LESSON 1

Unifying Characteristics of Life

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Earth is home to a great variety of **organisms,** from tiny single-celled bacteria to complex animals and plants. It may be difficult, at first, to see what all these organisms have in common, but all life on Earth shares several unifying characteristics.

Characteristics of Life

A closer look reveals that all organisms are composed of one or more **cells,** the basic building blocks of life. A cell is the smallest living unit of any organism, and has specific parts that allow it to carry out life processes. An organism may be **unicellular** or **multicellular.**

In addition to being composed of cells, all living organisms share the following characteristics and abilities:

- **Obtaining and using energy—**All organisms must obtain energy in some form, whether they absorb sunlight (like plants) or ingest other organisms to gain the energy stored in their molecules (like animals).
- **Maintaining a stable internal state—**Organisms and their cells function best at certain temperatures, pH levels, solute concentrations, and other conditions. They must keep levels from falling too low or rising too high. This process is called **homeostasis.**
- **The ability to grow—**Even single cells grow larger, and multicellular organisms grow by dividing, that is, duplicating, their cells many times over.
- **The ability to reproduce—**Almost all of the organisms in a species are able to reproduce. For unicellular organisms, reproduction consists of cell division.
- **Responding to stimuli in the environment—**A *stimulus* is a change (for example, in temperature or color) that an organism can detect. Responses may take different forms. Some are behavioral. For example, a rabbit may run away from a predator. Some plants move their leaves to face the incoming sunlight. Other responses do not involve movement. For example, some plants produce poisonous chemicals when insects begin to eat their leaves. To respond to changing conditions, organisms must be able to sense their environment. Many plants and animals can sense changes in light, temperature, and gravity.

An **organism** is a living thing, such as an animal, plant, fungus, protist, or bacteria.

A **cell** is the basic unit of life.

A **unicellular** organism, such as bacteria, has a single cell to carry out all life functions.

Multicellular organisms, such as animals and plants, may have trillions of cells with specialized functions within that organism's life cycle. The cells work together to carry out the organism's life functions.

Homeostasis is the process of maintaining a stable internal environment.

Both unicellular and multicellular organisms may reproduce sexually or asexually. For example, yeast is a single-celled fungus that sometimes reproduces sexually. Many plants can reproduce asexually as well as from seeds.

In low-light environments, eye pupils dilate to allow more light to pass into the eye. Describe **two** characteristics of life exhibited by this example.

Pupil dilation is a response to a stimulus—low light—in the environment. This response requires the use of energy. Pupil dilation is also an example of homeostasis, as constant light levels in the eye are maintained.

Characteristics of All Cells

All organisms consist of cells, and all cells share several characteristics that are essential to life. The **plasma membrane,** or *cell membrane,* forms the outside layer of a cell. It separates the cell from its environment and regulates the exchange of material into and out of the cell.

Cytoplasm is the substance that fills the cell's internal volume. It is composed mostly of water.

DNA is the molecule that stores genetic information, which allows the cell to pass it on to future generations. Genes are temporarily copied as RNA and brought to the ribosomes.

Ribosomes are the smallest organelles within the cell and many of them are found throughout the cytoplasm. They decode the genetic information in mRNA and assemble amino acids into proteins.

A **plasma membrane** is a molecular bilayer that encloses a cell.

DNA and RNA are both **nucleic acids,** biological macromolecules that act as blueprints to convey genetic information.

Ribosomes are made up of protein and RNA. They are not enclosed by membranes.

Which structure is **not** present in all organisms?

A a cell wall

B a plasma membrane

C genetic material

D cytoplasm

All cells contain a plasma membrane, cytoplasm, and some form of genetic material, so choices B, C, and D are incorrect. Cell walls are found in plants, fungi, and bacteria, but not in animals. Therefore A is the correct choice.

Viruses contain genetic information, but because they lack ribosomes and other cell structures, they are not considered organisms.

