Honors packet Instructions

The following are guidelines in order for you to receive FULL credit for this bio packet:

1. Professionally skim through the following packet.
    a. Annotate only the information necessary for you to write your preferred essay question. *There are two to choose from and I have included readings for both… it is a lot, so please use your brainpower wisely with this packet*
2. Answer the multiple choice questions correctly and JUSTIFY your answer
    Example Question: "Which of the following organelles is involved in photosynthesis?
    a) The mitochondria
    b) The endoplasmic Reticulum
    c) The liver
    d) The chloroplast
    Example answer: The correct answer is D because the chloroplast is an organelle that contains chlorophyll a pigment directly associated with Absorbing light from the sun. the other organelles listed have other functions throughout the cell, and the liver isn't an organelle at all.
3. Complete one the essay responses

you do not have to print out the packet in order to take notes and complete the quiz

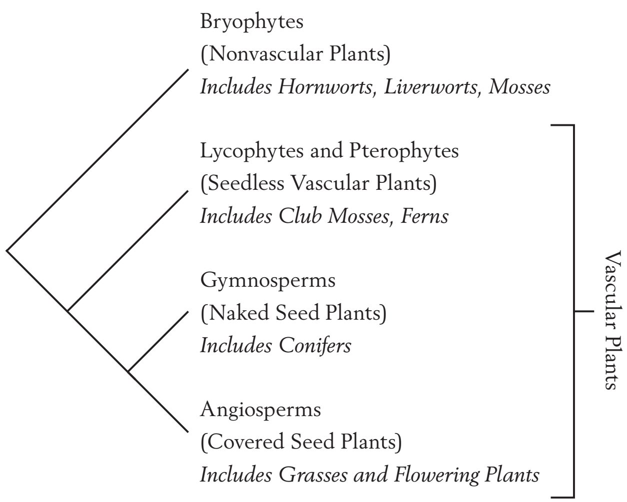
I HIGHLY ENCOURAGE YOU TO WORK IN STUDY GROUPS FOR THIS PACKET

See wynn for questions!

Review Chapter 11: Plants

The Diversity of Plants

Plants, from tiny mosses to giant redwoods, are found on almost every continent on Earth. Plants evolved from a species of green algae and have since adapted to terrestrial life. The phylogenetic tree shows the relationships among major groups of land plants.



Bryophytes, which include true mosses, liverworts, and hornworts, are *nonvascular* plants. They lack vascular (transport) tissues and therefore remain small. Bryophytes have an important adaptation to land: a tough-walled spore that can travel outside of water without drying out. A *spore* is a haploid cell that undergoes mitosis to produce a multicellular, haploid organism. (Bryophytes have haploid and diploid generations, as described in the next section.)

The remaining groups are the *vascular* plants. The lycophytes and pterophytes (including ferns) still share an important characteristic with bryophytes: they produce spores instead of seeds. However, these plants are able to transport water and dissolved nutrients from their roots to their leaves through a vascular system.

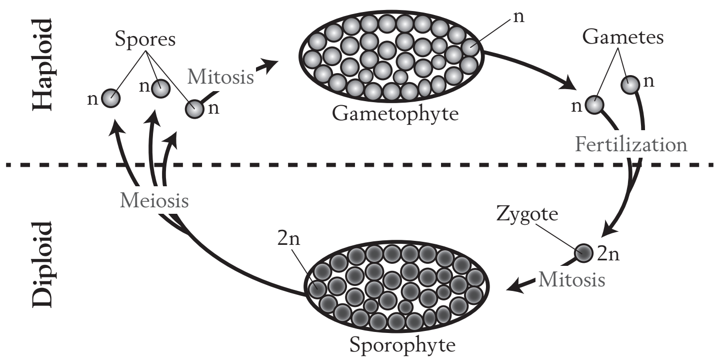
Among vascular plants, gymnosperms and angiosperms produce seeds instead of spores. A *seed* is an embryonic plant that is enclosed, along with food, in a protective covering (called an *integument*). Gymnosperms ("naked seed" plants) have seeds that are partially exposed to the air. Gymnosperms include conifers such as pine, fir, and spruce trees, as well as cycads and gingko trees.

Angiosperms, or flowering plants, produce seeds that are completely encased in an integument. Many angiosperms produce fruits or starchy grains associated with seeds. Angiosperms include deciduous trees, grasses, and all other flowering plants. Almost all agriculturally important plants are angiosperms.

Alternation of Haploid and Diploid Generations

All plants alternate between haploid and diploid generations, or forms. However, plants vary in the generation that forms the mature, or adult, plant. The diploid sporophyte form undergoes meiosis, giving rise to haploid spores. The spores divide mitotically to form a haploid plant body called a *gametophyte*. The gametophyte produces gametes (sperm and egg cells) via mitosis. (Compare to animals, which form gametes directly from the diploid body through meiosis.) Gametes join in fertilization to produce the diploid zygote, which divides mitotically to form the sporophyte generation.

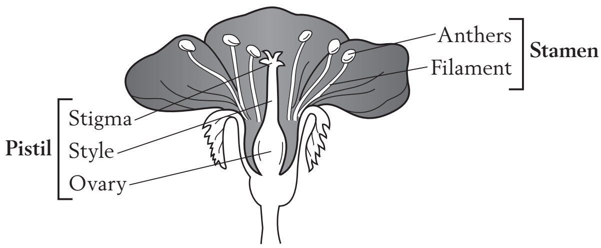
The diagram below summarizes the cycle of plant generations. Note that in mosses, the haploid gametophyte is the dominant generation. The green mosses visible on trees or in soil are all haploid gametophytes.



PLANTS	DOMINANT GENERATION	HAPLOID FORM (VIA MEIOSIS)	DIPLOID FORM (VIA FERTILIZATION)
Nonvascular plants (for example, mosses)	Haploid gametophyte	Spores that form the adult plant, which produces sperm and eggs; occurs by mitosis	Zygote, which forms inside the gametophyte; the sporophyte is a small structure dependent on the gametophyte; it produces and releases spores
Seedless vascular plants (for example, ferns)	Diploid sporophyte	Spores that divide mitotically to form small, leaf-like, free-living gametophytes, which produce gametes	Zygote and young and adult plants; adult plants produce haploid spores
Gymnosperms and angiosperms	Diploid sporophyte	Pollen grains and the interiors of ovules	Seeds and young and adult plants

Reproduction in Flowering Plants

Angiosperms are characterized by flowers, seeds, and fruits. (Note that not all angiosperms produce "showy" flowers or fruits.) The structure of a typical flower is shown below.



Pollen is produced in the anthers of the stamens. *Pollination*, the transfer of pollen to the stigma, may be carried out by insects, or the pollen may be dispersed by wind. A tube cell in the pollen grain forms a tube from the stigma, through the style, and into the ovary. Pollen also contains two sperm cells. One sperm cell fertilizes the egg cell to form the zygote, which divides mitotically to form the plant embryo contained in the seed. The other sperm cell combines with two nuclei in the ovule, forming a triploid cell. This gives rise to endosperm, the nutrient-rich, starchy tissue that provides food for the embryo within the seed.

Angiosperms: Monocots and Dicots

Most flowering plants fall into one of two main groupings: monocotyledons and dicotyledons. These groups are named for the number of seed leaves (cotyledons) in the embryonic plant. Monocots include palm trees, orchids, and grasses (which include economically important cereal crops, such as corn, wheat, and rice). Monocots do not produce true wood. Dicots include many fruit- and vegetable-producing plants and trees that produce hardwoods (for example, oaks, maples, birches). The criteria for distinguishing monocots and dicots are summarized in the table shown.

COTYLEDONS	PETALS	LEAVES	ROOTS	XYLEM AND PHLOEM
		MONOCOTS		
One	Multiples of three	Veins run parallel along the leaf	Fibrous root system with no main root	Distributed throughout stem
		DICOTS		
Two	Multiples of four or five	Veins branch out in a net	One main taproot, with smaller roots growing from it	Arranged in a ring

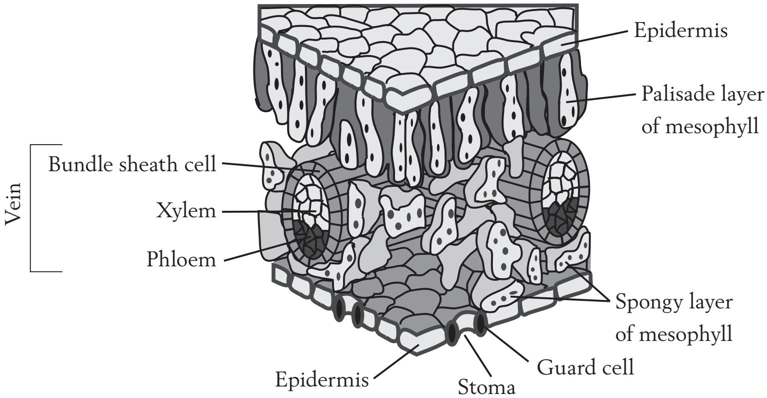
Plant Tissues and Organs

The basic body plan of a plant consists of a root system, which absorbs water and dissolved nutrients from the soil; and a shoot system, which carries out photosynthesis and transports nutrients to the roots. Vascular tissues distribute needed materials throughout the root and shoot systems. Nearly every part of a plant consists of tissue from three types or systems: dermal, vascular, and ground.

- *Dermal*. This is the "skin" of the plant, and includes the root covering, epidermis, and leaf cuticle.
- *Vascular*. This includes xylem and phloem in the plant's roots, stem, and leaves.
- *Ground*. This includes all other tissues that regulate dermal and vascular tissue and carry out photosynthesis.

Leaves

Plant leaves play primary roles in photosynthesis and water regulation. The structure of a plant leaf is shown, with its components described on the following page.



- *Epidermis*. These cells form the upper and lower surfaces of the leaf. They are covered in a protective cuticle and contain openings called *stomata*. The openings allow gas exchange between the air and the leaf cells and may be closed to prevent the loss of water from the leaf.
- *Mesophyll*. This middle layer of the leaf carries out photosynthesis. The mesophyll cells in the upper palisade layer are elongated and tightly packed. The lower, spongy layer is more loosely arranged. Spongy mesophyll cells are key in gas exchange between the mesophyll and the air spaces in the leaf.
- *Vein (vascular bundle)*. The leaf vein consists of xylem and phloem cells surrounded by bundled sheaf cells. Materials pass through this outer ring of cells, into and out of the mesophyll.

Vascular Tissues

Vascular tissues transport saps consisting of water, minerals, sugars, and other compounds throughout the plant body. Vascular tissues include xylem and phloem.

- *Xylem*. Xylem conducts water and minerals from a plant's roots to its leaves. Xylem is composed of dead, elongated cells called *tracheids* and *vessel elements*.
- *Phloem*. In contrast, the sugar-transporting phloem consists of living cells. Sap moves along long, narrow sieve cells; in angiosperms,

these are called *sieve-tube members*. These cells are regulated by companion cells that lie alongside them.

Water Transport and Regulation

Water is essential to land plants, which must absorb it from the soil and transport it, sometimes hundreds of feet, to the highest leaves. Two forces affect water transport: root pressure and transpiration. Transpiration is regulated by the opening and closing of stomata.

- *Root pressure*. Water and dissolved minerals from soil enter plants through the roots. A waxy layer within the root, the Casparian strip, prevents water from entering vascular tissue via the spaces between cells. Water must pass through the selective plasma membrane of root endodermis cells. Endodermis cells pump mineral ions (such as potassium, K^+) into the vascular tissue. This increases the amount of water entering the vascular tissue by osmosis. This process creates root pressure, a "push" of water into the plant. Root pressure plays a much smaller role in water transport than transpiration.
- *Transpiration*. Water in the leaf is lost to the environment as vapor that exits through the stomata. This water loss is called *transpiration*. Transpiration causes water from within cells to enter the spaces within the leaf. However, this water must be replaced by water in the xylem. Transpiration pulls water from the veins into plant leaves. Because of water's high cohesion (stickiness between water molecules) and adhesion (stickiness to vascular tissue surfaces), the pull of transpiration acts down the length of the plant. It is primarily responsible for the upward flow of sap through the xylem.
- *Stomata*. These openings in the leaf epidermis control transpiration by regulating the loss of water from the leaves. The pore in each stoma is surrounded by two guard cells, which can expand to open when turgid or wilt to close.

The guard cells pump potassium ions into their vacuoles. This causes water to enter via osmosis, increasing the pressure in the cell and causing turgor. The swollen guard cell opens, allowing gas exchange through the stomata. When water pressure is low, temperature is high, or it is night, potassium ions exit the guard cells, pulling water after them. The wilted guard cells block the stomata opening, preventing water loss from the plant.

Plant Growth

Plants have indeterminate growth thanks to tissues called *meristems*, which consist of cells that can differentiate to form new shoots, roots, and leaves. Apical meristems are located on the tips of shoots and roots and are responsible for *primary* growth, which increases a plant's length. The apical meristem is surrounded by leaf primordia, which form new leaves. During primary growth, meristem cells are left behind at the bases of leaves, forming axillary buds. *Apical dominance* refers to the fact that apical meristems suppress the development of nearby axillary meristems. As the plant grows, the axillary buds may develop and form new leaves or branches.

Lateral meristems are located inside the trunks and roots of woody plants and are responsible for increases in thickness. Vascular cambium and cork cambium are both lateral meristems.

