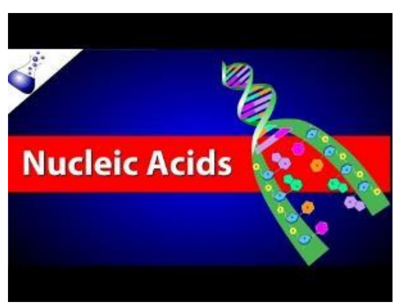


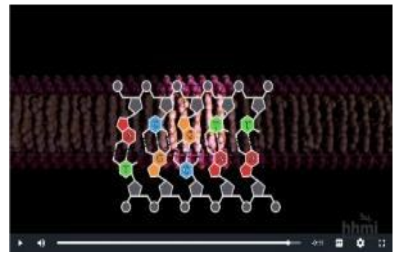
Table 3.6 Types of nucleic acids and their functions

Type of Nucleic Acid	Function
DNA	Encodes and transmits inherited genetic information from one generation to the next
RNA	Translates the information encoded in DNA for the production of proteins, and help in their synthesis

Watch this video to review nucleic acids: https://youtu.be/MA-ouz1LtpM



Watch this video to review chemical structure of DNA double helix: https://media.hhmi.org/biointeractive/media/chemical-structure-dna_2000.mp4



Review Questions for Learning Objective 35

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a nucleic acid?
2. What elements are nucleic acids made of?
3. What are the monomers that make the building blocks of nucleic acids?
4. What are the three components of a nucleotide?
5. List the types of nucleic acids described in the module
6. What are the functions of nucleic acid listed in the module?

Test for Learning Objective 35

1. Building blocks of nucleic acids are ___
   a. Amino acids
   b. Nitrogenous bases
   c. Nucleotides
   d. Phosphates

2. Components of nucleotides are ___
   a. Ribose or deoxyribose, a phosphate group, and monomer
   b. Ribose or deoxyribose, a phosphate group, and DNA
   c. Nitrogenous base, ribose or deoxyribose, and amino acid
   d. Nitrogenous base, ribose or deoxyribose, and a phosphate group

Learning Objective 36: Explain the meaning of complementary base pairing.

Listen to Learning Objective 36

NOTE: Before starting with this learning objective, review nucleic acids structure from learning objective 35

As mentioned in the previous learning objective, DNA molecules have billions of nucleotides organized in two strings forming a helix. Each sidepiece forms its backbone, composed of phosphate groups alternating with the sugar deoxyribose. Hydrogen bonds between nitrogen bases hold the two strands together. Because of the shape of the bases adenine (A), guanine (G), thymine (T), and cytosine (C), there is a specific way in which they pair: adenine always binds to thymine (and vice versa), and cytosine always binds to guanine (and vice versa). A-T pairing and C-G pairing are known as **complementary base pairings**. We see that all along the molecule of DNA all and every A binds always to a T, and all and every C binds always to a G, as shown in figure 3.30 below. This is why we say that the two nucleotide chains of the DNA are **complementary strands**.

Complementary base pairing makes protein synthesis possible as it will be described later in the protein synthesis module.

Figure 3.30.
(a) DNA double helix molecule showing the two complementary strands. The strands are held together by hydrogen bonds between cytosines and guanines, and adenines and thymines; **(b)** detail showing each nucleotide with its phosphate group, deoxyribose, and nitrogenous base, which form hydrogen bonds with **complementary bases**.
Art derivative of OpenStax College – CC-BY

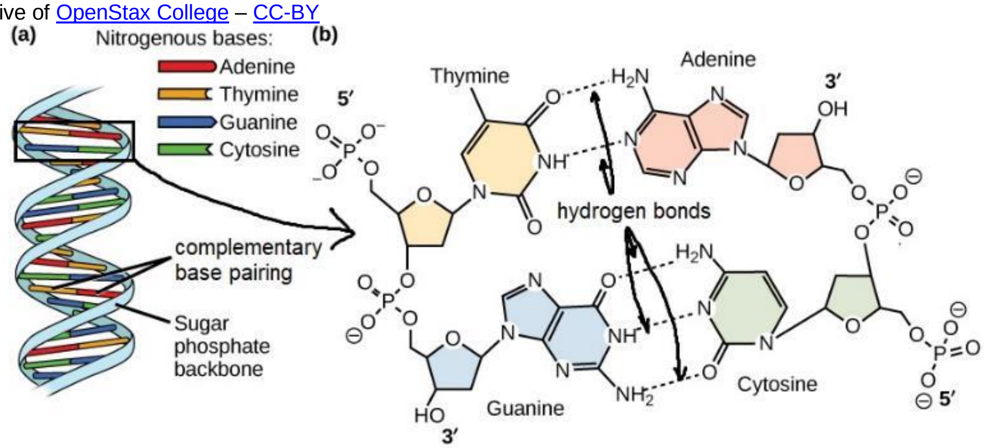
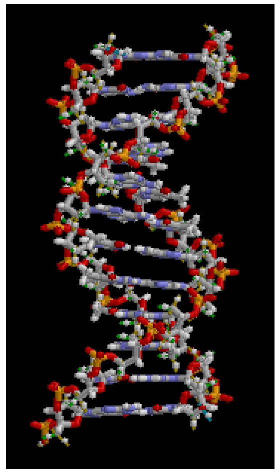


Figure 3.30B.
A 3D representation of a rotating DNA molecule segment. Each little ball represents an atom. Red and yellow represent phosphate groups atoms. The "rungs in the DNA ladder" represent the complementary base pairings.
Art by brian0918&#153 - Public Domain



Review Questions for Learning Objective 36

Write your answer in a sentence form. (Do not answer using loose words)

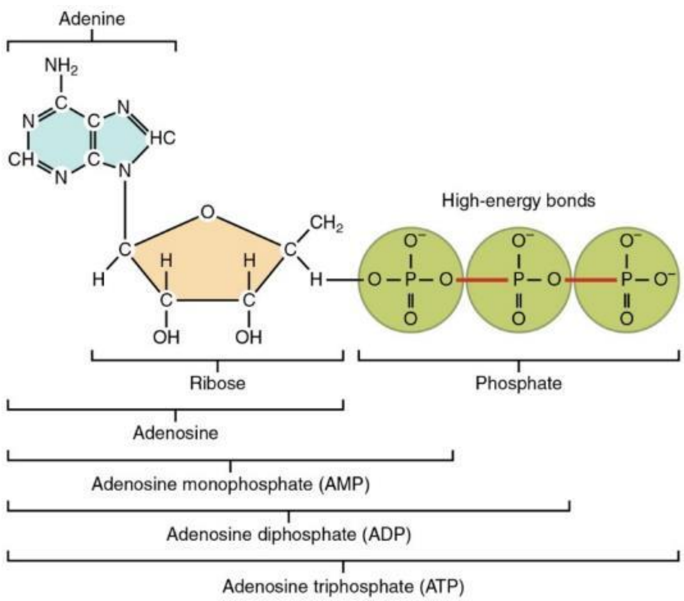
1. What does complementary base pairing mean?
2. What is the complementary strand to a DNA strand like this: AAGCTTAGCTAGGCC?

Learning Objective 37: Describe the structure and function of ATP in the cell.

Listen to Learning Objective 37

Nucleotides are the monomers that make up the nucleic acid polymers. Adenosine triphosphate (ATP) is a nucleotide that has an important function by itself. ATP is a direct and rapid energy source for most cellular activities. ATP consists of a single adenosine (the nitrogen-containing base adenine and the sugar ribose), linked to three phosphate ions.

Figure 3.31
The two covalent bonds on the right of the molecule (shown in red) are high energy bonds. When an enzymatic reaction breaks them down, a large amount of energy is released. This energy is ready to be used by a cell. On the other hand, when molecules (like the ones we incorporate in our diet) are broken down by enzymes they release energy. This energy can be temporarily held on ATP molecules in the covalent bonds formed between free phosphate groups and adenosine diphosphate (ADP). Art by OpenStax College – CC-BY



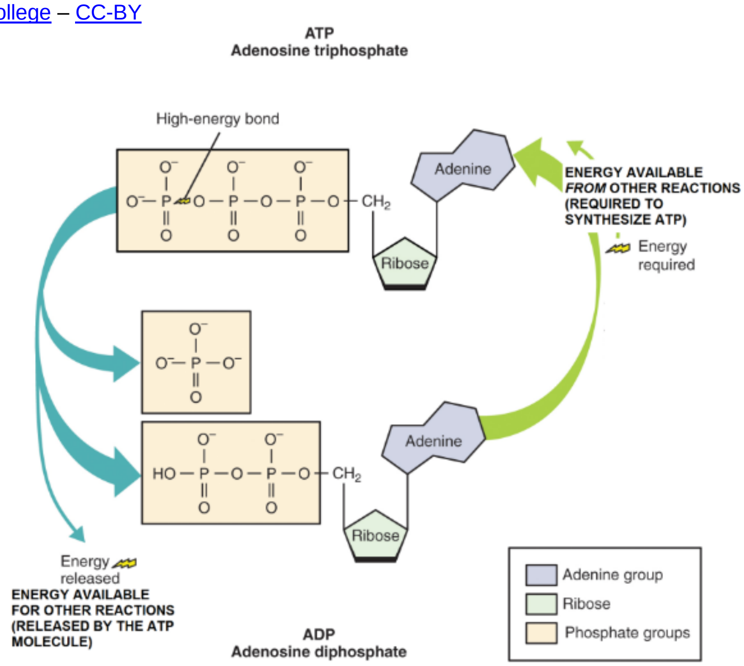
ATP is regularly referred to as the primary energy currency for the cell. ATP serves as an intermediary molecule between chemical reactions that release energy, and chemical reactions that require energy. It does so by temporarily "holding" the energy released by an enzymatic reaction in the covalent bonds that attach phosphates to ADP (the red ones in the figure above). Then, the molecule of ATP can give up that energy where it is needed.

The chemical formula summarizing this process, is

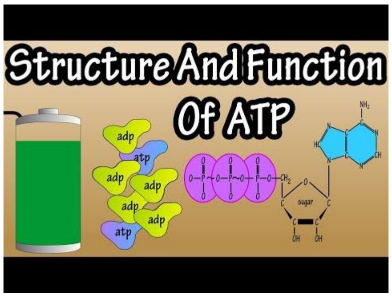
ATP ⇔ ADP + Pi (inorganic phosphate)

Since the reaction can go in either direction (from ADP to ATP, or from ATP to ADP), this is an example of a **reversible reaction**, and it is represented with a double arrow pointing in both directions.