Prokaryotic and Eukaryotic Cells

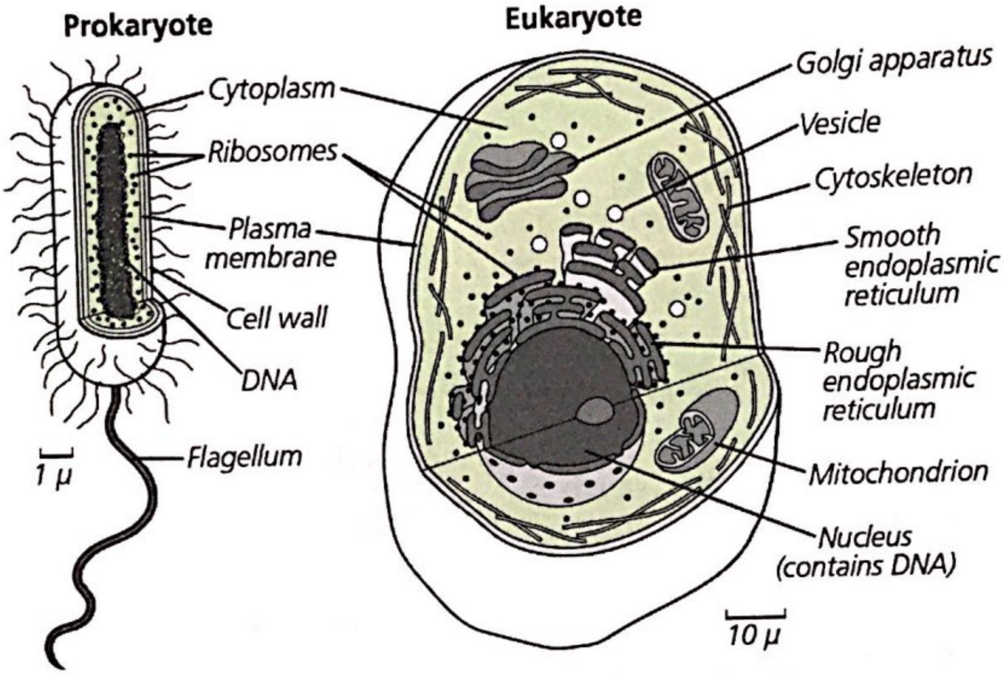
Prokaryotes and eukaryotes are the two main types of cells. **Prokaryotes** are unicellular organisms that lack membrane-bound organelles. This means that their DNA is not contained within a nuclear membrane, but is instead found directly in the cytoplasm. Prokaryotes are the oldest type of cell, originating about 3.5 billion years ago. They include common bacteria and bacteria-like cells (archaea) that are found in extreme environments.

A **prokaryotic** cell is much smaller and simpler than a eukaryotic cell, lacking a nucleus and other membrane-bound organelles.

Membrane-bound means being enclosed within a membrane inside the cytoplasm.

Eukaryotes are much more complex cells, normally larger than prokaryotic cells. They originated about 1.5 billion years ago. They have membrane-bound organelles located within the plasma membrane. Their DNA is contained within a nucleus. A *cytoskeleton*, or protein scaffold, helps to maintain the structure of these large cells. Eukaryotes include protists, fungi, animals, and plants. They may be either unicellular or multicellular.

All multicellular organisms are **eukaryotes,** so all multicellular organisms have cells with nuclei and membrane-bound organelles.



The simpler prokaryotic cell originated earlier than the complex eukaryotic cell.

Prokaryotic cells are generally smaller than eukaryotic cells because they are less complex, have less material inside them, and have limited ways to transport materials into and out of the cell efficiently. This table compares them.

PROKARYOTIC CELLS VERSUS EUKARYOTIC CELLS

	Prokaryotic Cell	Eukaryotic Cell
Nucleus	No	Yes
Cell Number	Unicellular	Unicellular or multicellular
DNA	Circular chromosome found in cytoplasm	Linear chromosomes contained in nucleus
Examples	Bacteria	Plants, animals, fungi, protists
Plasma Membrane	Yes	Yes
Membrane-bound Organelles	No	Yes
Ribosomes	Yes, small	Yes, large
Cell Wall	Yes	Present in plants and fungi
Cell Diameter	1–10 micrometers (μm)	10–100 micrometers (μm)

A micrometer (μm) is equal to 1×10^{-6} meter.

Describe two similarities and two differences between prokaryotes and eukaryotes.

There are many answers to this question. Similarities include the presence of genetic information (DNA), cytoplasm, a plasma membrane, and ribosomes in both types of cells. Differences include the lack of a nucleus in prokaryotes, the size difference between eukaryotes and prokaryotes, and the addition of membrane-bound organelles such as mitochondria and chloroplasts in eukaryotes.

Organelles of the Eukaryotic Cell

The eukaryotic cell contains a variety of membrane-bound **organelles** with very specific functions. The **nucleus** contains the cell's genetic information (DNA), packaged as chromosomes. **Mitochondria** are the powerhouses of the cell. These organelles synthesize the energy-rich ATP molecules required to carry out life processes.

Like all cells, eukaryotic cells contain ribosomes. Some ribosomes float unattached in the cytoplasm; they produce proteins used within the cell. Other ribosomes are attached to the exterior membrane of the **endoplasmic reticulum (ER),** a membrane-rich organelle that surrounds the nucleus. These ribosomes produce proteins that will be transported outside the cell. The endoplasmic reticulum wraps "packages" of these proteins into membrane *vesicles* and releases them. The **Golgi apparatus** absorbs and tags these vesicles with an "address" so they can be secreted by the cell for use elsewhere in the organism.