Hormones and Growth

Plant growth is regulated by hormones, chemical signals that are produced in one plant tissue and cause a response in other tissues. The hormone auxin was discovered in studies of phototropic responses in grass seedlings (coleoptiles). A *tropism* is a response toward or away from a stimulus; *phototropism* refers to a plant's bending toward a light source. Plant hormones are summarized below.

- *Auxin* stimulates the growth and differentiation of roots and shoots in fruit and causes tropic responses.
- *Gibberellin* stimulates growth of stems and leaves and stimulates flower and fruit development.

- *Abscisic acid* inhibits growth and germination and causes stomata to close.
- *Ethylene* ripens fruit and may stimulate or inhibit plant growth.
- *Cytokinin* regulates root growth and stimulates the germination of seeds.
- *Brassinosteroid* inhibits root growth as well as leaf abscission.

Review Questions

1. Which of these plant forms are diploid?

   I. Spore
   II. Sporophyte
   III. Gametophyte

   A. I only
   B. II only
   C. III only
   D. I and II
   E. II and III

2. Which of these correctly matches the plant cells to their tissue systems?

   I. Guard cell
   II. Palisade mesophyll cell
   III. Sieve-tube member

   A. I = dermal; II = ground; III = vascular
   B. I = dermal; II = vascular; III = ground
   C. I = ground; II = dermal; III = vascular
   D. I = ground; II = vascular; III = dermal
   E. I = vascular; II = ground; III = dermal

3. Which of these is/are responsible for an increase in the thickness of a plant?

   I. Apical meristem
   II. Vascular cambium
   III. Cork cambium

   A. I only
   B. II only
   C. III only
   D. I and II
   E. II and III

4. Which of these describes a difference between monocots and dicots?

   A. Monocot embryos form two leaves; dicot embryos form a single leaf.
   B. Monocot flowers may consist of five petals; dicot flowers may consist of six petals.
   C. Monocot leaves have a branching network of veins; dicot leaves have parallel veins.
   D. Monocot roots consist of many small roots growing from a taproot; dicot roots lack a taproot.
   E. Monocot vascular tissue is arranged randomly in the stem; dicot vascular tissue is arranged in a ring.

5. Which of these increase the movement of sap within the xylem?

   I. Water moves into guard cells' vacuoles.
   II. Humidity increases in surrounding air.
   III. Root endodermis prevents ions from entering xylem.

   A. I only
   B. II only
   C. I and III
   D. II and III
   E. I, II, and III

Answer Explanations

1. **B**. Only the sporophyte is diploid. The sporophyte produces haploid spores, which divide mitotically to produce the gametophyte. The gametophyte produces haploid gametes.

2. **A**. Guard cells, which make up the stomata of the epidermis, are classified as dermal tissue. Palisade mesophyll cells, which carry out photosynthesis, are classified as ground tissue. Sieve-tube members, which make up the phloem, are classified as vascular tissue.

3. **E**. The vascular cambium and the cork cambium are forms of lateral meristem, which increase the thickness (secondary growth) of woody plants. The apical meristem increases the length of a plant (primary growth) only.

4. **E**. Monocot vascular tissue is arranged randomly in the stem, while dicot vascular tissue is arranged in a ring. All other answer choices have characteristics reversed.

5. **A**. Water moving into guard cells increases turgor pressure, causing them to swell. Swollen guard cells open the stomatal pore, allowing water vapor to exit the leaf via transpiration. This, in turn, draws water up from the roots. In contrast, increasing humidity decreases water loss from the leaves. Root endodermis increases root pressure by pumping ions into the xylem.

Review Chapter 12: Animal Organ Systems, Part 1

Animals are complex, multicellular organisms. They must coordinate the actions of many specialized cells and tissues in order to meet the basic cellular needs: obtain nutrients and oxygen; dispose of carbon dioxide and other metabolic wastes; maintain osmotic (water) balance; and keep conditions within a narrow, optimal range for biochemical reactions. These functions are summed up by the term *homeostasis*. This chapter describes how the major mammalian body systems help to maintain homeostasis and carry out other life functions. A comparison with other types of animals is also provided.

The Muscular and Skeletal Systems

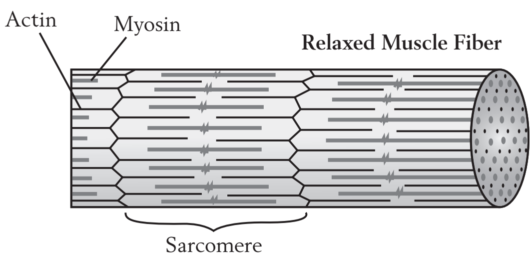
The muscular and skeletal systems function in locomotion, as well as in gas exchange and digestion. Mammalian muscle tissues are divided into three types, as follows:

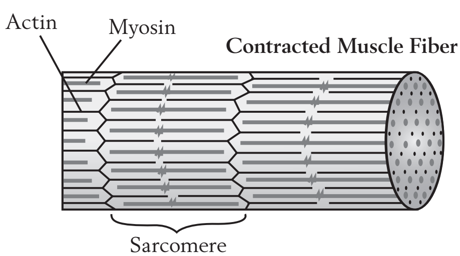
- *Skeletal muscle* is found beneath the skin and attached to bone. Voluntary contractions of skeletal muscles allow movement. Skeletal muscle has striations (stripes) due to the arrangement of muscle fibers.
- *Smooth muscle* lines the bladder, digestive tract, and arteries. It lacks striations and is not under voluntary control.

- *Cardiac muscle* is found in the heart. It shares characteristics of both smooth and skeletal muscle.

Contracting Muscle Fibers

Muscle fibers are long, thin, multinucleated cells packed together to make up muscle tissue. Each muscle fiber contains long strands made up of the proteins actin and myosin. Actin and myosin filaments are arranged in units called *sarcomeres*, as shown below; note how they partially overlap. When a muscle fiber is stimulated, the region of overlap increases, causing the fibers to contract. This is the sliding-filament model of muscle contraction.





Opposing Muscles Contract

Tendons attach muscles to the bones of the skeleton. Because muscles can only voluntarily contract but cannot extend, they often work in opposing pairs. As one muscle contracts, the opposing muscle is extended, and the limb moves toward the contracting muscle. To move the limb in the opposite direction, the opposing muscle must contract.

Skeletal Joints

Joints between bones allow for a range of motion. The following describes some of the joints in the body. Note that some structures in the body may include a combination of joint types.

- *Ball-and-socket joints* allow for the rotation of limbs. They occur where the upper arm bone attaches to the shoulder and where the upper thigh bone attaches to the hip.
- *Hinge joints* allow swinging motion in one dimension. Hinge joints can be found at the elbows and the knees.
- *Pivot joints* allow rotational motion in one dimension. They can be found at the elbows and neck.
- *Saddle and condyloid joints* allow movement in two planes. They are found in the hands, feet, wrists, and ankles.

Comparison: Hydrostatic Skeleton

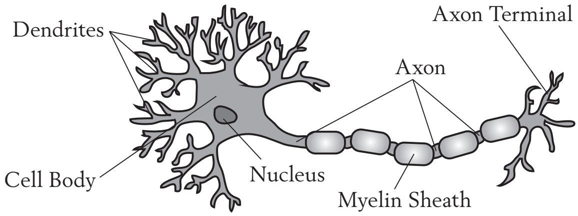
Contraction of opposing muscle pairs also occurs in organisms with exoskeletons (for example, arthropods). Animals that lack a skeleton (for example, annelids) may use a hydrostatic skeleton—fluid in a closed sac. Pressure applied to one part of the sac is distributed throughout the fluid, affecting other regions of the sac. For example, an earthworm contracts segments of its body, elongating other segments and thus moving forward.

The Nervous System

The cells of the brain, spinal cord, and body receive signals from the environment, process information, and carry out movements. They make up the nervous system, which includes cells called *neurons*.

Neurons and Action Potentials

A neuron consists of dendrites, which receive signals from other neurons; a cell body that contains the nucleus; and an axon that transmits a signal down its length and through the terminal branches. Cells called *glia* form myelin, which wraps around and insulates the axons of some cells. The long axons of neurons make up nerve fibers, and clusters of neuron cell bodies constitute ganglia.



Electrical signals called *action potentials* travel through neurons. An action potential results from a temporary shift in the balance of positively and negatively charged ions inside and outside the cell membrane. Action potentials are initiated when sodium ion (Na^+) channels are opened, allowing sodium into the cytoplasm. The balance is restored when potassium ions (K^+) exit the cytoplasm.

Neurotransmitters

Besides action potentials, the nervous system uses chemical messengers called *neurotransmitters*. When an action potential reaches the terminal axon branches, neurotransmitter molecules are released into a space called a *synapse*. Here, they bind to receptor proteins on the membrane of the adjacent cell's dendrites. Neurotransmitters affect the sodium and potassium channels of the cell and can create a new action potential. Serotonin, acetylcholine, and dopamine are examples of neurotransmitters.

Divisions of the Nervous System

The two major divisions of the nervous system are the central nervous system (CNS), which includes the neurons of the brain and spinal cord; and the peripheral nervous system (PNS), which includes all other neurons and originates in the cranium and between the vertebrae. The PNS is further divided into somatic and autonomic systems. The somatic system links the skeletal muscles to the CNS. The autonomic system regulates involuntary muscles and endocrine glands. It consists of the following divisions:

- *Sympathetic*. This division results in arousal and alertness, stimulating production of the "fight or flight" hormones (epinephrine and norepinephrine), increasing heart rate, and easing breathing.
- *Parasympathetic*. This division promotes "rest and digest" activities. It slows the heart rate, constricts the lungs, and stimulates the digestive organs.
- *Enteric*. This division controls the digestive organs and can be regulated by the other two autonomic divisions.

Comparison: Nerve Nets and Nervous System Complexity

Almost all animals are capable of motion due to the existence of a nervous system, whether simple or complex. The simplest type of nervous system is the nerve net of cnidarians (jellyfish, anemones, and hydras). The next level of complexity features nerve nets that coordinate the movements of multiple body parts. Still more complex nervous systems feature a brain, nerve cord (CNS), and ganglia (neuron clusters) that innervate specific sections of the body.

The Endocrine System

Endocrine organs or glands secrete hormones into the bloodstream. A *hormone* is a substance that has specific effects on certain tissues types. Hormones function by binding to receptor proteins on the plasma membranes of target cells. This binding changes the cell's activity. Some hormones pass directly into the cell's nucleus and affect gene transcription.

The endocrine system includes the following glands and their hormones:

- *Adrenal medulla*. Epinephrine and norepinephrine, responsible for the "fight or flight" response.
- *Pancreas*. Insulin, which lowers blood glucose, and glucagon, which raises blood glucose.

- *Thyroid*. Calcitonin, which lowers blood calcium, and thyroid hormones, which increase metabolism.
- *Parathyroid*. Parathyroid hormone, which increases blood calcium.
- *Gonads (testes and ovaries)*. Androgens, which promote male secondary sex characteristics; estrogens, which promote female secondary sex characteristics and growth of the uterine lining; and progesterone, which maintains the uterine lining in pregnancy.
- *Hypothalamus*. Regulates the pituitary via gonadotropin-releasing hormone (GnRH) and other hormones.
- *Pituitary*. The "master gland"; secretes a variety of hormones, including thyroid-stimulating hormone (TSH); growth hormone (GH); antidiuretic hormone, which promotes water retention; and follicle-stimulating hormone (FSH), luteinizing hormone (LH), prolactin, and oxytocin, all of which have roles in reproduction and pregnancy.

Calcium Regulation Feedback Loop

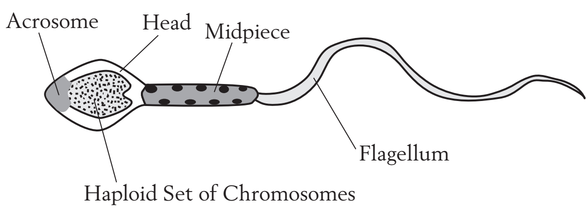
The body uses negative feedback loops to regulate internal conditions and maintain homeostasis. The level of calcium ions (Ca^{2+}) in the blood is maintained within a very narrow range. When levels fall too low or rise too high, the endocrine system responds by secreting hormones that correct the imbalance. When calcium falls too low, the parathyroid glands release parathyroid hormone (PTH). This hormone acts on the kidneys and small intestine to increase their absorption of calcium. PTH also acts on bones, causing them to break down and release calcium into the bloodstream. When calcium levels rise too high, the thyroid is stimulated to release calcitonin. This hormone causes the bones to take up calcium from the bloodstream, and the kidneys to decrease their calcium absorption.

Reproduction and Development

In mammals, both gamete production and secondary sex characteristics are regulated by sex hormones: androgens (such as testosterone), estrogens, and progesterone. Androgens are secreted in larger quantities by testes; ovaries secrete mainly estrogens and progesterone.

Production of Sperm

In males, sperm are produced inside the seminiferous tubules that make up the testes. Sperm cells then travel through the epididymis, where they develop further. From there, they exit the male reproductive tract through the vas deferentia, which pass through the prostate gland and connect to the urethra of the penis. The structure of a sperm cell is shown. Note that the head, which fuses with the egg, does not contain organelles other than a nucleus. Mitochondria packed in the midpiece ("neck") provide energy to the flagellum and allow the sperm to "swim."



The Female Reproductive Cycle

The female reproductive cycle involves hormones secreted by the hypothalamus and pituitary, which affect the ovaries, which in turn drive changes in the uterine lining. Positive feedback regulates this cycle, which consists of two phases: follicular and luteal. The follicular phase drives the maturation of a follicle, which releases the egg cell into the Fallopian tubes leading to the uterus. The estrogen and progesterone secreted by the follicle cause the uterine lining to build up.