Figure 3.32
Adenosine triphosphate (ATP) is the energy molecule in a cell. Energy released by decomposition reactions can be used to make a high energy covalent bond in ATP as shown in the figure. Then, ATP can give up this energy to be used for synthesis reactions
Art derivative of OpenStax College – CC-BY



Watch this video to review adenosine triphosphate (ATP) structure and function: https://youtu.be/hA4sRESz6Uw



Review Questions for Learning Objective 37

Write your answer in a sentence form. (Do not answer using loose words)

1. What type of organic molecule is ATP?
2. What is the function of ATP?

✍ Test for Learning Objective 37

1. ATP is a ___.
   a. Amino acid
   b. Nucleotide
   c. Monosaccharide
   d. Steroid

2. This is the primary energy currency for the cell:___.
   a. ARN
   b. ADN
   c. ATP
   d. ADP

MODULE 14: *Cell Structure and Function*

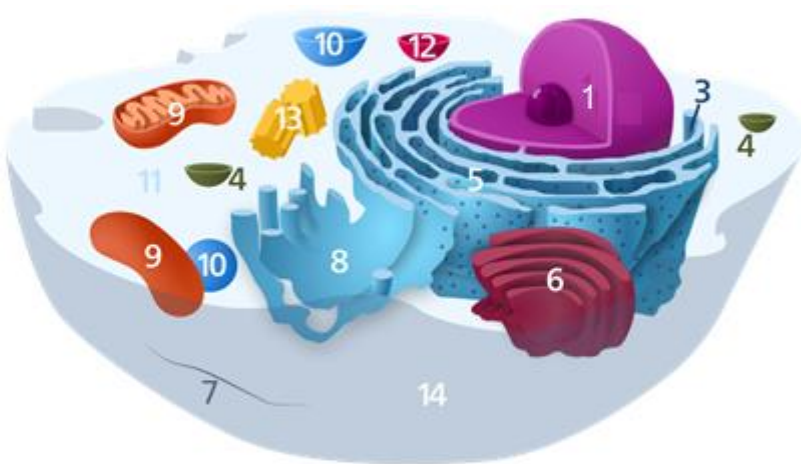
Learning Objective 38: Define a cell, identify the main common components of human cells, and differentiate between intracellular fluid and extracellular fluid.

Listen to Learning Objective 38

A **cell** is the smallest *living* thing in the human organism, and all living structures in the human body are made of cells. There are hundreds of different types of cells in the human body, which vary in shape (e.g., round, flat, long and thin, short and thick) and size (e.g., small granule cells of the cerebellum in the brain (4 micrometers), up to the huge oocytes (eggs) produced in the female reproductive organs (100 micrometers) and function. However, all cells have three main parts, the **plasma membrane**, the **cytoplasm** and the **nucleus**. The **cell membrane** (often called the plasma membrane) is a thin flexible barrier that separates the inside of the cell from the environment outside the cell and regulates what can pass in and out of the cell. Internally, the cell is divided into the cytoplasm and the nucleus. The **cytoplasm** (*cyto*-= cell; -*plasm* = "something molded") is where most functions of the cell are carried out. It looks a bit-like mixed fruit jelly, where the watery jelly is called the **cytosol**; and the different fruits in it are called **organelles**. The cytosol also contains many molecules and ions involved in cell functions. Different organelles also perform different cell functions and many are also separated from the cytosol by membranes. The largest organelle, the **nucleus,** is separated from the cytoplasm by a nuclear envelope (membrane). It contains the DNA (genes) that code for proteins necessary for the cell to function.

Generally speaking, the inside environment of a cell is called the **intracellular fluid (ICF)**, (intra- = within; referred to all fluid contained in cytosol, organelles and nucleus) while the environment outside a cell is called the **extracellular fluid (ECF)** (extra- = outside of; referred to all fluid outside cells). Plasma, the fluid part of blood, is the only ECF compartment that links all cells in the body.

Figure 4.1
3-D representation of a simple human cell. The top half of the cell volume was removed. Number 1 shows the nucleus, numbers 3 to 13 show different organelles immersed in the cytosol, and number 14 on the surface of the cell shows the plasma membrane.
Art derivative of Kelvinsong; PublicDomain



Review Questions for Learning Objective 38

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a cell?
2. What is a plasma membrane?
3. What is a cytoplasm?
4. What is the intracellular fluid (ICF)?
5. What is the extracellular fluid (ECF)?

Test for Learning Objective 38

1. The smallest living structure in the human body is the ___.
2. The ___ is the structure found at the surface of a cell.
3. The ___ is the internal environment where the majority of cell activity happens.
4. The ___ is the environment outside a cell.
   a. Cytoplasm
   b. Cytosol
   c. extracellular fluid (ECF)
   d. intracellular fluid (ICF)

Learning Objective 39: Describe the structure and functions of the cell membrane.

Listen to Learning Objective 39

The cell (or plasma) membrane separates the inner environment of a cell from the extracellular fluid. The membrane is often referred to as a fluid **phospholipid bilayer** because is composed of two layers of phospholipids, as figure 4.2 below shows.

Figure 4.2
Phospholipids form the basic structure of a cell membrane. Hydrophobic tails of phospholipids are facing the core of the membrane avoiding contact with the inner and outer watery environment. Hydrophilic heads are facing the surface of the membrane in contact with intracellular fluid and extracellular fluid.
Art derivative of OpenStax College – CC-BY

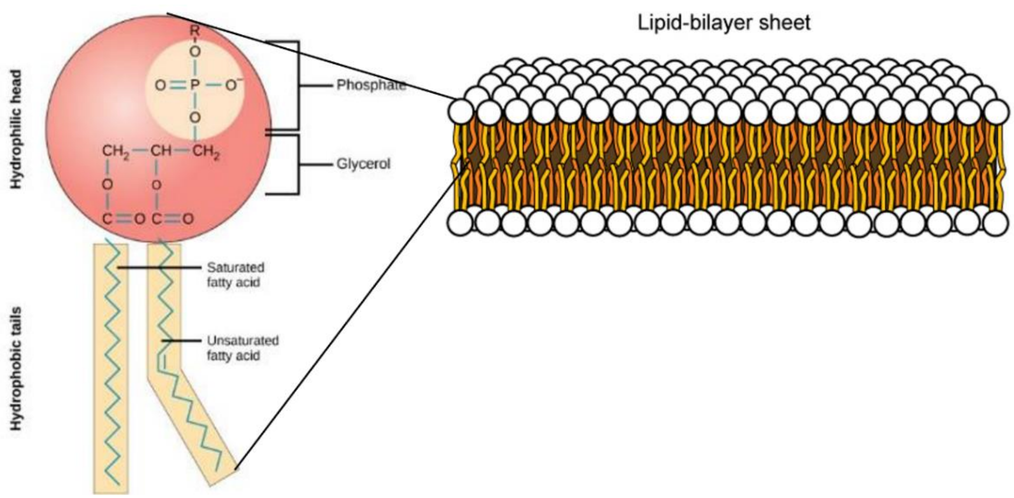
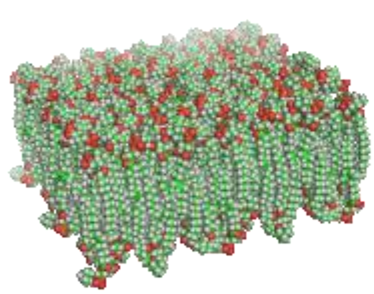
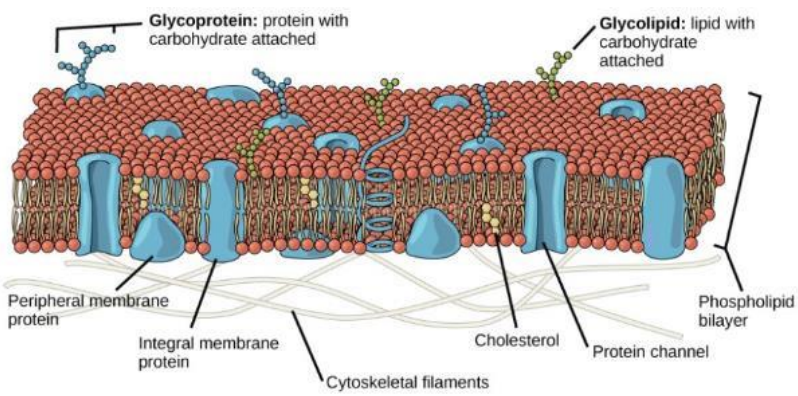


Figure 4.2B
3D rotating representation of the basic structure of a cell membrane. Compare with figure 4.2 above. Hydrophilic heads are represented in red, and hydrophobic tails (fatty acids chains) in green.
Art by Zephyris CC BY-SA

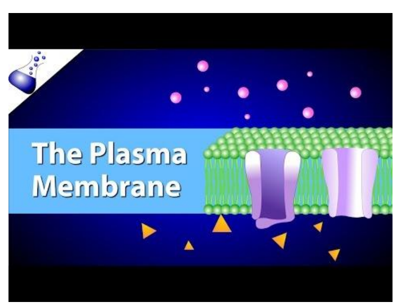


Not many substances can cross the phospholipid bilayer, so the membrane serves to separate the inside of the cell from the extracellular fluid. Other molecules found in the membrane include **cholesterol, proteins, glycolipids and glycoproteins**, some of which are shown in figure 4.3 below. Cholesterol, a type of lipid, makes the membrane less fluid. Different proteins found either crossing the bilayer (integral proteins) or on its surface (peripheral proteins) have many important functions. Channel and transporter (carrier) proteins regulate the movement of specific molecules and ions in and out of cells. Receptor proteins in the membrane initiate changes in cell activity by binding and responding to chemical signals, such as hormones (like a lock and key). Other proteins include those that act as structural anchors to bind neighboring cells and enzymes. Glycoproteins and glycolipids in the membrane act as identification markers or labels on the extracellular surface of the membrane. Thus, the plasma membrane has many functions and works as both a gateway and a selective barrier.

Figure 4.3
Small area of the plasma membrane showing lipids (phospholipids and cholesterol), different proteins, glycolipids and glycoproteins.