A eukaryotic cell produces and secretes a protein. Trace the path of the protein through the cell's organelles, starting with the original genetic information for the protein.

The genetic information for the protein is stored in the nucleus. It is transported to the ribosomes attached to the rough ER (where proteins bound for "export" are assembled). Once made, the protein is packed into a vesicle that travels to the Golgi apparatus. Then, it is "tagged" and sent to the plasma membrane, where it leaves the cell.

Animal and Plant Cells

Animal and plant cells have many of the same organelles, such as the plasma membrane and the nucleus. However, there are some differences. **Chloroplasts** are plant organelles that capture the energy of sunlight and transform it into chemical energy, like simple sugars. Chloroplasts contain the pigment *chlorophyll,* which absorbs the energy of sunlight much like a solar panel.

An **organelle** is a specialized part of a cell with a specific function.

The **nucleus** is an organelle that contains the genetic material of a eukaryotic cell.

Mitochondria are membrane-bound organelles where energy transformation takes place.

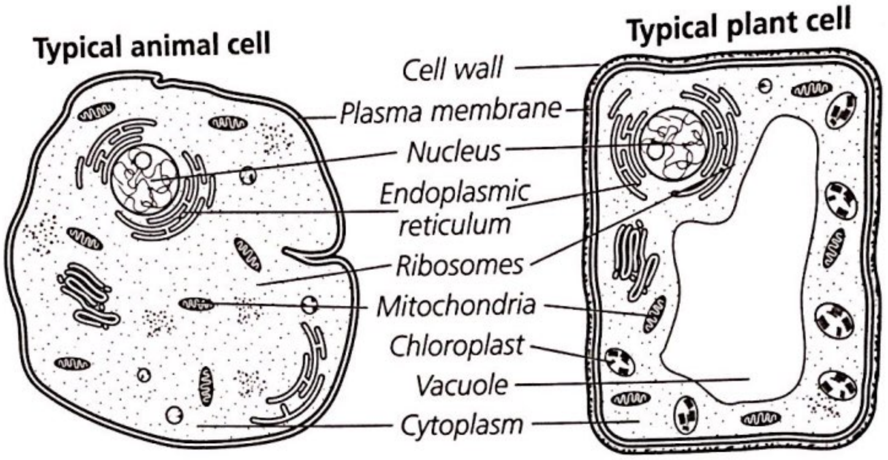
There are two kinds of **endoplasmic reticulum,** rough and smooth. Rough ER has ribosomes attached to the surface and produces proteins. Smooth ER is involved in the production of fatty acids and lipids. No ribosomes are attached to smooth ER.

A *vesicle* is a small membrane sac inside the cell, which may contain material for transport.

The **Golgi apparatus** is an organelle that processes materials for release from the cell.

Chloroplasts are plant organelles that transform sunlight into chemical energy.

Chlorophyll is the pigment that makes plants green.



Each organelle in a cell has a specific function.

Surrounding the plasma membrane of the plant cell is a rigid *cell wall*, which supports and gives structure to plant bodies. The large *central vacuole* is an organelle that stores water, nutrients, wastes, and other material. While animal cells may contain smaller vacuoles, they lack the large central vacuoles of plant cells. When filled with liquid, the plant cell's vacuole exerts pressure against the cell wall. This makes the plant rigid.

In addition to animals and plants, eukaryotes include fungi and protists, such as paramecia. Fungi and protists may share some of the characteristics of plants or animals, or may have unique characteristics. Fungi have cell walls, but they are composed of chitin rather than cellulose, as in plants.

The plant *cell wall* is a structure on the outside of the plasma membrane. It is made of cellulose.

The large *central vacuole* stores water, nutrients, and other material in a plant cell.

Plant cells contain some organelles not found in animal cells. Describe **two** organelles that play major roles in plant cells but not animal cells.

One structure found in plant cells but not in animal cells is a cell wall, a stiff outer layer that surrounds the plasma membrane and gives a cell rigidity and strength. Another structure is a chloroplast, an organelle where photosynthesis occurs. A third structure is the vacuole. Although small vacuoles can be found in other types of cells, a large central vacuole plays a major structural role in plant cells. It also stores water and nutrients for the cell. These roles require them to be much larger in plant cells than in animal cells.

IT'S YOUR TURN

Please read each question carefully. For a multiple-choice question, circle the letter of the correct response. For a constructed-response question, write your answers on the lines.