The luteal phase is driven by the corpus luteum, which develops from the follicle. It causes the uterine lining to thicken; if the egg is fertilized, it will implant in the uterine wall, and the corpus luteum will continue to secrete hormones to maintain pregnancy. Usually, the egg is not fertilized, and the corpus luteum degenerates. This causes a drop in estrogen and progesterone, which in turn causes the uterine lining in humans to be shed via menstruation. This cycle takes an average of 28 days.

Development of the Embryo

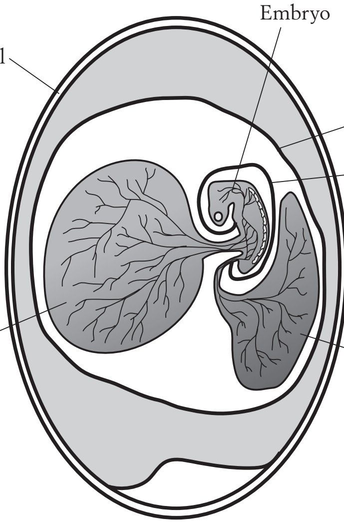
An animal develops from a single-celled, diploid zygote, which undergoes mitosis and differentiates to form tissues and organs. The zygote first undergoes *cleavage*, mitotic divisions that do not increase the size of the embryo. A cavity begins to form inside the solid ball of cells, resulting in a hollow sphere containing an inner cell mass. This stage is called a *blastocyst* in mammals. The blastocyst implants in the uterine wall, and the outer layer begins to form the placenta. After implantation, the inner cell mass undergoes gastrulation. Cells migrate to form three distinct cell populations called *germ layers*. Each layer will give rise to a specific set of tissues, as follows.

- *Endoderm*. This germ layer gives rise to the lining of the digestive system and other internal organs, as well as the pancreas, liver, thymus, thyroid, and parathyroid glands.
- *Mesoderm*. This germ layer gives rise to the muscular, skeletal, circulatory, lymphatic, excretory, and reproductive systems; the outer muscle layer of the digestive system; and the dermis of the skin.
- *Ectoderm*. This germ layer gives rise to the nervous system, several bones of the cranium, and skin epidermis. The ectoderm forms a hollow neural tube along the dorsal side of the embryo, which will form the CNS.

Comparison: The Amniotic Egg

Mammals—along with turtles, reptiles, and birds—are considered *amniotes* because they evolved from an ancestor that laid an amniotic egg. This type of egg has a leathery or hard shell that prevents the contents from drying out. Embryos produce specialized membranes that aid in gas exchange, nutrition, and protection from injury. These layers are described and shown on the next page.

- *Yolk sac*. Holds a nutrient-rich yolk that "feeds" the embryo through blood vessels.
- *Amnion*. Holds the embryo and amniotic fluid; protects the embryo.
- *Allantois*. Holds metabolic wastes; aids in gas exchange.
- *Chorion*. Exchanges gases (oxygen and carbon dioxide) with the air outside the egg.



Review Questions

1. Which of these correctly matches each structure to the germ layer from which it arises?

   I. Femur
   II. Brainstem
   III. Lungs

   A. I = endoderm; II = ectoderm; III = mesoderm
   B. I = endoderm; II = mesoderm; III = ectoderm
   C. I = ectoderm; II = endoderm; III = mesoderm
   D. I = mesoderm; II = endoderm; III = ectoderm
   E. I = mesoderm; II = ectoderm; III = endoderm

2. Which precedes an action potential traveling down the axon of a neuron?

   A. Neurotransmitters bind to receptors on the dendrite of the neuron.
   B. Neurotransmitters are released from the axon terminals of the neuron.
   C. The action potential travels through the synapse from a nearby neuron.
   D. Vesicles in the axon terminal release their contents at the synapse.
   E. The cell body releases neurotransmitters down the length of the axon.

3. A nerve leading to the small intestine causes the rate of digestion to increase. This nerve MOST LIKELY belongs to which of the following systems and divisions?

   I. Autonomic
   II. Sympathetic
   III. Peripheral
   IV. Enteric

   A. I and II only
   B. II and III only
   C. I, II, and III
   D. I, III, and IV
   E. II, III, and IV

4. Which of these is the MOST LIKELY result of blood calcium levels falling too low?

    A. The thyroid gland releases calcitonin, which binds to bone cells.
    B. The parathyroid glands release PTH, which binds to kidney cells.
    C. The thyroid gland releases thyroid hormone, which binds to small intestine cells.
    D. The pancreas releases glucagon, which binds to liver cells.
    E. The pituitary gland releases growth hormone, which binds to bone cells.

5. Which correctly describes a process or event in the female reproductive cycle?

    A. The cycle is regulated via a negative feedback loop.
    B. The corpus luteum releases an egg into a fallopian tube.
    C. Estrogen and progesterone cause a follicle to mature.
    D. Pituitary hormones cause the uterine lining to be shed monthly.
    E. A maturing follicle causes the uterine lining to build up.

Answer Explanations

1. **E**. The long bones are derived from the mesoderm; the nervous system, from the neural tube of the ectoderm; and the lungs, from the endoderm.

2. **A**. Action potentials are transmitted from input at the dendrites of a neuron, travel down the axon, and release neurotransmitters into the synapse between adjacent cells. These neurotransmitters bind to receptors on the dendrite of the second neuron, helping to produce a new action potential. Action potentials cannot travel through synapses.

3. **D**. The nerve is outside the CNS and so belongs to the peripheral nervous system (PNS). Because it is not under voluntary control, it must belong to the autonomic system. Because it promotes "rest and digest" functions, it must belong to the parasympathetic (rather than

sympathetic) nervous system. Finally, because it innervates the intestines, it is likely part of the enteric nervous system.

4. **B**. Parathyroid hormone (PTH) is secreted in response to low blood calcium levels. This hormone acts on the kidneys to take up more calcium and causes bones to release calcium into the blood.

5. **E**. Pituitary hormones cause a follicle in the ovary to mature and release an egg. The maturing follicle secretes estrogen and progesterone, causing the uterine lining to build up. After the egg is released, the follicle forms a corpus luteum, which disintegrates if pregnancy does not occur. This loss of the corpus luteum causes estrogen and progesterone levels to drop, which in turn causes the uterine lining to be shed.

Review Chapter 13: Animal Organ Systems, Part 2

Chapter 12 focused on those systems that regulate internal conditions and coordinate actions; this chapter focuses on the exchange of the body's materials with the environment. For example, the digestive system takes in food and digests it to produce nutrients, which can then be distributed to cells. The respiratory system exchanges oxygen and carbon dioxide with the air, and the excretory system eliminates the chemical by-products of metabolism. The circulatory system is essential to all of the other organ systems, as it transports these materials throughout the body.

The Digestive System

Animals ingest food and digest it (break it down) into simple nutrients. Digestion occurs in the tube-like digestive tract. Once food is digested, nutrients are absorbed into the body and transported through the bloodstream. Food may be digested mechanically or chemically (by enzymes). Three classes of nutrients are digested, as follows:

- *Proteins* are broken down into amino acids. Amino acids are used to build proteins in the cells.
- *Carbohydrates* (starches and sugars) are broken down into simple monosaccharides, such as glucose. Glucose is a preferred energy source.

- *Fats* or lipids are broken down into fatty acids and monoglycerides. Fats are also used for energy.

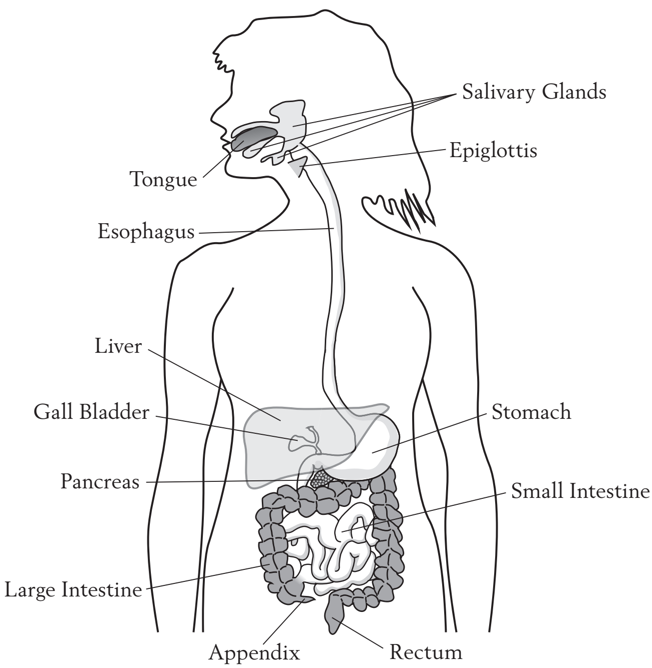
Mouth and Esophagus

The mouth, teeth, and tongue mechanically digest food, breaking it down into a soft mixture. Chemical digestion begins in the mouth, as salivary amylase begins to break down carbohydrates.

Food is swallowed, passing over the epiglottis that closes off the trachea and then into the esophagus. Peristaltic contractions of the esophagus push food to the stomach.

Stomach

The stomach lining secretes highly acidic gastric juice, with a pH between 1 and 3. This breaks down food chemically, and the enzyme pepsin begins to cleave proteins into smaller polypeptides. The stomach stores and churns food for several hours, producing a mixture called *chyme*.



Small Intestine: Digestion in the Duodenum

The chyme is then released into the duodenum (upper portion) of the small intestine. Here, it mixes with secretions from the duodenum, liver, and pancreas and is further digested.

Accessory Organs: Pancreas, Liver, and Gall Bladder

These are accessory organs in digestion; food does not pass through them, but they release substances into the digestive tract. The liver produces bile, which both helps to emulsify fats and raises the pH of the chyme. The emulsification of fats increases their surface area, allowing them to be digested by lipase from the pancreas. The pancreas secretes enzymes that digest carbohydrates, fats, proteins, and nucleic acids.

The gallbladder stores bile produced by the liver and releases it into the duodenum when needed. This allows a larger volume of bile to be released at one time.

Small Intestine: Absorption of Nutrients

After food is digested, it is absorbed in the remaining length of the small intestine. Tiny fingerlike projections, called *villi*, line the inner wall of this organ. The cells of the villi have projections called *microvilli*. Together, the villi and microvilli maximize the surface area available for absorption. Dissolved nutrients enter the cells of the villi and pass into tiny capillaries, where they enter the bloodstream to be distributed throughout the body. The first stop on this journey is to the liver, which regulates the balance of nutrients in the blood.

Large Intestine: Reabsorption of Water

Undigested material passes into the large intestine (colon), which houses a rich bacterial flora. These symbiotic bacteria use the nutrients in unabsorbed or undigested food and in return produce several essential vitamins, such as vitamin K. The remaining undigested matter, along with some bacteria, make up feces. Feces are stored in the rectum until they can be eliminated.

The large intestine is crucial in water regulation, absorbing much of the water released into the digestive tract up to this point. Too little water reabsorption leads to diarrhea; too much reabsorption results in constipation.

Glucose Regulation Feedback Loop

The level of glucose in the blood is regulated so that it remains within a tight range. The ingestion of a large meal leads to the absorption of glucose, raising blood glucose levels. The pancreas responds by secreting the hormone insulin, which stimulates the cells of the liver, brain, muscles, and other body tissues to take up more glucose. This depletes the glucose in the blood.

The liver converts glucose molecules to a polymer called *glycogen*, a storage form of glucose. When blood glucose drops too low, the pancreas secretes glucagon. This hormone causes the liver to convert stored glycogen to glucose and release it into the bloodstream, raising the glucose level. The regulation of blood glucose is an example of a negative feedback loop.

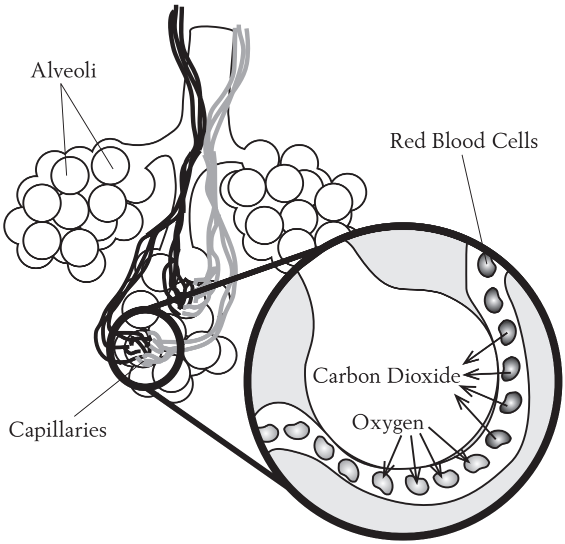
Comparison: Carnivores and Herbivores

The herbivore digestive system must work harder to extract nutrients from food. Herbivores generally have longer, more extensive digestive tracts, which may consist of multiple stomachs. In contrast, carnivores have shorter digestive tracts and can easily digest their protein-rich diets.

The Respiratory System

The respiratory system is responsible for obtaining the oxygen required for cellular respiration, and expelling carbon dioxide. Pulmonary (lung) respiration moves air into and out of the lungs. Gas exchange takes place within the alveoli of the lungs.

Air enters the body through the nasal cavity and pharynx (throat) and passes into the cartilage-lined trachea, which splits into two bronchi that enter the lungs and branch into a series of bronchioles. Cells along this tract are covered in *cilia*, microscopic "hairs" that keep the airways free of debris.