Watch this video to review membrane structure and composition: https://youtu.be/CNbZDcibegY



Review Questions for Learning Objective 39

Write your answer in a sentence form. (Do not answer using loose words)

1. What is the function of the cell membrane?
2. Which are the three types of biomolecules that form the cell membrane?

Test for Learning Objective 39

1. The cell membrane is made of __ layer(s) of phospholipids
    a. One
    b. Two
    c. Four
    d. Many

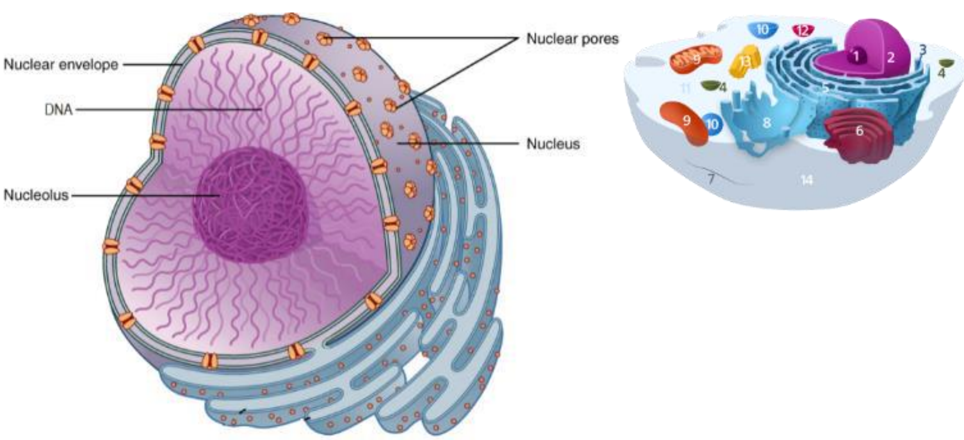
2. The cell membrane separates the ___ from the ___.
    a. Cytoplasm; nucleus
    b. Cytoplasm; organelles
    c. Extracellular fluid (ECF); intracellular fluid (ICF)
    d. Intracellular fluid (ICF); cytoplasm

Learning Objective 40: Describe the nucleus and its function.

[Listen to Learning Objective 40](#)

Almost all human cells contain a nucleus where DNA, the genetic material that ultimately controls all cell processes, is found. The nucleus is the largest cellular organelle, and the only one visible using a light microscope. Much like the cytoplasm of a cell is enclosed by a plasma membrane, the nucleus is surrounded by a **nuclear envelope** that separates the contents of the nucleus from the contents of the cytoplasm. **Nuclear pores** in the envelope are small holes that control which ions and molecules (for example, proteins and RNA) can move in and out the nucleus. In addition to DNA, the nucleus contains many nuclear proteins. Together DNA and these proteins are called **chromatin**. A region inside the nucleus called the **nucleolus** is related to the production of RNA molecules needed to transmit and express the information coded in DNA. See all these structures below in figure 4.4.

Figure 4.4
Nucleus of a human cell. Find DNA, nuclear envelope, nucleolus, and nuclear pores. The figure also shows how the outer layer of the nuclear envelope continues as rough endoplasmic reticulum, which will be discussed in the next learning objective.
Art by OpenStax College – CC-BY (nucleus) and Kelvinsong; PublicDomain (cell)



Review Questions for Learning Objective 40

Write your answer in a sentence form. (Do not answer using loose words)

1. What is the nuclear envelope?
2. What is a nuclear pore?
3. What is the function of the nucleus?

✍ Test for Learning Objective 40

1. The nucleus of a cell contains ___ in it.
   a. Genetic material
   b. Organelles
   c. Nuclear pores
   d. Nuclear envelope

Learning Objective 41: Describe the components of the cytoplasm and their functions.

Listen to Learning Objective 41

The function of the cytoplasm is to provide the appropriate environment where most cellular activity happens. The cytoplasm includes cytosol, organelles, inclusions, and a cytoskeleton. The **cytosol** is a semi-gelatinous fluid with dissolved ions, enzymes, nutrients and waste, and the environment where many chemical reactions happen in a cell. **Organelles** (*-elle* = diminutive; "little organ") are tiny organ-like intracellular structures made of macromolecules (such as proteins, carbohydrates, lipids, glycolipids, glycoproteins, lipoproteins), and they carry out specialized functions in the overall functions of the cell. Many organelles are separated from the cytosol by cell membranes, while others are not. **Inclusions** (sometimes called nonmembranous organelles) are undissolved particles, like fat droplets and glycogen granules. The **cytoskeleton** is an organelle that serves as the cell's internal scaffolding system and it is made of proteins. The cytosol and intracellular fluid have similar meanings, except intracellular fluid also includes fluid found inside of organelles.

Review Questions for Learning Objective 41

Write your answer in a sentence form. (Do not answer using loose words)

1. What is the cytosol?
2. What are organelles?
3. What are inclusions?
4. What is the cytoskeleton?

Test for Learning Objective 41

1. The ___ is the internal environment where many chemical and enzymatic reactions happen in a cell
    a. Cytoskeleton
    b. Cytosol
    c. Inclusion
    d. Plasma membrane

Learning Objective 42: Identify the structure and function of cytoplasmic organelles.

Listen to Learning Objective 42

An **organelle** is any structure inside a cell that carries out a metabolic function. The cytoplasm contains many different organelles, each with a specialized function. (The nucleus discussed above is the largest cellular organelle but is not considered part of the cytoplasm). Many organelles are cellular compartments separated from the cytosol by one or more membranes very similar in structure to the cell membrane, while others such as centrioles and free ribosomes do not have a membrane. See figure 4.5 and table 4.1 below to learn the structure and functions of different organelles such as mitochondria (which are specialized to produce cellular energy in the form of ATP) and ribosomes (which synthesize the proteins necessary for the cell to function). Membranes of the rough and smooth endoplasmic reticulum form a network of interconnected tubes inside of cells that are continuous with the nuclear envelope. These organelles are also connected to the Golgi apparatus and the plasma membrane by means of vesicles. Different cells contain different amounts of different organelles depending on their function. For example, muscle cells contain many mitochondria while cells in the pancreas that make digestive enzymes contain many ribosomes and secretory vesicles.

Figure 4.5

Typical example of a cell containing the primary organelles and internal structures. Table 4.1 below describes the functions of mitochondrion, rough and smooth endoplasmic reticulum, Golgi apparatus, secretory vesicles, peroxisomes, lysosomes, microtubules and microfilaments (fibers of the cytoskeleton).

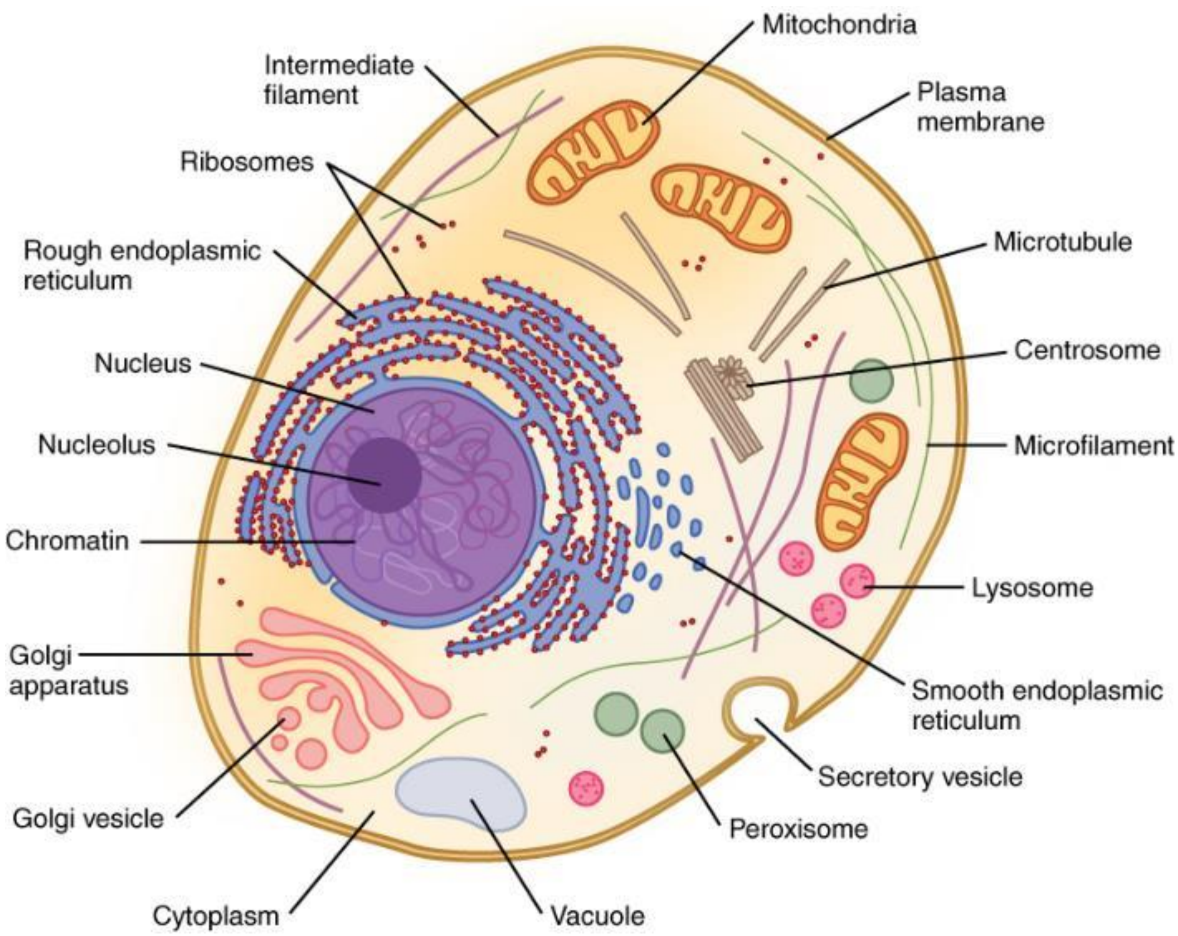
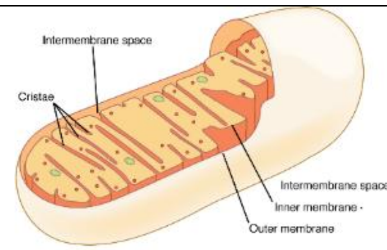
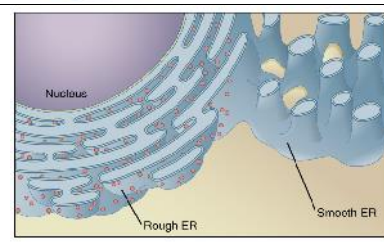
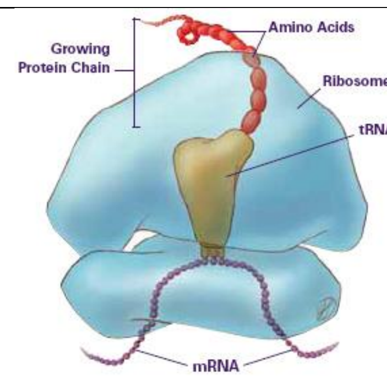
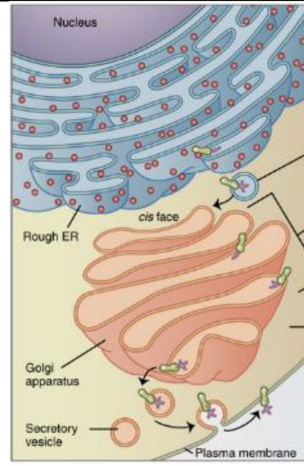
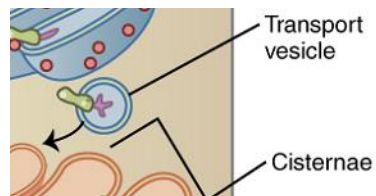
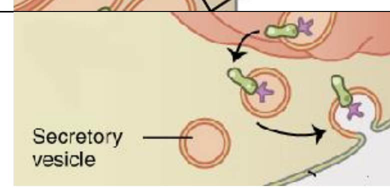
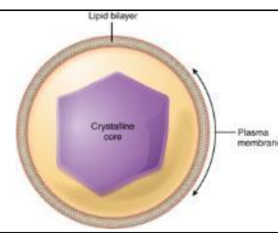
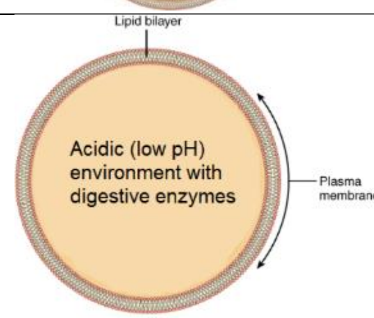