1 A mitochondrion produces ATP for energy. A plant's leaves turn toward the direction of sunlight. A bacteria cell secretes a waste product through its plasma membrane. Which characteristic of life do **all** of these examples describe?

- **A** growing and reproducing
- **B** obtaining and using energy
- **C** response to external stimuli
- **D** maintenance of homeostasis

2 Which do the cells of an *E. coli* bacterium and an elephant have in common?

- **A** ribosomes to assemble proteins
- **B** mitochondria to produce energy
- **C** chloroplasts found around the vacuole
- **D** chromosomes located in the cytoplasm

3 A cell from which organism would **most likely** be smallest?

- **A** a sugar maple tree
- **B** a five-spotted ladybug
- **C** a *Saccharomyces* yeast
- **D** a *Lactobacillus* bacterium

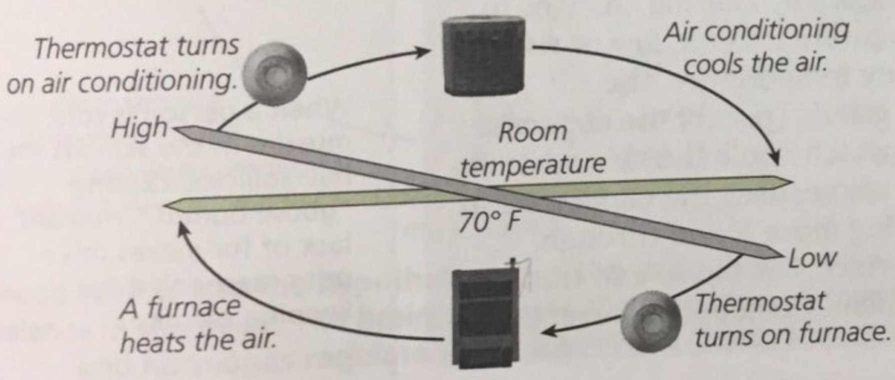
4 Which statement correctly pairs the organelle with its function?

- **A** The vacuole stores genetic information.
- **B** The chloroplast synthesizes proteins from amino acids.
- **C** The nucleus absorbs the sun's energy for photosynthesis.
- **D** The plasma membrane controls the flow of materials into the cell.

Every cell or complex organism is a **system**—a set of components that interact to produce something greater than the sum of its parts. Living systems work to maintain consistent internal states because changes in temperature or pH can affect their ability to function. All living things perform a balancing act in which internal conditions—including temperature, water, glucose, and oxygen—are regulated and maintained within specific ranges. This process is called **homeostasis.**

Thermoregulation

To maintain homeostasis, the body may rely on a cycle of monitoring and responding to internal conditions, called a *negative feedback loop.* This **homeostatic mechanism** is similar to the central heating and cooling system in a home. The home's thermostat is set to the desired temperature (say, 70°F). It detects the actual temperature of the air and, if it is lower or higher than desired, the thermostat affects the furnace or air conditioning. For example, if the detected air temperature is 74°F, the thermostat causes the air conditioning unit to turn on and cool the air. By continually sensing the air temperature, the thermostat ensures that the temperature remains around the set point.



A thermostat controls the heating and cooling systems, returning the home's temperature to a set point.

Negative feedback loops also regulate the body's internal states. Normal human body temperature is 37.0°C (98.6°F), and when it strays too far from this point, changes take place throughout the body to bring it back to normal. The hypothalamus of the brain senses the temperature of the blood passing through it. If temperature is too high or low, the hypothalamus sends signals to various parts of the body that cause it to release or retain heat. The mechanisms by which the body regulates temperature include shivering, perspiration, and the dilation (widening) or constriction (tightening) of the tiny blood vessels in the skin.

Homeostasis refers to the maintenance of a constant internal state. Glucose, water, temperature, and pH levels in the blood are maintained at constant levels.