The bronchioles transport air to the sac-like alveoli. Oxygen dissolves into the liquid lining the alveoli and crosses into the network of capillaries just beyond it. Hemoglobin in red blood cells binds to the oxygen molecules and carries them away. Carbon dioxide moves in the opposite direction, from the bloodstream, through the alveoli, and into to the air of the bronchioles.

Breathing: Inhalation and Exhalation

Air is inhaled and exhaled from the lungs by the action of the diaphragm (the muscle below the lungs) and the muscles of the ribcage. During inhalation, the diaphragm contracts and moves downward, and the rib cage expands. This increases the volume of the chest cavity, creating a negative pressure in the chest, which pulls air into the lungs. On exhalation, the diaphragm relaxes and moves upward and the ribs move inward, constricting the chest cavity and pushing air out of the lungs.

Comparison: Gills and Tracheal Systems

Fish use gills instead of lungs to exchange oxygen and carbon dioxide. Gills are composed of many delicate filaments. When water moves over these filaments, carbon dioxide passes into the water and dissolved oxygen enters them. Gills use a countercurrent exchange system, which allows gas exchange through passive transport. Blood flows in the opposite direction as the moving water. This ensures that the concentration of oxygen in the water is higher, at every point, than that of the blood.

Insects do not use these familiar types of respiratory and circulatory systems to exchange gases, but instead rely on a system of air-filled tubes called *tracheae*. These tubes connect to the outside air through openings called *spiracles*.

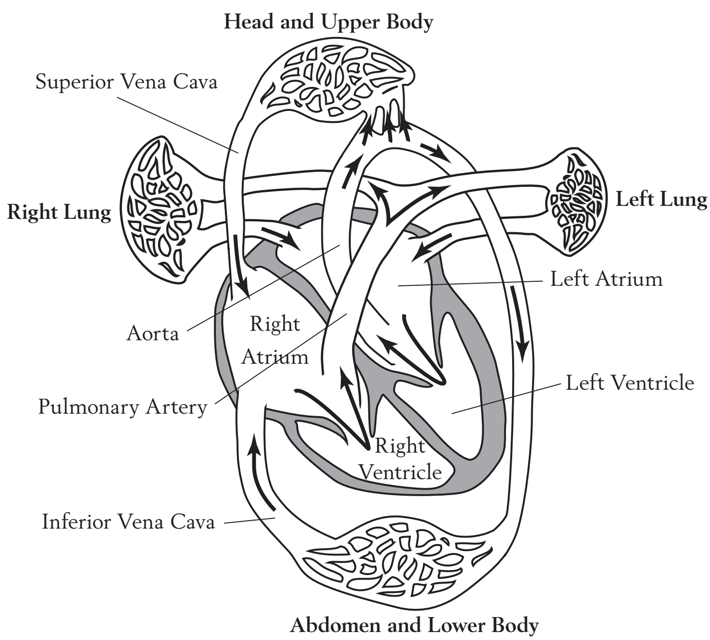
The Circulatory System

The circulatory system transports oxygen from the lungs and nutrients absorbed from the digestive tract to all the cells of the body. It also carries away wastes produced by the biochemical processes within these cells. The circulatory system consists of the heart, arteries (which carry blood away from the heart), veins (which carry blood toward the heart), and tiny capillaries (which allow substances to pass between the blood and individual cells).

Blood may be oxygenated, as when it returns from the lungs, or deoxygenated, as when it returns from the capillaries that feed the body's tissues. Capillaries from the lungs merge to form the pulmonary veins to the heart, which then pumps the oxygen-rich blood throughout the body.

The heart is divided into four chambers: the left and right atria (top) and the left and right ventricles (bottom). Veins connect to the atria, and blood passes from atrium to ventricle, where it is pumped out of the heart through an artery. The right and left sides of the heart are divided by a septum (wall), and make up two different circuits: pulmonary (right) and systemic (left). The pulmonary circuit collects deoxygenated blood from the two major veins called venae cavae. The heart pumps this blood via the pulmonary arteries to the lungs. The systemic circulation collects newly oxygenated blood from the pulmonary veins and pumps it via the aorta to the tissues of the body.

The aorta branches into ever-smaller arteries, vessels, and capillaries. Oxygen passes through the capillary walls into cells, and waste compounds pass into the capillary blood. They are transported back to the heart as the capillaries merge to form larger vessels and veins, which form the venae cavae leading into the heart. Blood cycles through the body from the lungs, to the left atrium, left ventricle, aorta, body tissues, venae cavae, right atrium, right ventricle, and back to the lungs.



Comparison: Open Circulatory Systems

The simplest invertebrates—sponges and cnidarians—lack a circulatory system. Solutes simply diffuse the short distances through cells. Arthropods and some mollusks have *open* circulatory systems, in which a tubular heart pumps a fluid called *hemolymph* into sinuses, or spaces, that contain the organs.

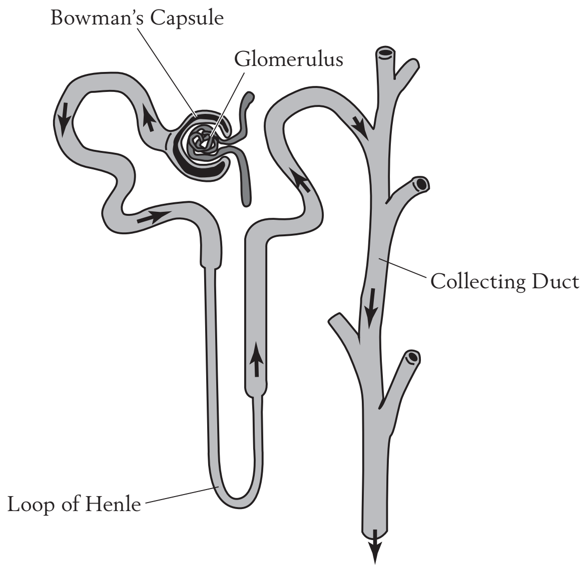
Contrast this with the *closed* circulatory systems of annelids and other animals (including vertebrates, squids, and octopuses). This type of system involves one or more hearts pumping blood through vessels. Although materials are exchanged between the blood and the cells, the blood does not directly contact the cells. Organisms with faster metabolisms have closed circulatory systems, in which higher pressure facilitates the exchange of materials.

The Excretory System

This system filters waste compounds from the blood and helps to maintain water balance (osmoregulation). Vessels transport blood to the kidneys, where wastes are filtered and water is returned to the circulatory system. Urine, consisting of waste compounds and some water, passes through the two ureters into the bladder, where it is stored until it can be eliminated through the urethra.

The task of the kidneys is to eliminate waste while conserving water. This is accomplished by filtering a larger volume of water and solutes from the blood and then selectively reabsorbing water and other useful substances from the filtrate. While the first step requires little energy, the second relies on both passive and active transport.

The mammalian kidney is packed with functional units called *nephrons*. Each nephron consists of a ball of capillaries called a *glomerulus*, which is enclosed in one end of a long tube. The glomerulus and tube covering it form the Bowman's capsule. Extending from the Bowman's capsule, the tube forms a hairpin at one point along its length, called the loop of Henle. The loop of Henle descends deeper into the center of the kidney and ascends back to the level of the Bowman's capsule. Last, the tube feeds into a urine-collecting duct.



Water and small molecules pass from the glomerulus to the tube via passive transport; cells and proteins are too large to pass into this filtrate. The filtrate contains glucose, salts, vitamins, and minerals that the body needs, as well as water that must be conserved. As the filtrate passes through the rest of the nephron, these substances are collected through both passive and active transport.

The loop of Henle is key in the reabsorption of water and salt. This is accomplished by varying both the permeability of the membrane throughout the loop and the concentration of the fluid outside of the loop. As filtrate moves down the loop, it becomes more concentrated. However, the fluid surrounding the loop also increases in concentration, due to its location within the kidney. Therefore, water can still move out of the loop through passive transport. (Recall that water will move osmotically from an area of low solute concentration to an area of high solute concentration.)

Comparison: Water Conservation

The purpose of urine is to prevent a buildup of nitrogen compounds from digested proteins and nucleic acids in the body. The simplest form of these nitrogen compounds is ammonia (NH_3). However, ammonia is highly toxic and must be dissolved in large volumes of water for excretion. Mammals solve this problem by converting ammonia to a less toxic compound, urea. Urea can be excreted in a smaller volume of water.

Mammals produce urine that is hyperosmotic (more concentrated) relative to the body's fluids, a process that allows them to conserve water. Desert mammals generally have longer loops of Henle, resulting in more concentrated urine. Birds have short loops, but produce uric acid (which is excreted as a paste) instead of urea (which must be dissolved). Freshwater fishes, in contrast, can excrete large volumes of water; they do not convert their ammonia to urea.

The Immune System

Multicellular animal bodies are susceptible to invasion by bacteria and viruses. Viruses enter a cell and use its transcription and translation capabilities to make multiple copies of themselves; the viruses then burst from the cell to invade others. The immune system protects the body by recognizing and destroying foreign cells and viruses. *Innate* immunity is present at birth and protects against a wide range of microbes. *Acquired* (or *adaptive*) immunity develops after exposure to a pathogen, or agent of infection. Acquired immunity is specific, while innate immunity is generic.

Innate Immunity

The skin and mucous membranes provide an external first line of defense against a wide range of microbes. Pathogens that pass these defenses are destroyed by white blood cells called *phagocytes* ("eater cells"), which engulf and digest the invaders. Macrophages are phagocytes that display molecules from the ingested pathogen on their surfaces. Cells called *natural killer cells* destroy body cells that are infected with bacteria or viruses.

The complement system aids in immunity by producing blood proteins that either destroy pathogens or prevent them from reproducing.

For example, virus-infected body cells secrete interferon proteins that induce other cells to prevent the production of viruses.

Inflammation also prevents infection. At sites of injury, mast cells release histamines, which dilate capillaries and allow immune cells and proteins to flood the site. Inflammation also promotes clotting, which forms a barrier to infection.

Acquired Immunity

Lymphocytes play a key role in acquired immunity by recognizing and responding to foreign molecules called *antigens*. The surface of B and T lymphocytes (cells) have antigen receptors, Y-shaped proteins that can bind to foreign molecules. B cells becomes activated by recognizing and binding to an antigen. Helper T cells may bind to an antigen displayed on the surface of a macrophage. Helper T cells stimulate B cells by releasing cytokines.

B cells may also produce antibodies and, instead of displaying these proteins on the cell surface, release them into the bloodstream. In this case, the proteins are called *immunoglobins*. Once exposed to an antigen, some of these cells retain a “memory” that allows the body to mount an immediate immune response the next time it is encountered. This memory is the basis for vaccines, which provide immunity by exposing B and T cells to antigens.

Review Questions

1. Which of these carries deoxygenated blood?

   I. Pulmonary veins
   II. Anterior vena cava
   III. Pulmonary arteries

   A. I only
   B. II only
   C. III only
   D. I and II
   E. II and III

2. What sequence is followed by the path of blood from the heart?

   A. Vena cava, right atrium, right ventricle, aorta, lungs
   B. Lungs, pulmonary vein, right atrium, right ventricle, aorta
   C. Vena cava, right atrium, right ventricle, lungs, pulmonary vein
   D. Vena cava, left atrium, left ventricle, lungs, pulmonary artery
   E. Left ventricle, lungs, pulmonary vein, pulmonary artery, right atrium

3. Which of these does NOT secrete any digestive enzyme?

   A. Salivary glands
   B. Liver
   C. Pancreas
   D. Small intestine
   E. Stomach

4. Which of these describes an adaptation to an arid environment?

   A. A short loop of Henle, which allows more filtrate to be removed from the blood
   B. A short loop of Henle, which allows less water to be removed from the filtrate
   C. A long loop of Henle, which allows more filtrate to be removed from the blood
   D. A long loop of Henle, which allows more water to be removed from the filtrate
   E. A long loop of Henle, which allows less filtrate to be removed from the blood

5. Which of these would a researcher test the blood for to determine if a person has been infected with a virus in the past?

   A. Antigens
   B. Antibodies
   C. Macrophages
   D. Pathogens
   E. Natural killer cells

Answer Explanations

1. **E**. The anterior and posterior venae cavae return blood to the heart after it has traveled to the tissues of the body. Because the blood has supplied oxygen to cells, it is deoxygenated. The heart pumps this deoxygenated blood to the lungs through the pulmonary arteries. It picks up oxygen and returns to the heart via the pulmonary veins.

2. **C**. Deoxygenated blood collects in the vena cava, which feeds into the right atrium of the heart. Blood from the right atrium enters the right ventricle, where it is pumped to the lungs via the pulmonary arteries. Oxygen-rich blood returns to the heart via the pulmonary veins.

3. **B**. The liver secretes lipase, which emulsifies fats and allows them to be digested by pancreatic lipase. However, the liver does not produce digestive enzymes.

4. **D**. A long loop of Henle allows more water to be removed from the filtrate before it is excreted as urine. This causes the urine to be even more hyperosmotic and conserves water.

5. **B**. Antigens or immunoglobulins produced by B and T cells are specific and provide a "memory" that helps to fight previously encountered pathogens, or infectious organisms. Antigens, produced by pathogens, would not linger in the blood. Macrophages and natural killer cells are part of the innate immune system and would not be specific to a particular virus.