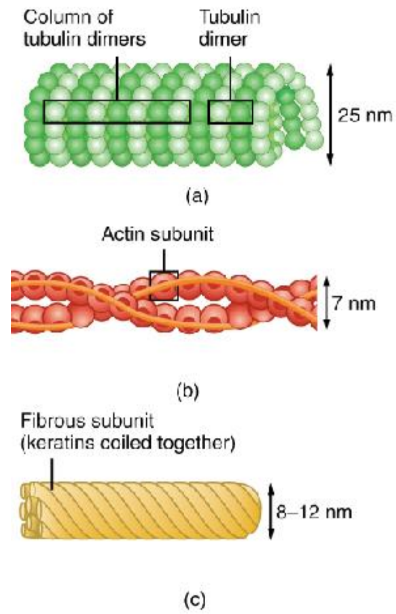
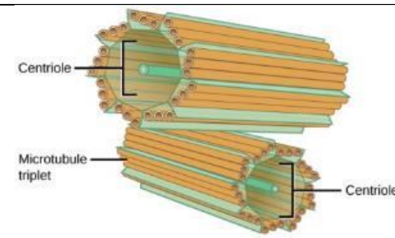
Table 4.1

Cellular Structures and their functions. Nucleus and plasma membrane were described in the previous learning objectives and are also important cellular structures

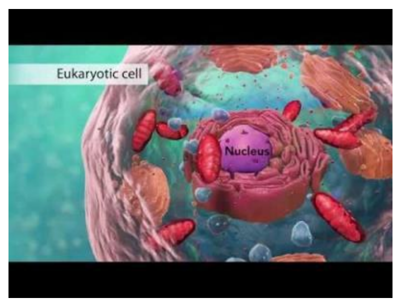
Table's art by OpenStax College – CC-BY

Organelles	Function	Structure
Mitochondria	Important in ATP (cellular energy) production	
Rough Endoplasmic Reticulum (RER)	Participates in protein synthesis (ribosomes in its membrane synthesize proteins)	
Smooth Endoplasmic Reticulum (SER)	Synthesizes lipids, and stores calcium in muscle cells	
Ribosomes (shown here synthesizing a protein) Found attached to RER and free in the cytosol	Synthesize proteins.	
Golgi apparatus (also known as Golgi complex)	Participates in protein modification, and packaging into small membrane-bound vesicles	

			
Vesicles are small round membrane-enclosed structures	**Transport Vesicles**	Move substances between compartments inside cells	
	Secretory Vesicles	Join with cell membrane to release contents, such as mucus, to ECF	
	Peroxisomes	Contain enzymes that catabolize (break down) fatty acids and some chemical toxins	
	Lysosomes	Contain digestive enzymes	

Fibers of the **Cytoskeleton** (a) microtubule made of tubulin, (b) microfilament made of actin, and (c) intermediate fibers made of keratins	Provide an internal cellular scaffolding	
Centrioles (found in an area in the cell called **centrosome**)	Organize DNA movement during cell division	

Watch this video to review organelles: https://youtu.be/URUJD5NEXC8



Review Questions for Learning Objective 42

Write your answer in a sentence form. (Do not answer using loose words)

1. What is an organelle?
2. Which are the organelles listed in the module?

Test for Learning Objective 42

1. Organelles are always inside the cell (T/F)
2. There is more than one organelle per cell (T/F)
3. Organelles are made of organic macromolecules (T/F)

MODULE 15: *Protein Synthesis*

Learning Objective 43: Define protein synthesis and name its two parts.

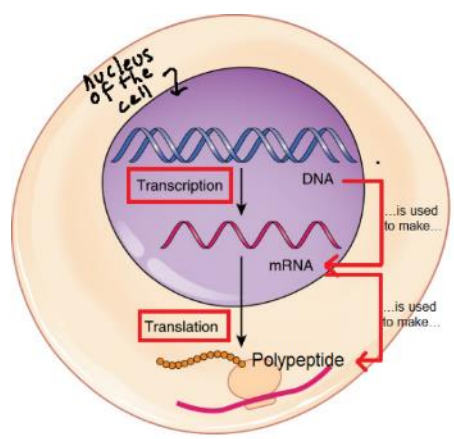
Listen to Learning Objective 43

NOTE: Before starting with this learning objective, **review proteins and amino acids** from learning objective 32.

As we saw in learning objective 32, proteins carry out most of the jobs in a cell and, relative to lipids, carbohydrates and nucleic acids, they serve the most diverse range of functions in our cells and body.

The biological function of a particular protein is given by its shape, which in turn is given by the sequence and number of amino acids that form the polypeptide/s in that particular protein. The "recipe" for what amino acids and how many of them to use to make a protein is coded (written) in the DNA. **Protein synthesis** is the process by which cells make proteins with the information stored in their DNA. Protein synthesis is studied in two parts: **transcription,** which happens in the nucleus; and **translation,** which happens in the cytoplasm. During **transcription,** a particular segment of DNA is used as a recipe to synthesize a form of RNA called messenger RNA (mRNA), During **translation,** that mRNA is used as a recipe to synthesize a particular polypeptide. These two steps are shown in figure 4.6 below.

Figure 4.6
The two parts of protein synthesis: transcription and translation.
Art derivative of OpenStax College – CC-BY



Review Questions for Learning Objective 43

Write your answer in a sentence form. (Do not answer using loose words)

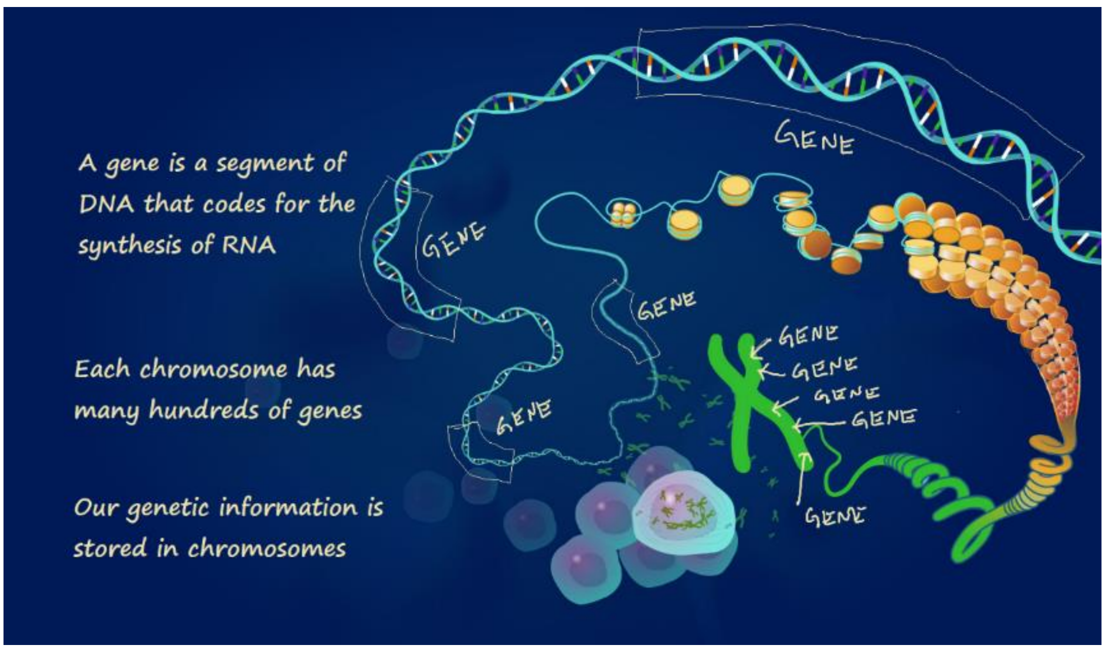
1. What is protein synthesis?
2. What is transcription, and where does it happen in a cell?
3. What is translation, and where does it happen in a cell?

Learning Objective 44: Define gene.