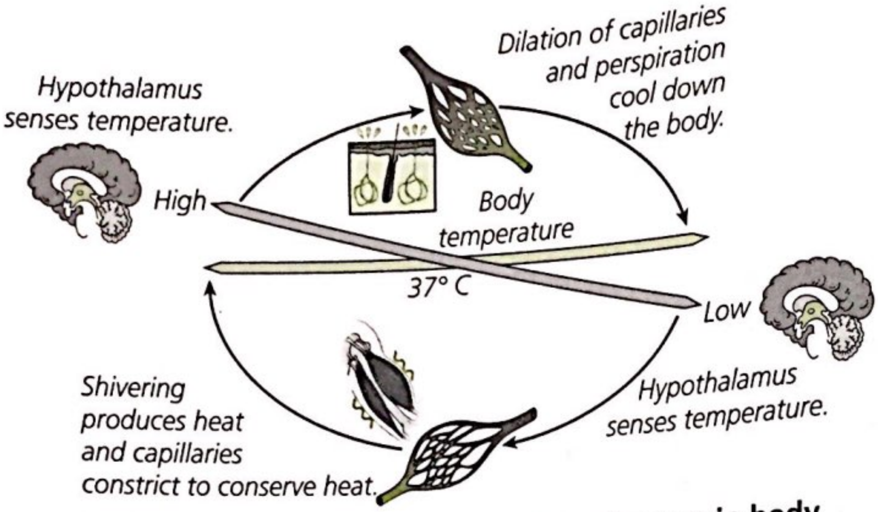
The processes by which an organism monitors and maintains a constant state, such as temperature, is a **homeostatic mechanism.**

Internal conditions are not perfectly constant. Instead, they vary slightly as the body returns them to set points, a process called *dynamic equilibrium.*

A *negative feedback loop* is so called because any change to a system causes the system to return to its original state.

In contrast, a *positive feedback loop* amplifies a change to the system, causing it to move farther and farther from its original state. Contractions of the uterus during childbirth are controlled by a positive feedback loop. They grow stronger and more frequent until childbirth is achieved.

The *hypothalamus* is an area deep within the brain that senses and regulates many of the body's internal states. It acts as the body's thermostat.



The hypothalamus of the brain detects changes in body temperature and instructs the body to conserve or release heat.

The human body maintains a constant internal temperature of 98.6°F. Which changes occur when the hypothalamus detects a temperature of 100.1°F?

A Muscle tissue shivers and skin capillaries dilate.

B Perspiration increases and skin capillaries dilate.

C Muscle tissue shivers and skin capillaries constrict.

D Perspiration increases and skin capillaries constrict.

The brain regulates body temperature by causing changes to other organ systems when temperature falls too low or rises too high. In the case of high body temperature, the hypothalamus causes the sweat glands (part of the endocrine system) to release more sweat, which cools the skin when it evaporates. The hypothalamus also causes the capillaries in the skin to dilate (widen), allowing more blood through. Because it is near the body's surface, the blood can transfer some of its heat to the environment. Choice B is correct.

Osmoregulation

Water is a critical component of life. Organisms must carefully regulate the balance of water and solutes (dissolved molecules and ions) in their bodies, a process called *osmoregulation*. The challenges of osmoregulation vary, depending on the organism's environment.

The fresh water of lakes and rivers is *hypotonic* to the cells of living things. Organisms that live in freshwater environments are faced with excess water entering the body and the loss of solutes. Freshwater fish, for example, excrete very dilute urine to eliminate excess water.

Thermoregulation **is the regulation of body temperature.**

Mammals are considered *endothermic* because our body temperature is independent of the external environment.

Reptiles and amphibians are considered *ectotherms* because they rely on the environment to regulate body temperature.

Perspiration cools the body through *evaporative cooling:* as sweat evaporates, it absorbs heat from the skin.

When a person is cold, tiny muscles in the skin lift the hair follicles, causing "goose bumps." Humans' lack of fur makes this a poor mechanism for keeping warm.

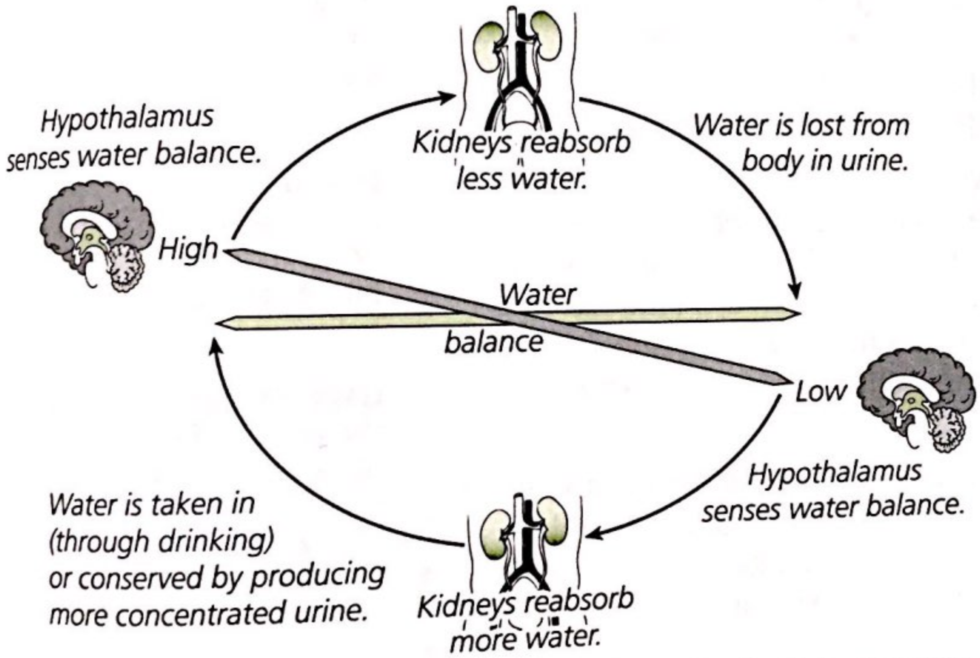
A freshwater environment is *hypotonic* to most organism's cells.