Chapter 4: **Organismal Biology**

- Reproduction
- Nutrition
- Circulation
- Immune System
- Respiration
- Thermoregulation and the Skin
- Excretion
- Endocrine System
- Nervous System
- Motor Systems
- Animal Behavior
- Plants

Living organisms must maintain constant interior conditions in a changing environment. The interior environment that cells must maintain includes water volume, salt concentration, and appropriate levels of oxygen, carbon dioxide, toxic metabolic waste products, and essential nutrients. Organisms must respond to their environment to avoid harm and seek out beneficial conditions, and must reproduce themselves. Single-cell organisms like prokaryotes or protists have relatively simple ways to meet these needs, while multicellular organisms have evolved more complex body plans that provide a variety of solutions to the common problems that all organisms face.

As multicellular organisms have evolved into larger and more complex forms over time, their cells have become more removed from the external environment and more specialized toward one specific function. These specialized cells form *tissues*, cells with a common function and often a similar form. Cells from different tissues come together to form *organs*, large anatomical structures made from several tissues working together toward a common goal. Organs in turn are part of organ systems, including systems for digestion, respiration, circulation, immune reactions, excretion, reproduction, and the nervous system and the endocrine system.

This chapter provides the basics of topics including reproduction, physiology, and animal behavior. Along the way, organisms such as protozoans, cnidarians (hydra), annelids

BELIEVE IT OR NOT

It's hard to believe, but true—all the nucleated cells of your body, regardless of structure or function, have exactly the same number of chromosomes (including two sex chromosomes). The only exceptions are gametes, which have half the normal number of chromosomes. This means that different cell types have different structures and functions not because their DNA is different, but because the genes expressed by that DNA are different.

(earthworms), and arthropods (insects) are described as prototypes to illustrate the range of solutions evolution has provided in different types of organisms. The unique solutions of plants are presented separately later in the chapter.

REPRODUCTION

One of the essential functions for all living things is the ability to reproduce, to produce offspring that continue a species. An individual organism can survive without reproduction but a species without reproduction will not survive past a single generation. Reproduction in eukaryotes can occur as either asexual or sexual reproduction. Prokaryotes have a different mechanism called *binary fission* for reproduction.

Mechanisms of Cell Division

One of the inherent features in reproduction is cell division. Prokaryotic cells divide and reproduce themselves through the relatively simple process of binary fission. Eukaryotic cells divide by one of two mechanisms: mitosis and meiosis. *Mitosis* is a process in which cells divide to produce two daughter cells with the same genomic complement as the parent cell; in the case of humans there are two copies of the genome in each cell. Mitotic cell division can be a means of asexual reproduction, and also is the mechanism for growth, development, and replacement of tissues. *Meiosis* is a specialized form of cell division involved in sexual reproduction that produces male and female gametes (sperm and ova, respectively). Meiotic cell division creates cells with a single copy of the genome in preparation for sexual reproduction in which gametes join to create a new organism with two copies of the genome, one from each parent.

Prokaryotic Cell Division and Reproduction

Prokaryotes are single-celled organisms and their mechanism for cell division, binary fission, is also their means of reproduction. As with all forms of cell division, one of the key steps is DNA replication. Prokaryotes have no organelles and only one chromosome in a single long, circular DNA. The single prokaryotic chromosome is attached to the cell membrane and replicated as the cell grows. With two copies of the genome attached to the membrane after DNA replication, the DNAs are drawn apart from each other as the cell grows in size and adds more membrane between the DNAs. When the cell is as big as two cells, the cell wall and membrane close off to create two independent cells. The simplicity of prokaryotic cells and the small size of their genome compared to eukaryotes may be a factor that assists in their rapid rate of reproduction, dividing as rapidly as once every 30 minutes under ideal conditions.

Bacteria and other prokaryotes do not reproduce sexually, but they do exchange genetic material with each other in some cases. *Conjugation* is one mechanism used by bacteria to move genes between cells by exchanging a circular extrachromosomal DNA with each other. In a process called *transduction*, viruses that infect bacteria can accidentally carry bacterial genes with them into a new cell that they infect. These processes can introduce new genes into bacteria, but do not involve the union of gametes from two parents that characterizes sexual reproduction.

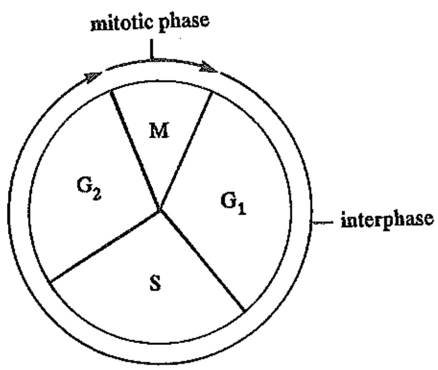
A TYPICAL CELL'S DAY

Typically, even rapidly dividing mammalian cells spend 90 percent of their time in interphase and only 10 percent in the mitotic phase.

Mitosis

Eukaryotic cells use mitosis to divide into two new daughter cells with the same genome as the parent cell. The growth and division of cells to make new cells occurs in what is known as the *cell cycle*. The cell cycle is a highly regulated process, linked to the growth and differentiation of tissues. Growth factors can stimulate cells to move through the cell cycle more rapidly, and other factors can induce cells to differentiate and stop moving forward through the cell cycle. Failure to control the cell cycle properly can result in uncontrolled progression through the cell cycle and in cancer. Cancer cells contain mutations in genes that regulate the cell cycle.

The four stages of the cell cycle are designated as G_1, S, G_2, and M. The first three stages of this cell cycle are interphase stages—that is, they occur between cell divisions. The fourth stage, mitosis, includes the actual division of the cell.



The Cell Cycle

Stage G_1. G_1 is characterized by intense biochemical and biosynthetic activity and growth. The cell doubles in size, and new organelles such as mitochondria, ribosomes, and centrioles are produced.

Stage S. This is the stage during which synthesis of DNA takes place (S is for synthesis). Each chromosome is replicated so that during division, a complete copy of the genome can be distributed to both daughter cells. After replication, the chromosomes each consist of two identical sister *chromatids* held together at a central region called the *centromere*. The ends of the chromosomes are called *telomeres*. Cells entering G_2 actually contain twice as much DNA as cells in G_1, since a single cell holds both copies of the replicated genome.

Stage G_2. The cell prepares for mitosis, making any of the components still needed to complete cell division.

IN A NUTSHELL

Mitosis proceeds in the following stages:

- *Prophase*: chromosomes condense, spindles form
- *Metaphase*: chromosomes align
- *Anaphase*: sister chromatids separate
- *Telophase*: new nuclear membranes form

Stage M (Mitosis and Cytokinesis). Mitosis is the stage in which the cell divides to create two similar but smaller daughter cells.

Mitosis (also called "nuclear division") is further broken down into four stages: *prophase*, *metaphase*, *anaphase*, and *telophase*. Prophase is often further subdivided to create *prometaphase*. Upon completion of mitosis, the cell completes its split into daughter cells via *cytokinesis*.

Prophase. During interphase, the chromosomes in the nucleus are very extended despite their packaging into chromatin, and it is not possible to see the chromosomes even under a microscope. *Prophase* begins with the condensation and separation of chromosomes so that they are visible under a microscope as dark solid bands if stained. Cell division cannot occur without this condensation, as the chromosomes would become tangled with each other. Another step in prophase is the separation of the *centrioles*, centers of microtubule formation. As the centrioles separate, they nucleate the *spindle apparatus*, a specialized system of microtubules that spans between the centrioles during mitosis. As the centrioles separate toward opposite poles of the cell, the spindle apparatus elongates between them. The nuclear membrane dissolves and the nucleolus becomes indistinct, allowing the spindle fibers access to the chromosomes. The spindle fibers attach themselves to each chromosome with a structure called the *kinetochore* that attaches in the middle of each chromosome at the centromere, setting the stage for metaphase.

Metaphase. In *metaphase*, the two centrioles are at opposite poles of the cell, with the spindle fully elongated between them, spanning the length of the cell, including the space that was previously occupied by the nucleus and is now the location of the condensed chromosomes. The kinetochore fibers, attached to the chromosomes at the centromere, align the chromosomes at the metaphase plate, a plane halfway between the two ends of the cell. The alignment of the chromosomes prepares the cell to pull the chromosomes apart toward the two ends of the cell.

Anaphase. During S phase, each chromosome is replicated and the replicated copies stay bound together. From S phase up through metaphase, each chromosome contains two copies, and each copy is called a sister chromatid. During *anaphase*, the two sister chromatids in each chromosome are pulled apart by the kinetochore and spindle fibers. The telomeres at the ends of the chromosomes are the last part of the chromatids to separate. Each chromatid then has its own centromere by which it is pulled towards opposite poles of the cell through the shortening of the kinetochore fibers. It is crucial that when the sister chromatids separate, each daughter cell receives one of each chromosome. If this does not happen, the cell lacking a chromosome or the other cell with an extra chromosome may not function normally if it is lacking a copy of many genes or has an extra copy of genes.

Telophase. At the beginning of *telophase*, the sister chromatids have been pulled apart so that one copy of each chromosome, a complete copy of the genome, is at one end of the cell and another copy is at the other end. At this point, the spindle apparatus disappears, a nuclear membrane reforms around each set of chromosomes, and the nucleoli reappear. The chromosomes uncoil, resuming their spread-out interphase form.

Each of the two new nuclei contains a complete copy of the genome identical to the original genome and to each other.

Cytokinesis. After the cell has divided its DNA in *mitosis*, it enters cytokinesis, dividing the cell. In cytokinesis, the cytoplasm and all the organelles of the cell are divided as the plasma membrane pinches inward and seals off to complete the separation of the two newly formed daughter cells from each other.

Asexual Reproduction

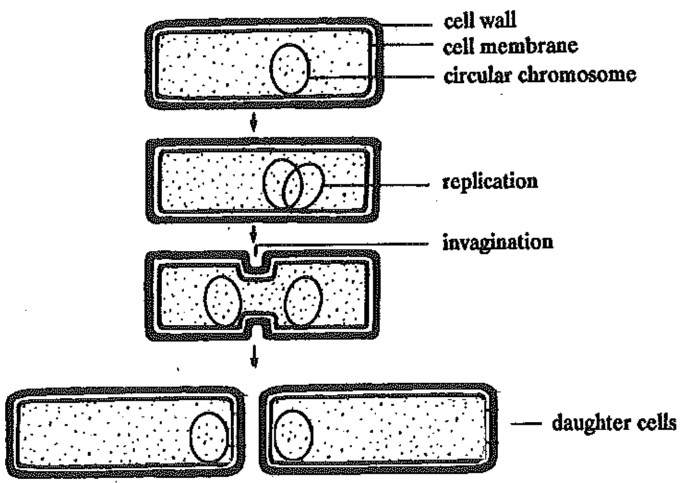
Asexual reproduction is any method of producing new organisms in which fusion of nuclei from two individuals (fertilization) does not take place. The fusion of nuclei from two parent individuals to create a new individual is *sexual reproduction*. In asexual reproduction, only one parent organism is involved. The new organisms produced through asexual reproduction form daughter cells through mitotic cell division and are genetically identical clones of their parents (save any mutations incurred during DNA replication). Asexual reproduction serves primarily as a mechanism for perpetuating primitive organisms and plants, especially in times of low population density. Asexual reproduction can allow more rapid population growth than sexual reproduction, but does not create the great genetic diversity that sexual reproduction does.

DON'T MIX THESE UP ON TEST DAY

Binary fission results in equal division of the cytoplasm and symmetrical daughter cells. *Budding* involves an unequal division of the cytoplasm and asymmetrical daughter cells.

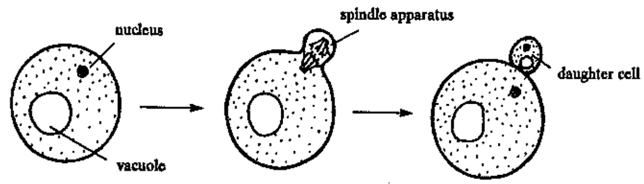
Binary fission occurs in prokaryotes (algae and bacteria). In this process, a single DNA molecule attaches to a plasma membrane during replication and duplication, while the cell continues to grow in size. Hence, each daughter cell receives a complete copy of the original parent cell's chromosomes.

This type of reproduction occurs at a rapid pace. Undesirable, potentially harmful bacteria cells, for example, can reproduce every 20 minutes under optimal conditions.



Binary Fission

Budding is a form of mitotic asexual reproduction that involves an unequal division of cytoplasm (*cytokinesis*) between the daughter cells and equal division of the nucleus (*karyokinesis*). The parent cell forms a smaller daughter cell that sprouts off with less cytoplasm than the parent. Eventually the daughter organism becomes independent and is released. Although budding is common in unicellular organisms such as yeast, it also occurs in some multicellular organisms such as hydra, forming small, identical copies of the parent.



Budding

THE EGGS OF THE ROTIFER

The rotifer, a tiny aquatic animal, has two types of eggs that develop via parthenogenesis. These eggs mature to produce females and degenerate males that cannot feed themselves. These males produce sperm that will fertilize eggs to produce zygotes. These zygotes are so hardy that they can survive even if the pond in which they live dries up.

Asexual reproduction is not common in animals, although it does bring with it certain benefits. It is suitable for animal populations that are widely dispersed, as animals that practice asexual reproduction do not need to find another animal to fertilize them sexually. Asexual reproduction allows rapid growth of a population when conditions are suitable and has a much lower energetic cost than sexual reproduction. The two major types of asexual reproduction found in animals are *parthenogenesis* and *regeneration*.