Listen to Learning Objective 44

All of our cells genetic information is stored in chromosomes and each chromosome contains many genes. A **gene** (gene- = "give birth", "beget") is a segment of DNA containing information that codes for the synthesis of an RNA molecule, which in many cases is used to synthesize a polypeptide. Genes are located throughout chromosomes as shown in figure 4.7 below. There are also some genes found in mitochondria, but this module deals with nuclear genes only.

Figure 4.7
Illustration showing gene locations at different scales of DNA packaging.
Art derivative of National Human Genome Research Institute - Public Domain



Review Questions for Learning Objective 44

Write your answer in a sentence form. (Do not answer using loose words)

1. What is a gene?
2. Where are genes found in a cell?

Learning Objective 45: List the three forms of ribonucleic acids (RNA).

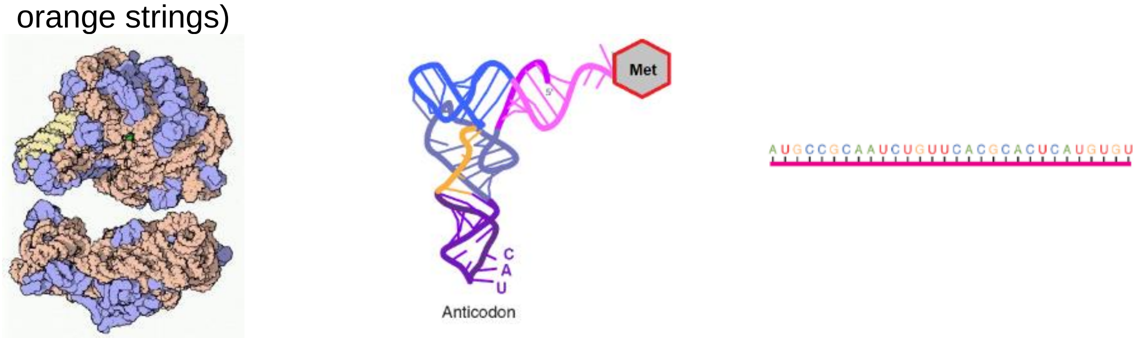
Listen to Learning Objective 45

NOTE: Before starting with this learning objective, review ribosomes from learning objective 42.

There are three forms of ribonucleic acids (RNA): **messenger RNA (mRNA)**, **ribosomal RNA (rRNA)**, and **transfer RNA (tRNA)**. mRNA participates in transcription and translation, and rRNA and tRNA participate in the translation. Figure 4.8 below shows a simple comparison, including their functions. More details about the different forms of RNA in the following learning objectives.

Figure 4.8
Comparison among the three forms of ribonucleic acids (RNA).
Art derivative of OpenStax College – CC-BY

rRNA as part of a ribosome (rRNA is only the orange strings)	**tRNA** (with amino acid methionine attached to it)	**mRNA**



rRNA, together with proteins, forms ribosomes	**tRNA** transports amino acids necessary for protein synthehsis	**mRNA** brings the recipe necessary for protein synthesis

Review Questions for Learning Objective 45

Write your answer in a sentence form. (Do not answer using loose words)

1. Which are the three forms of RNA?
2. What is the function of each of them?

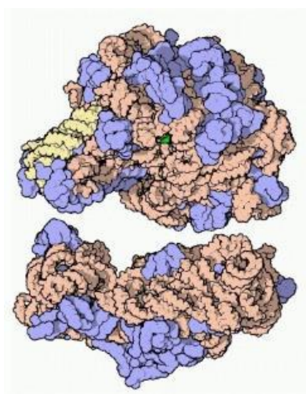
Learning Objective 46: Explain the role of ribosomal RNA (rRNA) in protein synthesis.

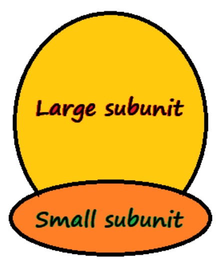
Listen to Learning Objective 46

NOTE: Before starting with this learning objective, review ribosomes from learning objective 42.

Ribosomes, the protein factories in cells, are made of **ribosomal RNA (rRNA)**, and proteins. rRNA plays a structural function in a cell, since it is part of the ribosome. Ribosomes are formed by a small subunit and a large subunit as shown in figure 4.9 below.

Figure 4.9
Two different representations of ribosomes. **Left**: ribosomal subunits, with RNA in orange and yellow and proteins in blue. The large subunit is on top and the small subunit is on the bottom. **Right**: a simple representation of a ribosome with large and small subunits together.
Art on the left: by The Protein Data Bank CC-BY-4.0 license





Review Questions for Learning Objective 46

Write your answer in a sentence form. (Do not answer using loose words)

1. What does rRNA stand for?

2. What is the function of rRNA?

Learning Objective 47: Define genetic code, and the term codon.

Listen to Learning Objective 47

NOTE: Before starting with this learning objective, review nucleotides from learning objective 35.

Generally speaking, a code is a system of symbols (such as letters or numbers) used to represent meanings. The **genetic code** is a set of sixty-four groups, with three mRNA nucleotides each group ("symbols"), used to represent twenty amino acids ("meanings"). A sequence of three mRNA nucleotides is what we call a **codon**. Figure 4.10 below shows the genetic code with all the codons and all the amino acids in a three-way table. The first letter of the codon is shown in the row labels on the left, the second letter of the codon is shown in the column labels, and the third letter of the codon is shown in the row labels on the right. The intersection of the three letters shows the amino acid coded by that codon. For example, AUG *codes* for the amino acid methionine (Met). Then, for example, using the genetic code, the mRNA sequence AUG GAG CAA UGA *codes* for a short peptide formed by the amino acids Met-Glu-Gln (AUG for Met, GAG for Glu, and CAA for Gln); and the last codon, UGA, *codes* for stop, meaning that that is the end of the peptide. Verify using the table showing the genetic code in figure 4.10 below.

Figure 4.10

Table showing the genetic code. This is a three-way table showing all the codons and what amino acid each codon represents. Amino acids are named in the table by their abbreviation; see under the table for references.

Art derivative of National Human Genome Research Institute in Public Domain

RNA codon table

1st position	2nd position U	2nd position C	2nd position A	2nd position G	3rd position
U	Phe	Ser	Tyr	Cys	U
	Phe	Ser	Tyr	Cys	C
	Leu	Ser	stop	stop	A
	Leu	Ser	stop	Trp	G
C	Leu	Pro	His	Arg	U
	Leu	Pro	His	Arg	C
	Leu	Pro	Gln	Arg	A
	Leu	Pro	Gln	Arg	G
A	Ile	Thr	Asn	Ser	U
	Ile	Thr	Asn	Ser	C
	Ile	Thr	Lys	Arg	A
	Met	Thr	Lys	Arg	G
G	Val	Ala	Asp	Gly	U
	Val	Ala	Asp	Gly	C
	Val	Ala	Glu	Gly	A
	Val	Ala	Glu	Gly	G

Amino Acids

Ala: Alanine
Arg: Arginine
Asn: Asparagine
Asp:Aspartic acid
Cys:Cysteine
Gln: Glutamine
Glu: Glutamic acid
Gly: Glycine
His: Histidine
Ile: Isoleucine
Leu: Leucine
Lys: Lysine
Met: Methionine
Phe: Phenylalanine
Pro: Proline
Ser: Serine
Thr: Threonine
Trp: Tryptophane
Tyr: Tyrosisne
Val: Valine

Review Questions for Learning Objective 47

Write your answer in a sentence form. (Do not answer using loose words)

1. What is the genetic code?
2. What is a codon?
3. Using the genetic code, what would be the "meaning" of AUG UUC AAG GCG UAA?

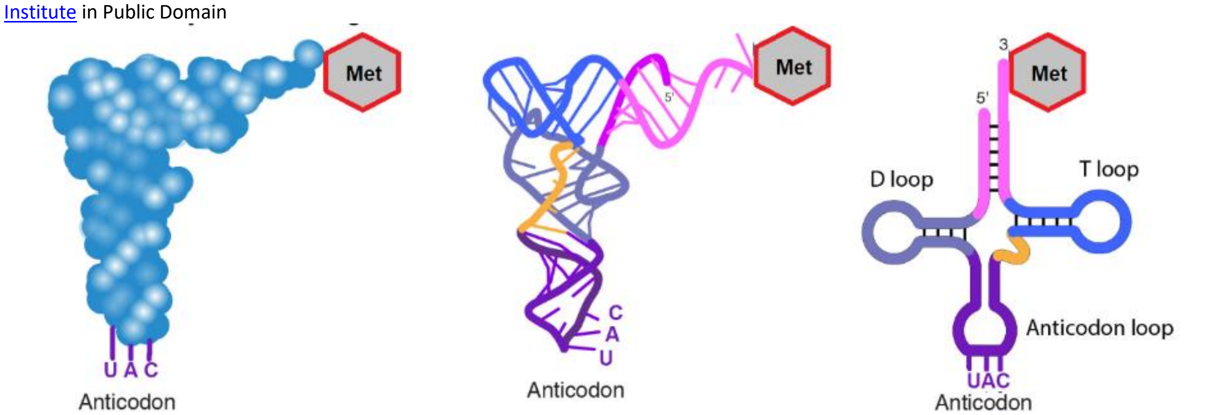
Learning Objective 48: Describe the structure of tRNA, define the term anticodon, and explain the role of tRNA in protein synthesis.

Listen to Learning Objective 48

NOTE: Before starting with this learning objective, review complementary pairing from learning objective 36.

The **transfer RNA (tRNA)** is a relatively small molecule and its role is to bind a free amino acid in the cytosol and deliver it to the ribosome to be used for the synthesis of proteins. There are two important parts in all and each tRNA molecule: the **amino acid-accepting end**, which binds to a specific amino acid to be delivered; and a three-nucleotide sequence on the other tip of the molecule, called the **anticodon**. The anticodon binds to a complementary codon in the mRNA molecule. For example, anticodon UAC in a tRNA molecule binds to the AUG complementary codon in the mRNA molecule. That tRNA molecule has an amino acid-accepting end for a specific amino acid (methionine, Met, in this case) that corresponds to the AUG codon in the genetic code. We will put all these pieces together later on in the translation learning objective.