The saltwater marine environment is *isotonic* to most animals, such as fish. However, the solutes in seawater differ from those in the animals' bodies.

Organisms that inhabit saltwater oceans and seas are *isotonic* to their environment. However, they must find ways to retain the solutes they need and eliminate the excess sodium and chloride ions in seawater. Marine fish have specialized gill cells that excrete excess chloride ions.

The challenge for land animals is to conserve water. To achieve this, their urine is much more concentrated than their blood, containing a high ratio of solutes to water. This allows them to excrete excess solutes while conserving water. In the kidneys, the blood is first filtered into an intermediate fluid. Then, the kidneys reabsorb water and useful solutes from this fluid. By controlling reabsorption, the body can control how much water is lost in urine.

Another mechanism for maintaining water balance is the sensation of thirst. The brain sends signals to the mouth and throat that produce a feeling of dryness. This creates a drive (motivation) to drink fresh water, replacing the water that the body has lost.



Blood vessels and the hypothalamus of the brain detect water balance in the body. The brain produces the sensation of thirst and hormones regulate water loss in the kidneys.

Land animals constantly lose water through evaporation, perspiration, and urination. Water balance must be maintained to prevent dehydration. In mammals, the hypothalamus of the brain senses the concentration of solutes in cells. Nerve signals from special blood vessels sense the amount of fluid in the blood. These signals tell the hypothalamus whether the body needs to take in and conserve water, or whether excess water should be excreted. The brain produces hormonal signals that affect the amount of water the kidneys reabsorb.

Some prokaryotic organisms are adapted to the extremely salty, *hypertonic* environments of the Great Salt Lake and the Dead Sea.

The feeling of thirst, which motivates you to drink, is the body's way of maintaining water balance. A loss of as little as 1% of the body's water can produce this sensation.

The body senses both the volume of water outside the cells (such as blood) and the concentration of solutes inside the cells.

Dehydration is dangerous because it changes the concentration of solutes in the body. The water lost in perspiration and urine must be replaced by drinking and eating.

A paramecium is a single-celled protist. Its contractile vacuole is an organelle that pumps water out of the cell. What can you conclude about the paramecium's environment?

The contractile vacuole removes excess water from the paramecium. The paramecium must therefore inhabit an environment that is hypotonic to the cell. It most likely lives in a freshwater environment, such as a pond or lake.

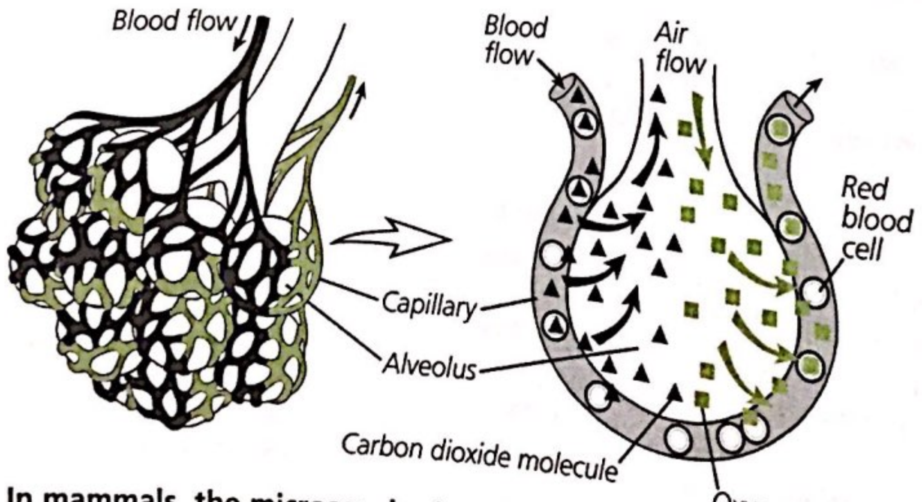
Gas Exchange

The body's cells require oxygen to carry out respiration, which produces carbon dioxide. The levels of dissolved oxygen and carbon dioxide in the blood must be regulated to allow respiration to take place.