When people think about asexual reproduction in animals, they usually have *parthenogenesis* in mind. During sexual reproduction, an ovum does not develop without fertilization by a sperm, and the resulting zygote contains a diploid genome with one copy from each parent. In parthenogenesis, an egg develops in the absence of fertilization by sperm through mitotic cell division. This form of reproduction occurs naturally in bees: fertilized eggs develop into worker bees and queen bees, while unfertilized eggs become male drone bees. Artificial parthenogenesis can be performed in some animals. The eggs of rabbits and frogs, for example, can be stimulated to develop without fertilization, by giving them an electric shock or a pinprick.

Regeneration is the ability of certain animals to regrow a missing body part. Sometimes parts of an animal grow into a complete animal, resulting in reproduction. For example, the planaria (a flatworm), the earthworm, the lobster, and the sea star can all regenerate limbs or entire organisms. This process is similar in nature to vegetative propagation.

Both regeneration and vegetative propagation are poorly understood. One possible explanation is that both are enabled by the presence of undifferentiated stem cells in certain plants or animals; if stimulated properly, these stem cells can differentiate as they divide and grow to form new organs. Improved understanding of stem cells and the ability to use them to improve regeneration could lead to revolutionary advances in medicine, such as regeneration of damaged spinal nerves after a crippling accident, regeneration of heart tissue after a heart attack, or healing of brain tissue after a stroke.

Sexual Reproduction

Most multicellular animals and plants reproduce sexually, as do many protists and fungi. *Sexual reproduction* involves the union of a *haploid cell* from two different parents to produce diploid offspring. These haploid cells are the *gametes*, sex cells produced through meiosis in males and females. Gametes have a single copy of the genome (one of each chromosome), and diploid cells have two copies of the genome (two of each chromosome). In humans, all of the cells of the body are diploid, with the exception of the gametes. When the male gamete (the sperm) and the female gamete (the egg) join, a *zygote* is formed that develops into a new organism genetically distinct from both its parents. The zygote is the diploid single-cell offspring formed from the union of gametes.

Sexual reproduction ensures genetic diversity and variability in offspring. Since sexual reproduction is more costly in energy than asexual reproduction, the reason for its overwhelming prevalence must be that genetic diversity is worth the effort. Sexual reproduction does not create new alleles (alternate forms of a given gene), though. Only mutation can do that. Sexual reproduction increases diversity in a population by creating new combinations of alleles in offspring and therefore new combinations of traits. Genetic diversity is not an advantage to an individual, but allows a population of organisms and its species to adapt and to survive in the face of a dynamic and unpredictable environment.

The diversity created by sexual reproduction occurs in part during meiotic gamete production and in part through the random matching of gametes to make unique individuals. The range of mechanisms involved in sexual reproduction in animals, including humans, are detailed below.

Gamete Formation

Specialized organs called *gonads* produce gametes through meiotic cell division. Male gonads, *testes*, produce male gametes, *spermatozoa*; while female gonads, *ovaries*, produce eggs, *ova*. A cell that is committed to the production of gametes, although it is not itself a gamete, is called a *germ cell*. The rest of the cells of the body are called *somatic cells*. Only the genome of germ cells contributes to gametes and offspring. A mutation in a somatic cell, for example, may be harmful to that cell or the organism if it leads to cancer, but a mutation in a somatic cell will not affect offspring since the mutation will not be found in germ-cell genomes. Germ cells are themselves diploid and divide to create more germ cells by mitosis, but create the haploid gametes through meiosis.

HERMAPHRODITES

Organisms such as the hydra and the earthworm are *hermaphrodites*, with both functional male and female gonads.

The production of both male and female gametes involves meiotic cell division. Meiosis in both spermatogenesis and oogenesis involves two rounds of cell division, in which a single diploid cell first replicates its genome; it then divides once into two cells, each with two copies of the genome. Without replicating their DNA, these two cells divide again to produce four haploid gametes. Meiosis also involves recombination between the homologous copies of chromosomes during the first round of meiotic cell division. This recombination is one of the key sources of genetic diversity provided during sexual reproduction and is discussed in more detail in chapter 5, Classical Genetics.

DON'T MIX THESE UP ON TEST DAY

Spermatogenesis:

- Produces four mature sperm; each sperm has an *X* or *Y* chromosome and does not donate mitochondria to the embryo
- Is a continuous process
- Produces fresh sperm daily

Oogenesis:

- Produces one egg and two to three polar bodies
- Produces ova with only *X* chromosomes
- Is a discontinuous process
- Produces ova that donate mitochondria to the embryo
- Produces a limited supply of ova early in life that are arrested in development and finish meiosis later in life

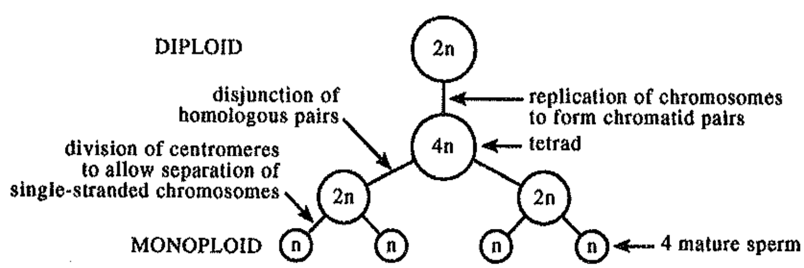
There are also many differences in meiosis as conducted during sperm production and oogenesis, as outlined below.

Human Male Reproductive System

The human male produces sperm in the *testes*, gonads located in an outpocketing of the abdominal wall called the *scrotum*. The sperm develop in a series of small, coiled tubes within the testes called the *seminiferous tubules*. *Sertoli cells* in the seminiferous tubules support the sperm and *Leydig cells* make the *testosterone* that supports male secondary sex characteristics. The *vas deferens* carry sperm to the urethra that passes through the penis. During ejaculation, the *prostate gland* and *seminal vesicles* along the path add secretions to the sperm that carry and provide nutrients for the sperm as part of *semen*.

As gonads, the testes have a dual function: to produce both sperm and male hormones (such as testosterone). Leydig cells in the testes secrete testosterone beginning at puberty. *Testosterone* and other steroid hormones (collectively called *androgens*) induce secondary sexual characteristics of the male, such as facial and pubic hair, changes in body shape, and deepening voice changes.

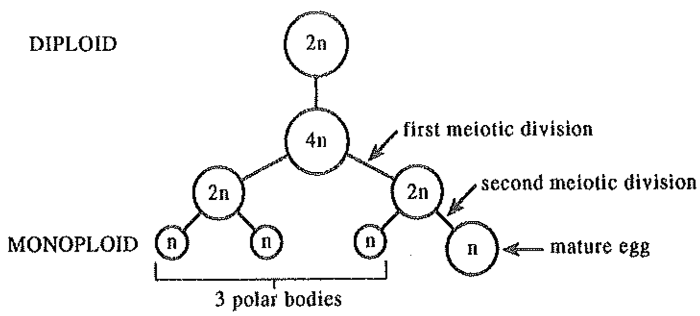
Spermatogenesis is the meiotic development of sperm in males. Sperm production occurs throughout adult life in males, and meiosis in sperm production is continuous, proceeding forward without a significant pause. In the testes, diploid germ cells divide mitotically to create primary *spermatocytes*, which continuously undergo meiosis to form four haploid *spermatids* from each primary spermatocyte. The four spermatids are equivalent in size and function and all four result in viable gametes. Spermatids must mature further to develop the head with DNA and the tail for motility that are found in mature sperm. A specialized sac at the tip of the sperm, called the *acrosome*, is full of enzymes that allow the sperm to break through the protective layers around the egg. One strategy in developing birth control has been to inhibit these enzymes so that the sperm cannot penetrate the egg. The testes are located outside the abdominal cavity because they must remain 2–4 degrees cooler than the rest of the body to ensure proper development of sperm.



Spermatogenesis

Human Female Reproductive System

The *ovum* (egg) develops in a process called *oogenesis* that, unlike spermatogenesis, is not completed in a single continuous process. During development of female children, ova progress to meiotic prophase I in the first round of meiotic cell division and then become arrested, stuck at this stage. These ova remain arrested in meiosis throughout the life of a woman, except for the ova that mature during each menstrual cycle and progress through this meiotic block. Women are born with all the *eggs* they will ever have, while males produce fresh sperm daily. This is the reason that genetic anomalies are more common in the eggs of older women; these anomalies have had years to accumulate in ova, while sperm have a short life span.



Oogenesis

The completion of the first meiotic cell division by maturing ova preparing for ovulation creates one cell with most of the cytoplasm and another smaller cell that has little cytoplasm. This smaller cell may itself divide later to create two smaller cells, but it does not create viable ova and is called a *polar body*. The developing ovum becomes a secondary oocyte that pauses again in the second meiotic cell division even as it is released during ovulation. The ova in humans do not actually complete oogenesis until after fertilization, at which time they release the last polar body, and the nuclei of the male and female gametes join to create the diploid zygote. The unequal distribution of cytoplasm during oogenesis is another feature that is distinct from spermatogenesis.

Ovaries are paired structures in the lower portion of the abdominal cavity in females. As part of the menstrual cycle, one ovum develops each month within a follicle in an ovary. The follicle is a collection of cells around the ova that support its development and secrete hormones. Each ovary is accompanied by a *fallopian tube*, also called an *oviduct*, one on each side of the abdomen. During ovulation, an ovum leaves the ovary from the follicle and is ejected into the upper end of the oviduct. At birth, all the eggs that a female will ovulate during her lifetime are already present in the ovaries, but these eggs develop and ovulate at a rate of one every 28 days (approximately), starting at puberty.

The ovaries also produce female sex hormones such as *estrogen*. Like male sex hormones, the female sex hormones regulate the secondary sexual characteristics of the female, including the development of the *mammary* (milk) *glands* and wider hip bones (pelvis). They also play an important role in the menstrual cycle, which involves the interaction of the pituitary gland, ovaries, and uterus.

MENSTRUATION TIME LINE

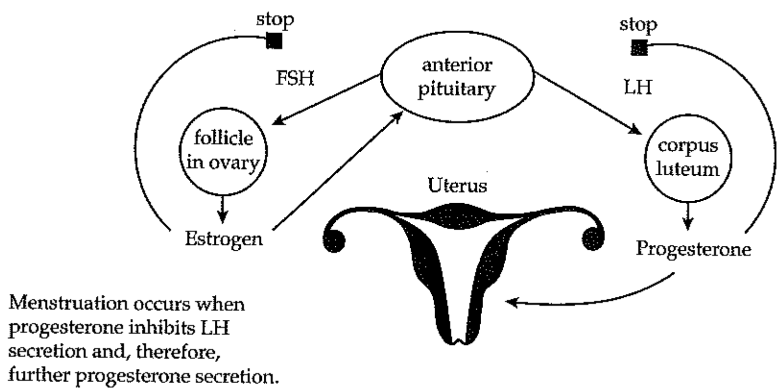
Number of Days	*Menstrual Stage*
1	Menstruation
4	Follicular Stage
13	Ovulation
14	
15	Corpus Luteum Stage
28	

The Menstrual Cycle

The *menstrual cycle* is a repeating sequence of events in the tissues and hormones of the female body. We will describe the process in humans. The key hormones in the menstrual cycle are gonadotropin-releasing hormone (GnRH) from the hypothalamus, follicle-stimulating hormone (FSH) and luteinizing hormone (LH) from the pituitary, and *estrogen* and *progesterone* from the ovary, each regulating the secretion of the other hormones as part of the menstrual cycle. GnRH stimulates FSH and LH secretion, which in turn stimulate the production of estrogen and progesterone. Estrogen and progesterone inhibit the production of FSH and LH as well as GnRH usually, with a key exception that is required for ovulation. Estrogen and progesterone also regulate the tissues in the uterus involved in the menstrual cycle.

There are four stages in the menstrual cycle:

- The follicular stage
- Ovulation
- The corpus luteum (luteal) stage
- Menstruation



Menstrual Cycle

PREGNANCY GIVEAWAY

A pregnancy test looks for the presence of hCG, or human chorionic gonadotrophic hormone, the substance that maintains the uterine wall. If a woman is not pregnant, she will not produce hCG.

In the *follicular stage* of menstruation, FSH from the anterior pituitary gland stimulates a follicle to mature and produce estrogen. Estrogen promotes thickening of the uterine lining to support an embryo if fertilization occurs. This stage lasts approximately nine to ten days.

When the follicle is mature, a surge in LH secretion from the pituitary causes *ovulation*, the release of the ovum from an ovary. The LH surge is a key factor in ovulation, and ovulation will not occur without it. Constant high levels of estrogen block the LH surge and block ovulation. This is the mechanism by which many birth control pills act.

After ovulation, the remains of the follicle in the ovary create the *corpus luteum*. LH from the pituitary stimulates the corpus luteum to produce progesterone and estrogen, which stimulates vascularization (growth of blood vessels) and lining formation in the uterus in preparation for implantation of the fertilized egg. This stage lasts 12 to 15 days. Then, if no fertilization or implantation has occurred, the increased estrogen and progesterone block LH production. Without LH, the corpus luteum atrophies and progesterone levels fall. Without progesterone, the thickened, spongy uterine wall that had been prepared for implantation breaks down. The degenerating tissue, blood, and unfertilized egg are passed out as *menstrual flow*. This stage lasts approximately four days, bringing the total to 28 days for the entire cycle.

If fertilization occurs, the developing placenta produces hCG (*human chorionic gonadotrophic hormone*), which maintains the corpus luteum. The corpus luteum then continues to make progesterone and estrogen. Progesterone prevents menstruation and ensures that the uterine wall is thickened so that embryonic development can occur and pregnancy can continue. With time, the placenta develops and takes over the production of estrogen and progesterone for the duration of pregnancy.