Figure 4.11 Different representations of the same tRNA showing the three nucleotides that form the **anticodon** (UAC in this example) and the **amino acid-accepting end** of the molecule (with the amino acid methionine, Met, in this example). Art derivative of National Human Genome Research Institute in Public Domain



Review Questions for Learning Objective 48

Write your answer in a sentence form. (Do not answer using loose words)

1. What does tRNA stand for?
2. What is the function of tRNA?

3. Which are the two important parts in an tRNA molecule?
4. What is an anticodon?

Learning Objective 49: Explain the role of mRNA in protein synthesis, and describe what happens during transcription.

Listen to Learning Objective 49

NOTE: Before starting with this learning objective, review complementary pairing from learning objective 36, and nucleic acids structure from learning objective 35.

As mentioned before, ribosomes are the protein factories of a cell, and are found in the cytoplasm; whereas genes that code (have the "recipe") for the synthesis of proteins are found in the nucleus as part of the nuclear DNA. During **transcription,** a gene is copied or "transcribed" into a type of RNA called messenger RNA (mRNA). Then, the role of the mRNA is to carry the genetic code of a particular gene from the nucleus into the cytoplasm of a cell. **Transcription** is the process of transcribing ("copying") a gene sequence into an RNA sequence during the first part of protein synthesis.

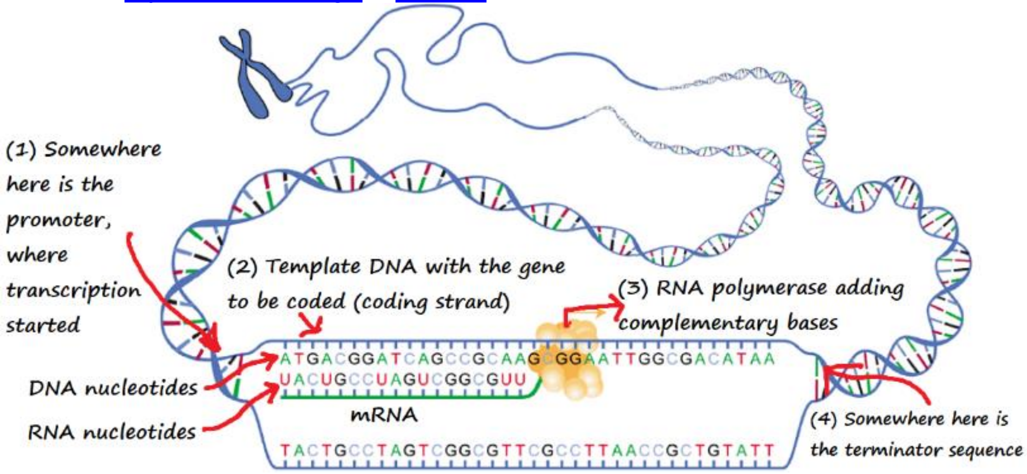
These are the main events during transcription:

1. A specific sequence of nucleotides at the beginning of the gene, called ***promoter***, triggers the start of transcription
2. Transcription starts when the enzyme ***RNA polymerase*** unwinds the DNA segment containing the gene. One strand, referred to as the ***coding strand***, becomes the template with the gene to be coded.
3. The RNA polymerase then aligns the correct RNA nucleotide (A, C, G, or U) with its complementary base on the coding strand of DNA, and adds new nucleotides to a growing strand of RNA. Recall that there are not thymines (T) in RNA, but uracils (U) instead. Uracil is complementary to adenine (same as thymine).
4. At the end of the gene, a sequence of nucleotides called the **terminator** sequence causes the new mRNA to change its shape. This, in turn, makes the mRNA to separate from the gene and from the enzyme RNA polymerase, ending transcription.

Before the mRNA molecule leaves the nucleus and proceeds to protein synthesis, it is modified in a number of ways not discussed here. For this reason, it is often called a pre-mRNA at this stage.

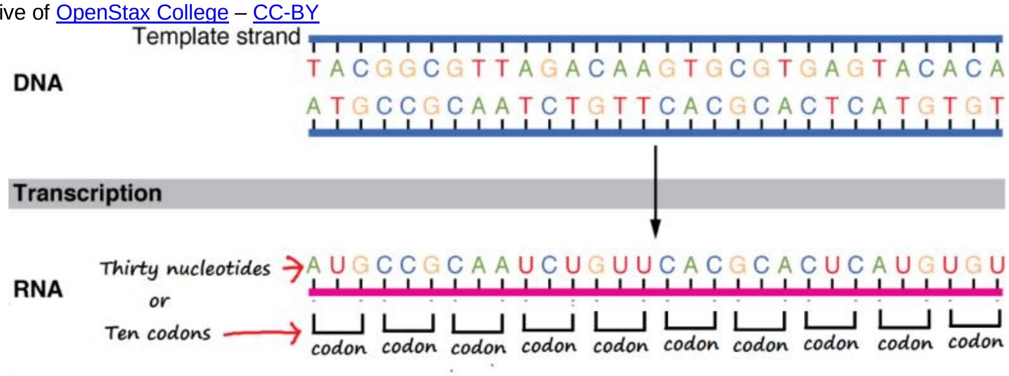
Figure 4.12 below shows transcription during the elongation stage. Note that in the figure a mRNA with eighteen bases has been already formed, and more are still left to be added.

Figure 4.12
Unzipped DNA molecule showing the action of RNA polymerase during translation, and mRNA synthesis in progress.
Art derivative of OpenStax College – CC-BY

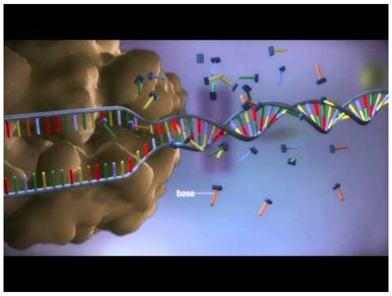


In summary, during transcription, a gene is *transcribed* ("copied") nucleotide by nucleotide into a mRNA. Note in figures 4.12 and 4.13 above and below that every T in the DNA has **its complementary A** in the mRNA, every A in the DNA has **its complementary U** in the mRNA, every C in the DNA has **its complementary G** in the mRNA, and every G in the DNA has **its complementary C** in the mRNA. Note that each set of three mRNA nucleotides is called a **codon**.

Figure 4.13
Transcription showing DNA template strand, and a mRNA complementary strand with its codons. In this case, the mRNA has **thirty nucleotides** or, what is the same, **ten codons**.
Art derivative of OpenStax College – CC-BY



Watch this video to review transcription (*stop at 1:10*. After that, translation starts, which will be covered in a following learning objective):
https://youtu.be/gG7uCskUOrA



Review Questions for Learning Objective 49

Write your answer in a sentence form. (Do not answer using loose words)

1. What does mRNA stand for?
2. What is the function of mRNA?
3. What is a promoter?
4. What is a coding strand?
5. What is the function of the enzyme RNA polymerase?
6. Which are the four nucleotides that make the mRNA?
7. What is a terminator sequence?
8. Answer in just two lines, what happens during transcription?

> ➲ **Learning Objective 50:** Describe what happens during translation.

Listen to Learning Objective 50

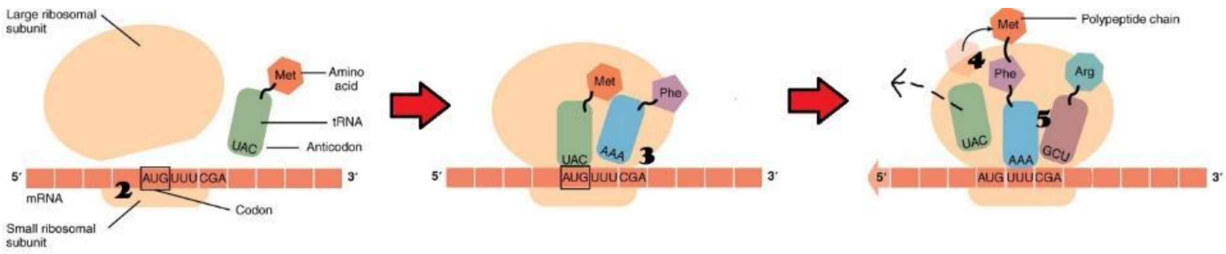
NOTE: Before starting with this learning objective, review complementary pairing from learning objective 36, amino acid and protein structure from learning objective 32, and nucleic acids structure from learning objective 35.

Once transcription has finished, the mRNA leaves the nucleus through the nuclear pores and moves into the cytoplasm. During **translation**, tRNA molecules carry amino acids to the ribosome, and they meet the mRNA, which will direct protein synthesis. Recall that a polypeptide is a chain of many amino acids; and a protein may contain one or more polypeptides.

These are the main events during **translation**:

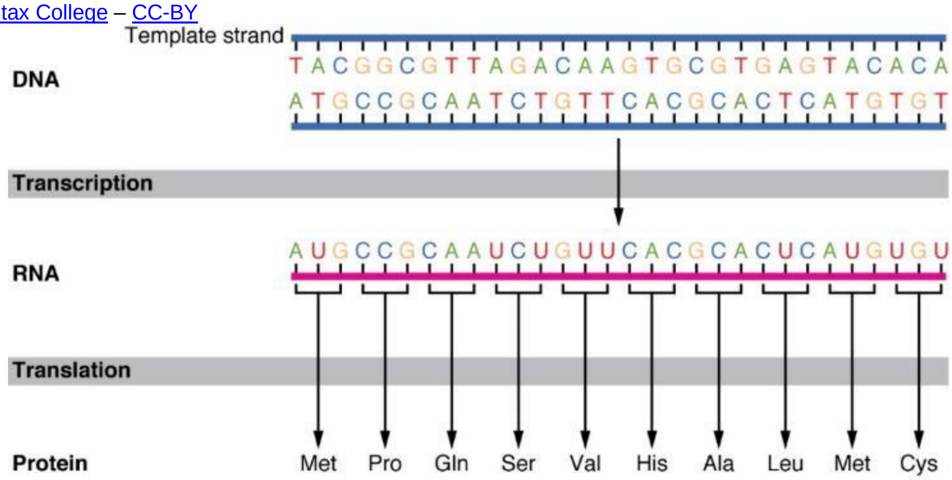
1. An enzyme binds amino acids to the corresponding tRNA molecules (not shown in the figure 4.14 below)
2. The small subunit of the ribosome binds to the mRNA, and slides until it finds the **start codon** AUG. This binding stimulates the large subunit of the ribosome and a tRNA with the complementary anticodon UAC to join in (see figure 4.14).
3. A tRNA with an anticodon (AAA) complementary to the second codon (UUU) binds to the mRNA (see figure 4.14).
4. The amino acid in the first tRNA (methionine, Met) breaks off and binds to the amino acid in the second tRNA (Phe), and the first tRNA leaves the ribosome leaving Met behind (see figure 4.14).
5. The second tRNA moves over to make room for a third tRNA with the anticodon GCU, which is complementary to the third codon CGA (see figure 4.14).
6. As the mRNA moves relative to the ribosome, successive tRNA move through the ribosome and the polypeptide chain is formed adding amino acids one by one up to the **stop codon** (not shown in figure 4.14 below). At this point, no more amino acids are added. The first three amino acids of the polypeptide in the figure below are Met-Phe-Arg. Note that there is one amino acid added per codon.
7. Once the stop codon is reached, the final polypeptide is released and the last tRNA is released as well. Finally, the large and the small subunit of the ribosome separate.
8. As the polypeptide is released, it folds in the space taking a shape that will determine it biological function.