Fish perform gas exchange through the gills. Water flows over the capillaries in the gills, which contain a higher concentration of carbon dioxide and a lower concentration of oxygen than the surrounding water. These differences cause carbon dioxide to move into the water and oxygen to move into the bloodstream, through passive transport.

Mammals perform gas exchange through passive transport within the lungs. Capillaries, tiny blood vessels, surround each of the microscopic air sacs in the lungs called *alveoli.* The blood flowing to the alveoli contains too much carbon dioxide and too little oxygen. Carbon dioxide in the capillaries crosses the surface of the alveoli and enters the air inside. Oxygen in the alveoli crosses in the other direction, into the capillary blood.

When cells use up oxygen more quickly, such as during strenuous exercise, the body compensates by moving air into and out of the lungs faster. This increases the rate of gas exchange and helps to maintain the levels of oxygen and carbon dioxide in the bloodstream.



In mammals, the microscopic alveoli of the lungs are surrounded by capillaries. Gases are exchanged between the air inside the alveoli and the blood flowing through the capillaries.

The elimination of carbon dioxide and the intake of oxygen is called gas *exchange.*

Fish gills use a *counter-current exchange system* in which capillary blood moves opposite to the flow of water. This makes gas exchange more efficient.

Carbon dioxide dissolves to form a weak acid. If too much carbon dioxide is present, the pH level of the blood can fall dangerously low.

Gas exchange in gills and the alveoli of lungs takes place through passive transport. Gases move from where they are more concentrated to where they are less concentrated.

The hemoglobin protein in red blood cells helps to bind oxygen molecules.

Air pressure helps to push oxygen into the capillaries. At higher altitudes, air pressure is lower. What is the effect of moving to higher altitudes on the human body? How can the body compensate, in the short and long term, to maintain homeostasis?

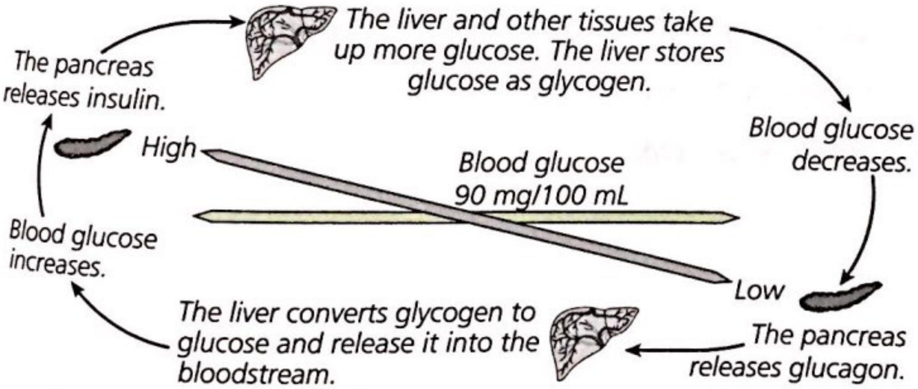
At higher altitudes, less oxygen will enter the bloodstream and the cells of the body will receive less oxygen. The body can temporarily compensate by increasing breathing rate. After some time, the body increases the number of red blood cells in the blood, which helps it to take in more oxygen from the alveoli.

Regulation of Blood Glucose

The human body requires a blood glucose level of around 90 mg/100mL. If it falls too low or rises too high, homeostatic mechanisms bring it back into range. The control of glucose is achieved through a negative feedback loop, as shown in the diagram. The organ that senses blood glucose levels is the pancreas.

When the pancreas detects high glucose levels, it releases the *hormone* insulin. Insulin causes the cells of the muscles, liver, and other tissues to allow more glucose to cross the plasma membrane. The liver converts this glucose to glycogen. As a result, blood glucose falls back to normal.

When blood glucose is lower than 90 mg/100mL, the pancreas secretes another hormone, glucagon. Glucagon has the opposite effect on the liver, causing it to break down stored glycogen and release the glucose into the bloodstream. These changes bring about homeostasis.



A negative feedback loop regulates blood glucose levels. Hormones produced by the pancreas drive this process.

After skipping a meal and exercising, a body's blood glucose falls to 85 mg/100 mL. What changes will occur in the body?

The pancreas responds by secreting the hormone glucagon. This causes the liver to break down glycogen to its monomer, glucose, and release the glucose into the bloodstream.

A *hormone* is a chemical signal that is released into the blood by endocrine organs. Hormones reach all tissues, but affect only those tissues with specific receptor proteins on their surfaces.