Embryonic Development

The first step in development is *fertilization*. If sperm are present in the oviduct during ovulation, and a sperm succeeds in encountering the ovum, then fertilization can occur, forming a *zygote*, a single *diploid* cell. In fertilization, the egg nucleus (containing the *haploid number*, or n chromosomes) unites with the sperm nucleus (containing n chromosomes). This union produces a zygote of the original diploid or $2n$ chromosome number. In this way, the normal ($2n$) somatic number of chromosomes in a diploid cell is restored, and the cell has two homologous copies of each chromosome. Everything else in development up to adulthood consists of mitotic divisions.

HOW MANY EGGS?

Animals that practice external fertilization and external development must produce many eggs and sperm in order to ensure survival of the species. On the other hand, animals that practice internal fertilization and development invest their energy in taking very good care of a smaller number of offspring.

If there are two or more eggs released by the ovaries, more than one can be fertilized. The result of multiple fertilizations will be fraternal (*dizygotic*) twins, which are produced when two separate sperm fertilize two eggs. Fraternal twins are related genetically in the same way that any two siblings are. Drugs to treat infertility often induce multiple ovulation and can lead to multiple-birth pregnancies.

If there is only one fertilized egg, twins may still result through separation of identical cells during the early stages of cleavage (for example, the two-, four-, or eight-cell stage) into two or more independent embryos. These develop into identical (*monozygotic*) twins, triplets, and so forth, since they all came from the same fertilized egg and have essentially identical genomes. Identical twins are often used in human genetic studies to determine what traits are genetically inherited, since most differences between twins must be caused by their environment.

When the egg and the sperm join, they trigger a cascade of events that occur as the zygote begins to divide rapidly. These events, which are part of the process of fertilization, may occur either externally or internally.

External fertilization occurs in vertebrates that reproduce in water, including most fish and amphibians. Eggs are laid in the water, and sperm are deposited near them in the water. The sperm have flagella, enabling them to swim through the water to the eggs. Since there is no direct passage of sperm from the male to the female, the sperm are likely to be diluted and the chances of fertilization for each ovum are reduced

ECTOPIC PREGNANCY

Sometimes the blastula implants itself outside the uterus and develops there, a situation referred to as an ectopic pregnancy.

considerably. External fertilization also decreases the probability of survival of the young after fertilization since the developing animals are easy targets for predators. Internal fertilization is found in vertebrate land animals (like reptiles, birds, and mammals). The moist passageway of the female reproductive tract from the vagina through the oviducts provides a direct route to the egg for mobile sperm and increases the chance of fertilization.

The number of eggs produced depends upon a number of factors. One of these factors is the type of fertilization employed. Because very few sperm actually reach the egg during external fertilization, this process requires large quantities of eggs to ensure success. The type of development practiced by the organism is also significant. If development occurs outside the mother's body from the very beginning, many eggs are required to ensure survival of at least some of the offspring. Finally, the less care the parents provide, the more eggs are required to guarantee survival of enough offspring to continue the species.

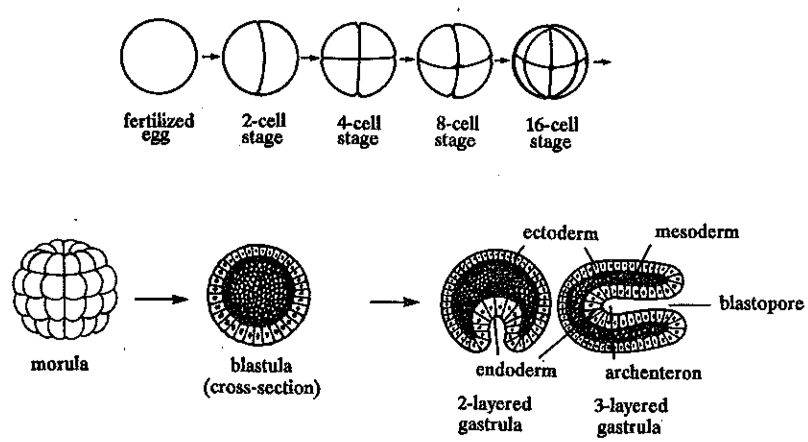
DON'T MIX THESE UP ON TEST DAY

The *ectoderm* develops into the skin, the nervous system, and the eyes, hair, and teeth.

The *mesoderm* develops into the muscles, the skeleton, the circulatory system, the kidney, and the gonads.

The *endoderm* develops into the lining of the digestive and respiratory tracts, and the lining of the bladder, pancreas, and liver.

Development of the Embryo. Cleavage of the embryo starts in the oviduct immediately after fertilization. The developing embryo travels down the oviduct, and, within five to ten days, implants itself in the uterine wall. Initially, the fertilized embryo divides into many undifferentiated cells. In the earliest stages, mitotic divisions result in one cell producing two cells, which produce four cells, which produce eight cells, and so on. This ultimately creates what is known as a *morula*, a solid ball of cells. Cells in the morula continue to rapidly divide mitotically to form the *blastula*, a hollow ball of cells (a single layer thick). The central cavity of the blastula is filled with fluid secreted by the cells, and is referred to as the *blastocoel*. More rapid division of cells at one end of the blastula causes an inpocketing or involution known as the two-layer *gastrula*. Two germ layers, the *ectoderm* and *endoderm*, are initially present, endoderm on the inside and ectoderm on the exterior. In a three-layer gastrula, *mesoderm* cells develop between the ectoderm and endoderm. This formation and rearrangement of the three germ layers is known as *gastrulation*.



Cleavage of the Egg

Differentiation of Embryonic or Germ Layers. In the next stage of embryonic development, the cells of each germ layer begin to differentiate and specialize to form tissues, organs, and organ systems. Differentiation of cells occurs when the form and function of cells changes to reflect a distinct function or developmental fate. A cell is determined if its developmental fate is set in place even if it does not yet look differentiated. The ectoderm develops into the epidermis of skin, nervous system, and sweat glands. The endoderm becomes the lining of digestive and respiratory tracts, parts of the liver and the pancreas, and the bladder lining. Finally, the mesoderm develops into the muscles, skeleton, circulatory system, excretory system (except bladder lining), gonads, and inner layer of skin (dermis).

EGG-LAYING MAMMAL

The duck-billed platypus, native to Australia, does not develop its young internally as do most other mammals. Instead, it lays a leathery egg. It is classified as a mammal because of its fur and milk glands.

External Development of Embryo. External development occurs outside the female's body, in water or on land. The eggs of fish and amphibia, for example, are fertilized externally in water and develop in water inside the egg, feeding on the yolk. External development on land occurs in reptiles, birds, and a few mammals, such as the duck-billed platypus.

There are many adaptations for embryonic development within eggs and on land. One of these is a hard shell for protection, which is brittle in birds and leathery in reptiles. Embryonic membranes also help to provide a favorable environment for the developing embryo. Evolution of the watertight egg was one of the adaptations that permitted terrestrial vertebrates to become more independent of water.

IN A NUTSHELL

There are four types of embryonic membranes:

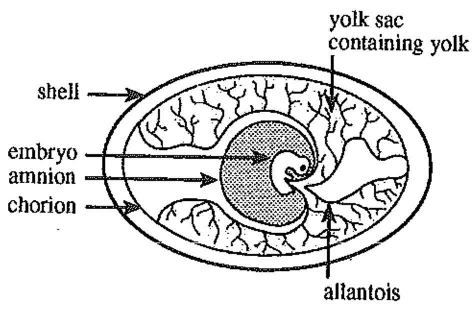
- Yolk sac
- Allantois
- Chorion
- Amnion

Types of embryonic membranes include the *chorion*, which lines the inside of the egg shell. This moist membrane permits gas exchange through the shell. The *allantois*, a saclike structure developed from the digestive tract, is another embryonic membrane. It carries out functions like respiration and excretion, particularly the exchange of gases with the external environment. The allantois layer has many blood vessels to take in O_2 and give off CO_2, water, salt, and nitrogenous wastes. A third embryonic membrane, the *amnion*, encloses the amniotic fluid. Amniotic fluid provides a watery environment for the embryo to develop in and provides protection against shock. Finally, the *yolk sac* encloses the yolk. Blood vessels in the yolk sac transfer food to the developing embryo.

Internal Development. In animals that develop internally, fertilization and embryo development occur within the mother. This internal development can take a number of different forms, depending on whether or not a placenta is utilized in sustaining the embryo. The *placenta* includes tissues of both the embryo and the mother. It is the site at which exchange of food, oxygen, waste, and water can take place.

A TOUGH FIRST CHALLENGE

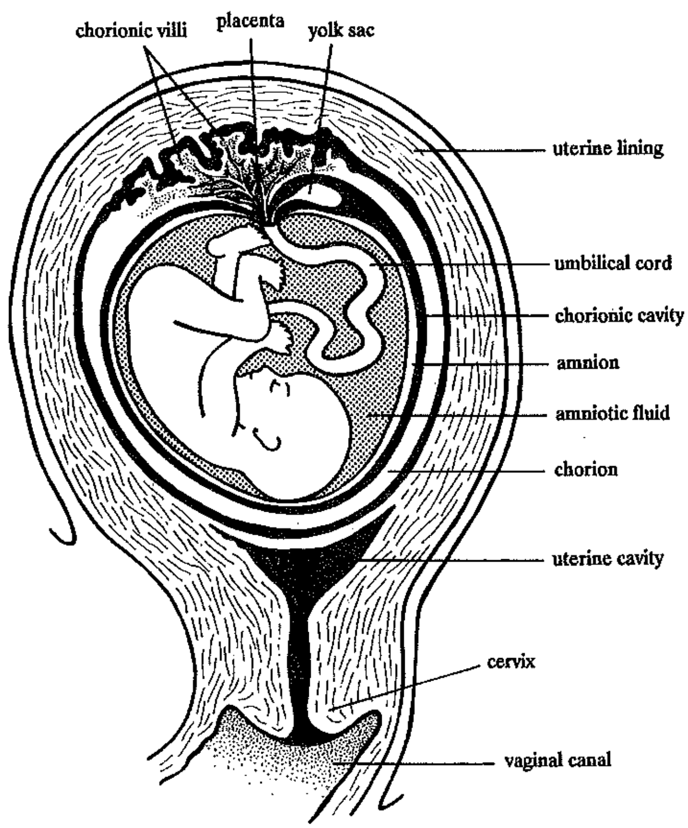
Marsupials, such as the kangaroo, are nonplacental animals. The newborn kangaroo is very immature. After birth, the immature infant must climb up its mother's stomach to the pouch, where it is protected and fed milk.



Egg

In some nonplacental animals, development occurs inside the mother but the embryo lacks a placenta. Thus, there is no region of exchange of materials between the blood of the mother and the embryo. Eggs must therefore be relatively large, as their yolk must supply the developing embryo's needs. Tropical fish and opossums are examples of nonplacental animals. Embryos develop inside the oviduct, obtaining food from the yolk of the egg, and are born alive after a relatively brief period of internal embryonic development.

In placental animals, there is no direct contact between the bloodstreams of the mother and the embryo. Transport is accomplished by diffusion and active transport between juxtaposed blood vessels of the mother and embryo in the placenta. The eggs of placental animals are very small, since the embryo is only briefly maintained until a placental connection is completed. Humans, for example, have no yolk, but they do have a yolk sac. The *umbilical cord* that attaches the embryo to the placenta is composed completely of tissues of embryonic, not maternal, origin. This cord contains the umbilical artery and vein. As in birds and reptiles, the amnion of placental mammals provides a watery environment to protect the embryo from shock.



Human Embryo

Postembryonic Development. The development of the embryo to adulthood is termed *maturation*. Maturation involves cell division, differentiation, increase in size, and development of a distinctive adult shape. Maturation can be interrupted (such as in the metamorphosis of arthropods) or uninterrupted (as in mammals). Differentiation of cells is complete when all organs reach adult form. Further cell division is needed only for repair and replacement of tissues. In humans, growth occurs rapidly in children, followed by sexual maturation during puberty.

NUTRITION

Animals are multicellular heterotrophic organisms that must get their energy and raw material through the consumption of food. Food comes in large chunks of insoluble material mostly bound up in biological polymers that cells cannot access to use directly. Food must be digested to be absorbed and used by cells. Digestion involves *mechanical* breaking of food into small pieces, *chemical* breakdown of food into its molecular building blocks, followed by *absorption* of digested nutrients. Digestion can be intracellular, occurring through the action of intracellular enzymes; or extracellular, using enzymatic secretions in a gut cavity to break down nutrients into simpler compounds that are absorbed by cells lining the gut.

PARTS OF DIGESTION

1. Mechanical—breaking food into small pieces
2. Chemical—breaking down biopolymers into small pieces with enzymes
3. Absorption—taking nutrients up into cells

In many organisms, including humans, the mechanical breakdown of large fragments of food into small particles occurs through cutting and grinding in the mouth and churning in the digestive tract. The molecular composition of these food particles is unchanged by breaking food into smaller pieces, but making the pieces smaller gives enzymes greater access to the molecules in the food.

Chemical breakdown of molecules in digestion is accomplished through enzymatic hydrolysis. Food in large part consists of large biological polymers, including proteins, nucleic acids, and carbohydrates (like starch). Organisms first hydrolyze these with enzymes into their building-block components. The smaller digested nutrients (glucose, amino acids, fatty acids, and glycerol) are absorbed by cells lining the gut to be metabolized or transported to other parts of the body.