Figure 4.14
Translation from RNA to Protein. See the text above for an explanation and match the numbers in this figure with the numbering of the list above.
Art derivative of [OpenStax College](#) – [CC-BY](#)

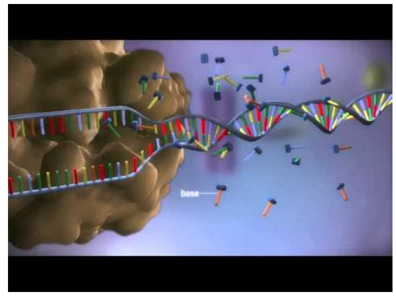


In summary, during protein synthesis there is a segment of DNA, a gene, that is transcribed into mRNA, which is then translated into a polypeptide. The figure below shows the flow of information from a gene into a polypeptide (protein): the DNA sequence TAC GGC GTT AGA CAA GTG CGT GAG TAC ACA is transcribed into the RNA sequence AUG CCG CAA UCU GUU CAC GCA CUC AUG UGU, which is translated into the polypeptide Met-Pro-Gln-Ser-Val-His-Ala-Leu-Met-Cys.

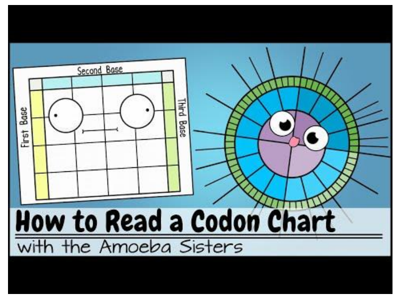
Figure 4.15
Protein synthesis and the genetic code. DNA holds all of the genetic information necessary to build a cell's proteins. The nucleotide sequence of a gene is ultimately translated into an amino acid sequence of the gene's corresponding protein. In this example, the 30 nucleotides in the DNA are transcribed into 30 nucleotides in the mRNA, which in turn are translated into a ten-amino acid long peptide.
Art by [OpenStax College](#) – [CC-BY](#)



Watch this video to review protein synthesis and its two parts, transcription and translation: https://youtu.be/gG7uCskUOrA



Watch this video to review how to use the genetic code chart and translate an mRNA into a peptide: https://youtu.be/LsEYgwuP6ko



Review Questions for Learning Objective 50

Write your answer in a sentence form. (Do not answer using loose words)

1. In just two lines, what happens during translation?
2. Expand your previous answer, and explain every one of the eight main events listed above in the text

Learning Objective 51: Discuss why protein synthesis is an important process.

Listen to Learning Objective 51

The importance of protein synthesis is associated with proteins function. We have seen in learning objective 32 that proteins have a wide range of functions in our cells. To name a "few": proteins carry substances in the blood or lymph throughout the body (e.g., hemoglobin and albumin); provide structural support (e.g., collagen); form part of different structures, like the cytoskeleton, the inner skeleton in a cell (e.g., tubulin); work as chemical messengers that coordinate the activity of different body systems (e.g., insulin, or oxytocin); protect the body from foreign pathogens (e.g., antibodies); participate in muscle contraction (e.g., actin, myosin), temporarily store oxygen and iron (e.g., myoglobin and ferritin, respectively), receive messages from other cells (e.g., insulin receptor, and all membrane receptors).

Moreover, proteins work as enzymes. Enzymes make all synthesis, decomposition, and exchange reactions in a cell possible. All the carbohydrates, lipids, nucleic acids, and proteins that we incorporate in our diet are metabolized by enzymes. Enzymes recycle them to obtain energy and the building blocks we need to make our own carbohydrates, lipids, nucleic acids, and proteins. Proteins are not only responsible for all the activities mentioned in the first paragraph, but they are also responsible for building all and every single structure in a cell. Ultimately, protein synthesis allows the expression of the information stored in our genes, which will determine how cells and organisms look and how they work.

Review Questions for Learning Objective 51

Write your answer in a sentence form. (Do not answer using loose words)

1. What is the function of proteins that makes protein synthesis important?
2. How are protein synthesis and the information stored in our genes related?

UNIT 5 • *Organ and Organ System Levels: The Highest Complexity Levels*

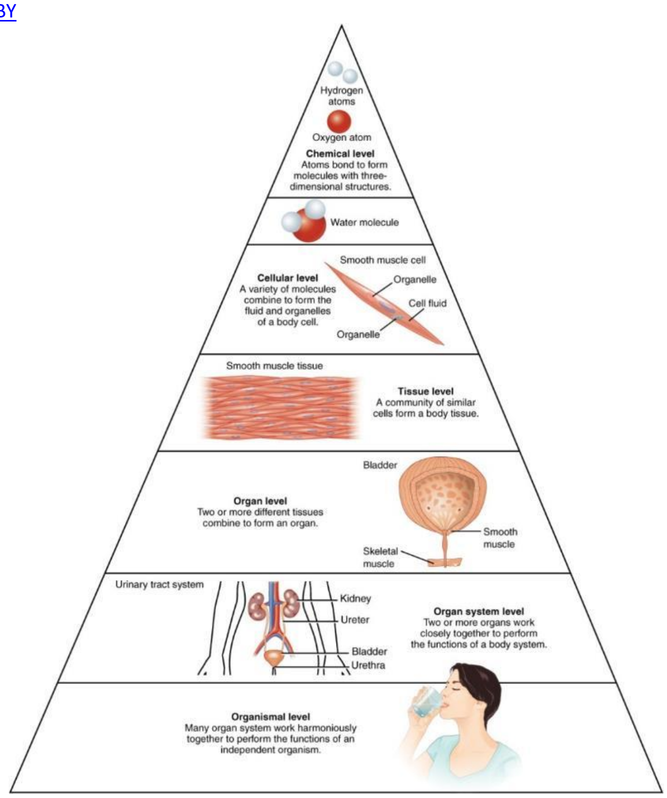
MODULE 16: *Organs and Systems of the Human Organism*

Learning Objective 52: Define organ and organ system, and list the organ systems in the human organism.

Listen to Learning Objective 52

An **organ** is a group of tissues that work together for the overall function of the organ, and an **organ system** is a group of organs that work together to perform a specific function. The human organism consists of eleven organ systems. They are Integumentary System, Skeletal System, Muscular System, Nervous System, Endocrine System, Cardiovascular System, Lymphatic System, Respiratory System, Digestive System, Urinary System, and Female and Male Reproductive System.

Figure 5.1
Organs and organ systems are the highest levels of complexity forming the human organism.
Art by OpenStax College – CC-BY



Review Questions for Learning Objective 52

Write your answer in a sentence form. (Do not answer using loose words)

1. What is an organ system?
2. List all the organ systems in the human organism

Test for Learning Objective 52

1. This is the best definition of organ: ___
   a. An organ is a group of cells that work together in the same region of the body
   b. An organ is a group of tissues that work together in the same region of the body
   c. An organ is a group of cells that work together for the overall function of the organ
   d. An organ is a group of tissues that work together for the overall function of the organ

Learning Objective 53: Describe the functions of the organs systems, and list the main organs of each system.

Listen to Learning Objective 53

Refer to figures 5.2 and 5.3 below to determine the organs and functions of the eleven organ systems. Note that some organs perform activities that directly participate in the functioning of more than one system. For example, the testes and ovaries both have an endocrine function (producing sex hormones) and a reproductive function (producing, cells called gametes that will fuse to make a new organism). Another example is the pancreas, which has an endocrine function (producing hormones) and a digestive function (producing juices that help digestion).

All organ systems must work correctly for an organism, such as humans, to maintain homeostasis and health. Since all organ systems are ultimately made of ions and molecules, an understanding of the chemical and cellular organization of the body, as reviewed in this course, is needed in order to successfully master human anatomy and physiology.

See figures 5.2 and 5.3 in the following page.

Figure 5.2

Organs and function of Integumentary System, Skeletal System, Muscular System, Nervous System, Endocrine System, Cardiovascular System.