Glucose is the simple sugar that cells break down for energy. Glycogen is the macromolecule that animals form as a way to store glucose. The liver stores glycogen and releases it as glucose when needed.

Diabetes is a disorder of blood glucose homeostasis. In type I diabetes, the pancreas does not produce enough insulin. In type II diabetes, the tissues do not respond to the insulin in the blood.

IT'S YOUR TURN

Please read each question carefully. For a multiple-choice question, circle the letter of the correct response. For a constructed-response question, write your answers on the lines.

1 Which of the following would **best** help to maintain homeostasis when a person's internal body temperature reaches 97.5°F?

A shivering

B perspiring

C dilation of capillaries

D formation of goose bumps

2 Some animals excrete nitrogen-containing wastes as urea in urine. Others excrete uric acid in the form of a thick paste. In which type of environment does the excretion of uric acid provide the greatest advantage?

A a desert ecosystem

B a rainforest ecosystem

C a freshwater pond ecosystem

D a saltwater marine ecosystem

3 Which is **not** an example of an organism maintaining homeostasis?

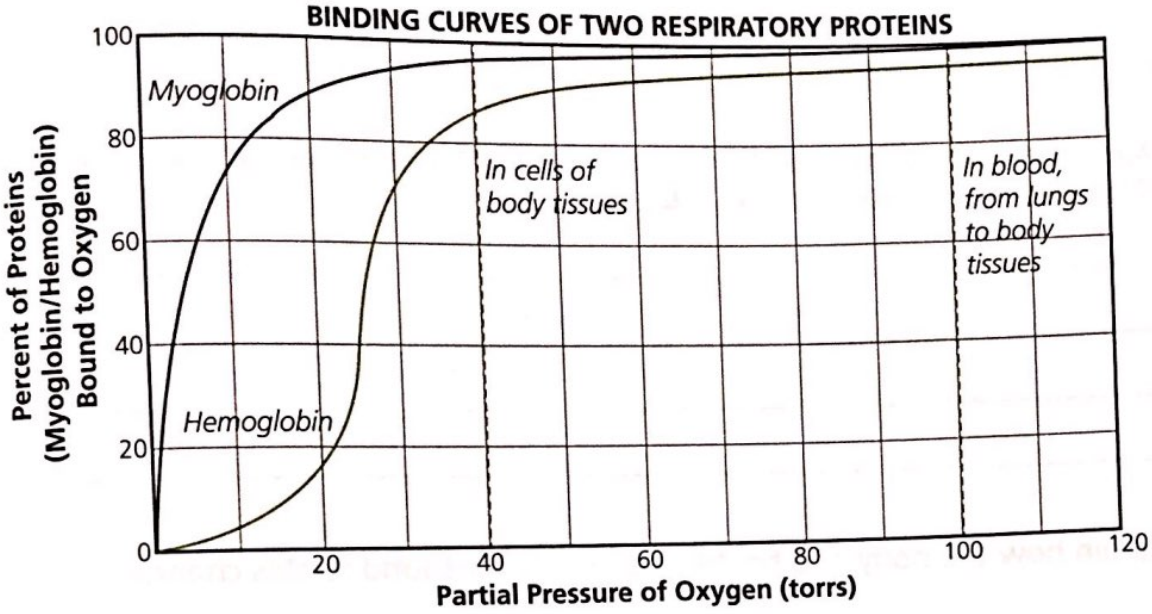
A A jogger stops to drink at a water fountain.

B A turtle spends hours sitting on a sunny rock.

C A deer seeks out salty foods to add to its diet.

D A rabbit hides among grasses to avoid a hawk.

Use the graph below to answer question 4.



4 Myoglobin and hemoglobin are two proteins that bind to oxygen. Hemoglobin is present in red blood cells. Myoglobin, a similar protein, is present in muscle cells. The amount of oxygen dissolved in body fluids is measured as partial pressure. The graph above shows the percent of each protein that is bound to oxygen at different partial pressures. How does the binding of oxygen by myoglobin affect oxygen homeostasis?

A It reduces the amount of oxygen in the cells of body tissues.

B It increases the amount of oxygen in the alveoli of the lungs.

C It reduces the amount of oxygen in the blood returning to the lungs.

D It increases the amount of oxygen in the blood leaving the body tissues.

5 The digestive system breaks down food to basic components, such as glucose. These molecules are then absorbed into the body.

A person consumes a large meal.

A Explain how the consumption of the meal will affect blood glucose, which is normally maintained at 90 mg/mL.

B Explain how the body of a healthy person will respond to this change.

C In type II diabetes, the body tissues become less sensitive to insulin. Explain how the response of a person with type II diabetes will differ from that of a healthy person.