Art by OpenStax College – CC-BY

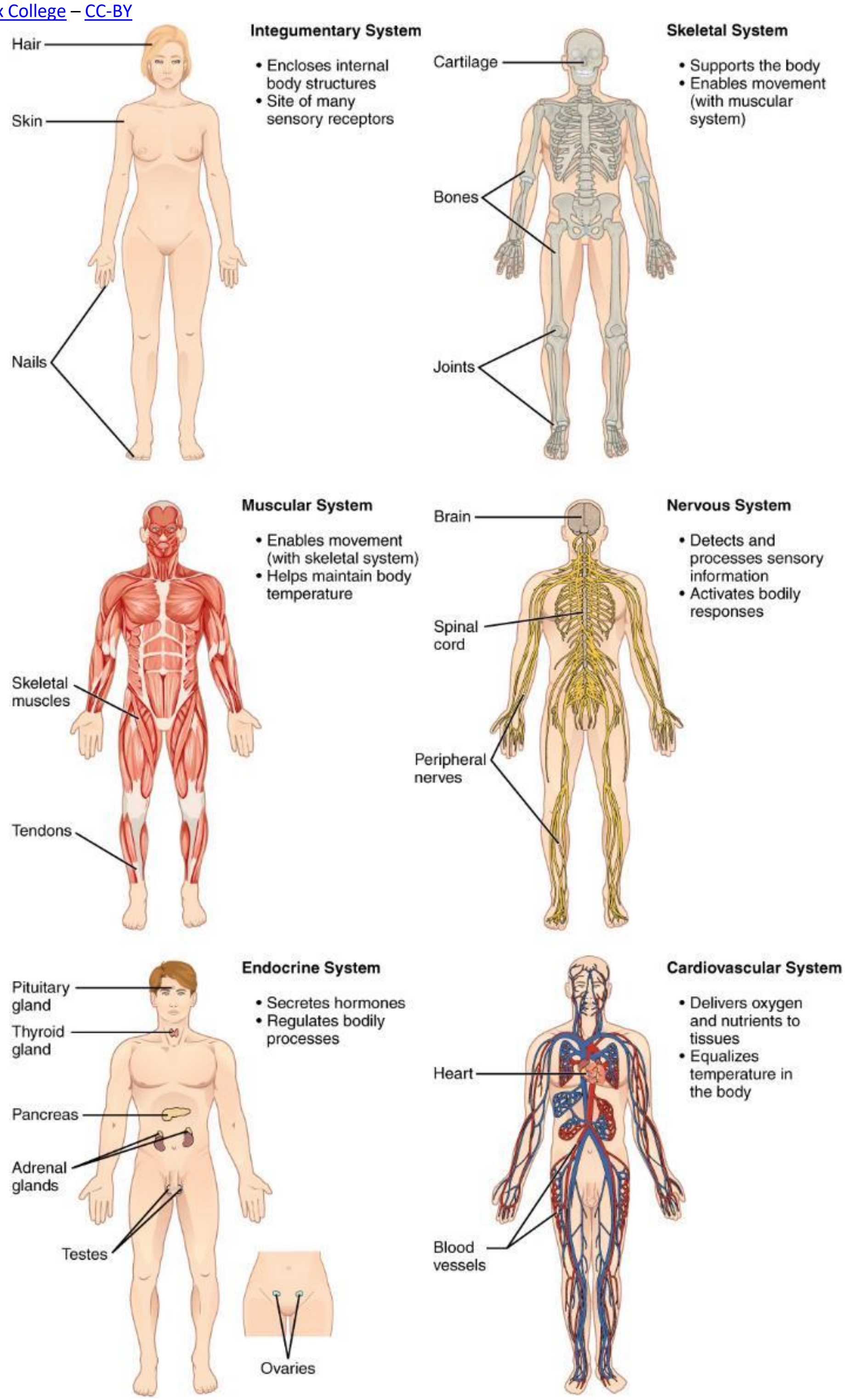
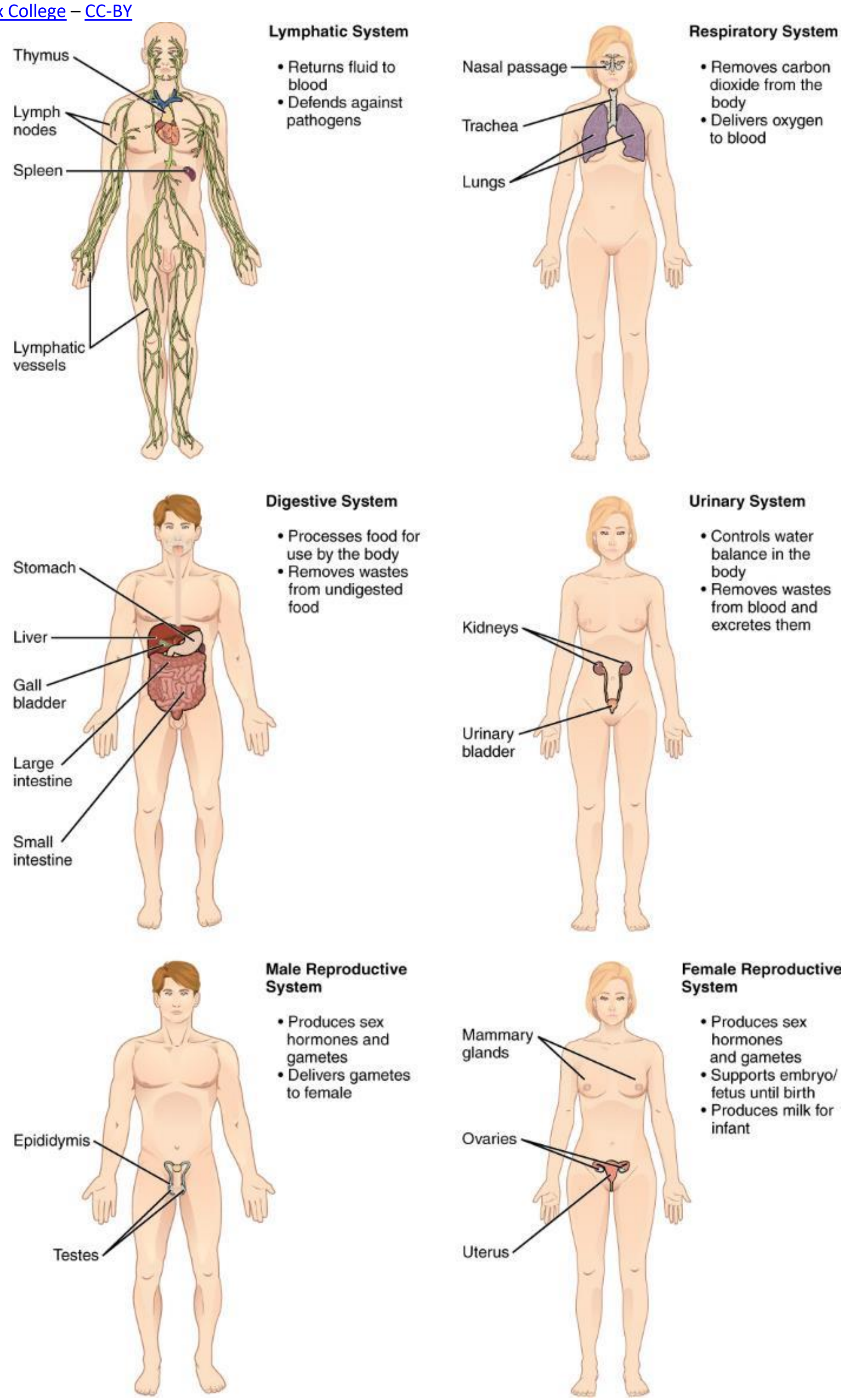


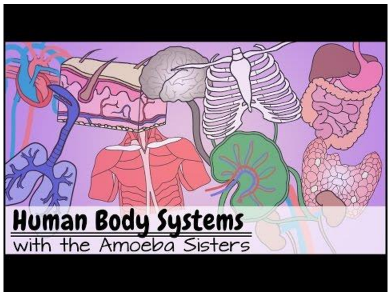
Figure 5.3

Organs and function of lymphatic system, respiratory system, digestive system, urinary system, and female and male reproductive system.

Art by [OpenStax College](#) – [CC-BY](#)



Watch this video to review Levels of Organization and a Human Body Systems Functions Overview: https://youtu.be/gEUu-A2wfSE



Review Questions for Learning Objective 53

Write your answer in a sentence form. (Do not answer using loose words)

1. What is the function of the Integumentary System?
2. List the organs of the Integumentary System
3. What is the function of the Skeletal System?
4. List the organs of the Skeletal System
5. What is the function of the Muscular System?
6. List the organs of the Muscular System
7. What is the function of the Nervous System?
8. List the organs of the Nervous System
9. What is the function of the Endocrine System?
10. List the organs of the Endocrine System
11. What is the function of the Cardiovascular System?
12. List the organs of the Cardiovascular System
13. What is the function of the Lymphatic System?
14. List the organs of the Lymphatic System
15. What is the function of the Respiratory System?
16. List the organs of the Respiratory System
17. What is the function of the Digestive System?
18. List the organs of the Digestive System
19. What is the function of the Urinary System?
20. List the organs of the Urinary System
21. What is the function of the Female Reproductive System?
22. List the organs of the Female Reproductive System
23. What is the function of the Male Reproductive System?
24. List the organs of the Male Reproductive System

Test for Learning Objective 53

1.
2. These are all organs of the integumentary system: ___
   a. Hair, skin, and nails
   b. Muscle, skin, and nails
   c. Hair, skin, and tendons
   d. Muscle, skin, and tendons
3. This is one of the functions of skeletal system: ___
   a. Encloses internal body structures

b. Supports the body
c. Helps maintain body temperature
d. Regulates body processes

4. These are all organs of the muscular system: ___
a. Cartilage, bones, and skeletal muscles
b. Cartilage, tendons and skeletal muscles
c. Cartilages and skeletal muscles
d. Tendons and skeletal muscles

5. This is one of the functions of the nervous system: ___
a. Secretes hormones
b. Defense against pathogens (disease causing agents)
c. Detects and processes sensory information
d. Removes waste from the skin

6. These are all organs of the endocrine system: ___
a. Spleen, pancreas, and thyroid gland
b. Spleen, liver, and thyroid gland
c. Pituitary gland, pancreas, and thyroid gland
d. Pituitary gland, liver, and thyroid gland

7. This is one of the functions of cardiovascular system: ___
a. Delivers oxygen and nutrients to tissues
b. Delivers oxygen to blood
c. Returns fluid to blood
d. Enables movement

8. These are all organs of the lymphatic system: ___
a. Thymus, lymph nodes, and spleen
b. Thymus, lymph nodes, and pituitary gland
c. Pancreas, lymph nodes, and liver
d. Pancreas, lymph nodes, and spleen

9. This is one of the functions of respiratory system: ___
a. Encloses internal body structures
b. Delivers oxygen and nutrients to tissues
c. Delivers oxygen to blood
d. Delivers air to the tissues

10. These are all organs of the digestive system: ___
a. Kidneys, stomach, and small intestine
b. Kidneys, large intestine, and small intestine
c. Liver, stomach, and small intestine
d. Liver, stomach, and spleen

11. This is one of the functions of urinary system: ___
a. Removes carbon dioxide from the body
b. Removes wastes from undigested food
c. Removes wastes from blood and excretes them
d. Removes pathogens (disease causing agents) from the blood

12. This is what female and male reproductive systems have in common: ___
a. Production of sex hormones and gametes (sex cells)
b. Production and support of the embryo
c. Production of milk
d. Production of internal fetal structure