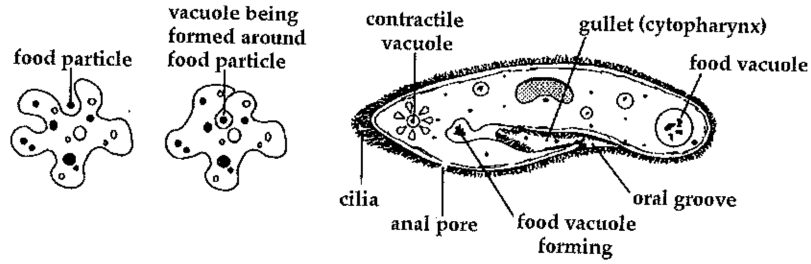
In addition to carbohydrates, fats, and proteins, there are many small molecules that are essential nutrients, including minerals and vitamins. Many of these act as coenzymes for enzymatic activity and are found associated with essential enzymes. Niacin, for example, is used to make NADH. These vitamins and minerals are essential in the diet since the body cannot produce these substances through biosynthesis.

Ingestion and Digestion in Protozoa and Cnidarians

Protozoans utilize *intracellular digestion*. In amoebae, pseudopods surround and engulf food through *phagocytosis* and enclose it in food vacuoles. *Lysosomes* (containing digestive enzymes) fuse with the food vacuole and release their digestive enzymes, which break down macromolecules like proteins, nucleic acids, and carbohydrates into their building blocks. The resulting simpler molecules diffuse into the cytoplasm, and unusable end products are eliminated from the vacuoles.

THEY GRAB THEIR FOOD, TOO

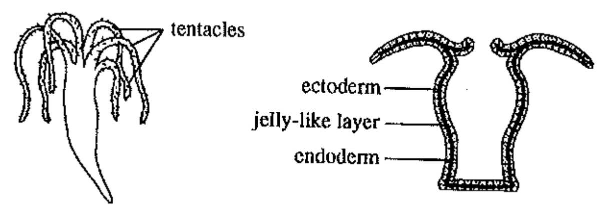
Many simple organisms, such as paramecia or hydra, sweep food into their oral grooves or mouths with their cilia or tentacles.



Protozoan Digestive System

In the *paramecium*, cilia sweep microscopic food such as yeast cells into the oral groove and cytopharynx. A food vacuole forms around food at the lower end of the cytopharynx. Eventually, the vacuole breaks off into the cytoplasm and progresses toward the anterior (front) end of the cell. Enzymes are secreted into the vacuole and the products diffuse into the cytoplasm. Solid wastes are expelled at the anal pore.

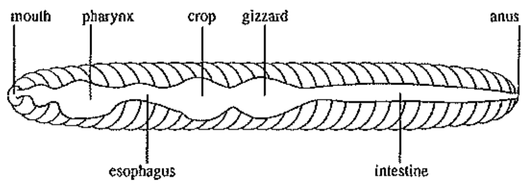
Hydra (phylum *Coelenterata*, also called *Cnidarians*) employ both intracellular and *extracellular digestion*. Tentacles bring food to the mouth (ingestion) and release the particles into a cuplike sac. The endodermal cells lining this gastrovascular cavity secrete enzymes into the cavity. Thus, digestion principally occurs outside the cells (extracellularly). However, once the food is reduced to small fragments, the gastrodermal cells engulf the nutrients and digestion is completed intracellularly. Undigested food is expelled through the mouth. Every cell is exposed to the external environment, thereby facilitating intracellular digestion.



Hydran Digestive System (external view and in cross-section)

Ingestion and Digestion in Annelida (Earthworms)

Since the earthworm's body is many cells thick, only the outside skin layer contacts the external environment. For this reason, this species requires a more advanced digestive system and circulatory system. Like higher animals, earthworms have a complete one-way, two-opening digestive tract. Their digestive tract is a tube that moves food through the animal in one direction instead of a sac like in cnidarians. Having a tube is more efficient than having a sac, as food moves in one direction through the tube, and digestion can become a stepwise process with specialization of parts of the tube for specific digestive processes. The parts of the digestive tube in annelids include the mouth, pharynx, esophagus, crop (to store the food), gizzard (to grind the food), intestine (which contains a large dorsal fold that provides increased surface area for digestion and absorption), and anus (where undigested food is released).



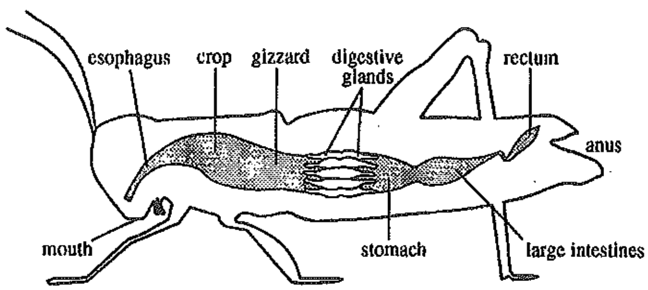
Digestive System of Annelida

CROPS, STOMACHS, AND GIZZARDS

Crops and stomachs store food; gizzards grind it.

Ingestion and Digestion in Arthropoda

Arthropods (such as grasshoppers) have a similar digestive system as annelids, except that they utilize jaws for chewing and salivary glands for better digestion.



Digestive System of Arthropoda

EPHEMERAL ARTHROPODA

Mayflies belong to the order Ephemerata, which means short-lived. The adult flies emerge from the pupae, mate, and die within 24 hours. These insects do not eat during their adult lifetimes; in fact, they do not even possess functioning mouths.

Ingestion and Digestion in Humans

The human digestive system consists of the *alimentary canal* and the associated glands that contribute secretions into this canal. The alimentary canal is the entire path of food through the body: the *oral cavity, pharynx, esophagus, stomach, small intestine, large intestine*, and *rectum*. Many glands line this canal, such as the gastric glands in the wall of the stomach and intestinal glands in the small intestine. Other glands, like the pancreas and liver, are outside the canal proper and deliver their secretions into the canal via ducts.

Mechanical Digestion. Food is crushed and liquefied by the teeth, tongue, and peristaltic contractions of the stomach and small intestine, increasing the surface area upon which the digestive enzymes can work. *Peristalsis* is a wavelike muscular action conducted by smooth muscle that lines the gut in the esophagus, stomach, small intestine, and large intestine. Rings of muscle circling the gut contract, and move a ring of contraction down the gut, moving the food within the gut as well.

DON'T MIX THESE UP ON TEST DAY

Mechanical digestion involves chewing in the mouth, grinding in the gizzard, and churning in the digestive tract.

Chemical digestion involves enzymes that break down carbohydrates (e.g., amylase), proteins (e.g., pepsin), or lipids (e.g., lipase).

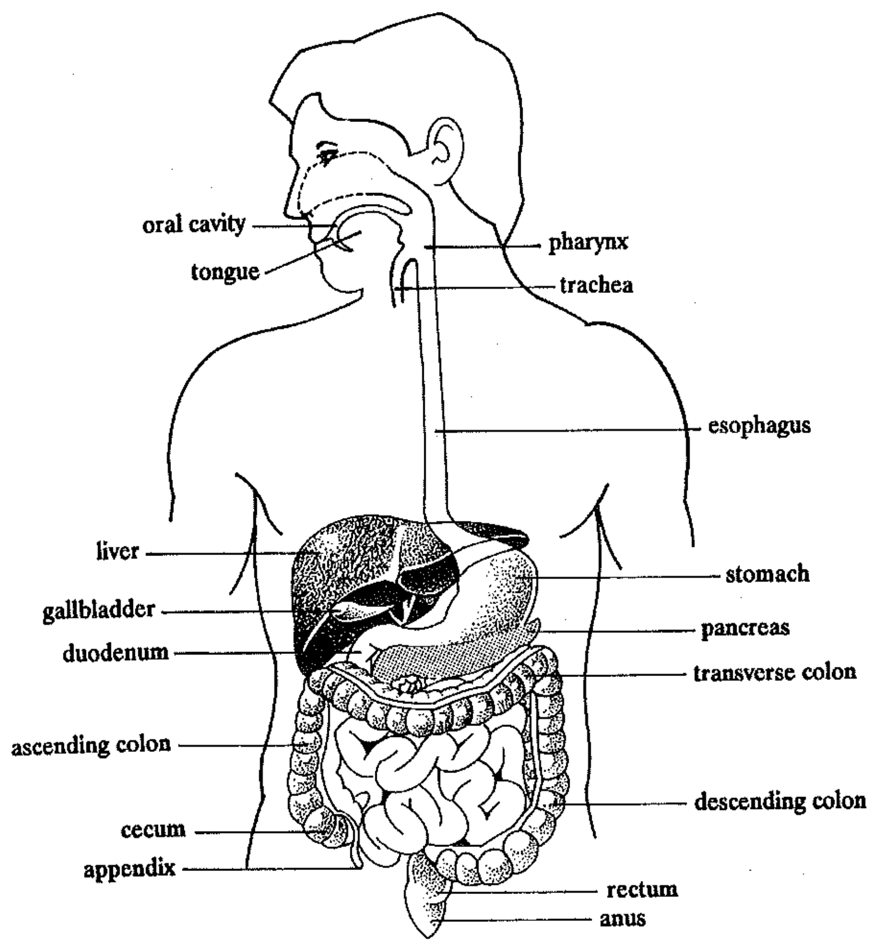
Chemical Digestion. Several exocrine glands associated with the digestive system produce secretions involved in breaking food molecules into simple molecules that can be absorbed. Polysaccharides are broken down into glucose, triglycerides are hydrolyzed into fatty acids and glycerol, and proteins are broken down into amino acids.

Chemical digestion begins in the mouth. In the mouth, the *salivary glands* produce saliva that lubricates food and begins starch digestion. *Saliva* contains *salivary amylase* (ptyalin), an enzyme that breaks the complex starch polysaccharide into maltose (a disaccharide). As food leaves the mouth, the *esophagus* conducts it to the stomach by means of peristaltic waves of smooth muscle contraction.

BUSY LIVER

The liver is responsible for:

- Detoxification of toxins
- Storage of iron and vitamin B_{12}
- Destruction of old erythrocytes
- Synthesis of bile
- Synthesis of various blood proteins
- Defense against various antigens
- Beta-oxidation of fatty acids to ketones
- Interconversion of carbohydrates, fats, and amino acids



Human Digestive System

In the *stomach*, *gastric glands* produce *hydrochloric acid* and the enzyme *pepsin*. The acidity of the stomach provides the low pH environment necessary for the optimum enzymatic activity of pepsin. In addition, the acidity destroys ingested microorganisms. *Chyme* (partially digested food in the stomach) enters the *duodenum* through the *pyloric sphincter.*

The *liver* is also involved in digestion by producing *bile*, an important factor in fat digestion. Bile is stored in the *gallbladder* prior to its release into the small intestine. Bile salts are detergents that emulsify fats, breaking large fat globules into smaller droplets to expose a greater surface area of the fats to the action of pancreatic lipase.

The liver also helps regulate blood glucose levels and produces urea. Glucose and other monosaccharides absorbed in the *small intestine* during digestion are delivered to the liver directly from the intestine via the *hepatic portal vein* without passing first through the rest of the tissues. Glucose-rich blood is processed by the liver, which converts excess glucose to glycogen for storage in the liver. If the blood has a low glucose concentration, the liver converts glycogen into glucose and releases it into the blood, restoring blood glucose levels to normal. The liver also synthesizes glucose from noncarbohydrate precursors via the process of gluconeogenesis when blood glucose levels are low. Glycogen metabolism is under both hormonal and nervous control.

Pancreatic lipase is produced and secreted by the *pancreas*, which is also responsible for manufacturing *amylase* (for starch digestion), *trypsin*, and *chymotrypsin* (for protein digestion). Unlike pepsin, these enzymes have a pH optimum in the alkaline range. The necessary alkaline environment is created by the release of large quantities of bicarbonate ion (HCO_3^-) by the pancreas along with the digestive enzymes. This bicarbonate neutralizes the acidity of the chyme released into the duodenum from the stomach.

Pancreatic proteases like trypsin are produced and stored in inactive forms called *zymogens*. Zymogens are activated after secretion when they are cleaved by another protease. The production of these digestive enzymes as inactive zymogens prevents damage to the pancreatic tissues that occurs if proteases are prematurely active, for example, if pancreatic secretions are blocked.

As food enters the small intestine, digestion continues. Glands in the wall of the intestine produce aminopeptidases (for polypeptide digestion) and disaccharidases (for digestion of maltose, lactose, and sucrose). The pancreatic and small intestinal enzymes are responsible for the bulk of digestion in the gastrointestinal tract. In addition, most of the absorption of the digested nutrients occurs in the small intestine. The large intestine is devoted mainly to water and vitamin K absorption, and the rectum acts as a transient storage place for feces prior to their elimination through the anus.

QUICK QUIZ

Where does digestion of the following foods begin?

1) Carbohydrates
2) Proteins
3) Lipids

Answers:
1) In the mouth (through the action of salivary amylase)
2) In the stomach (through the action of pepsin)
3) In the small intestine (through the action of bile and lipase)

DIGESTIVE ENZYMES

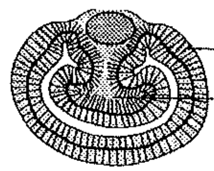
Lipids—lipase
Starch—amylase
Proteins—pepsin
trypsin
chymotrypsin

Adaptations for Absorption

It is not enough for organisms to simply digest food. They must also be able to transport this food to their cells to be used for energy. To be transported to cells, food molecules must be absorbed out of the interior of the gut. As organisms become larger, adaptations for absorption become increasingly complex.

Protozoa and Hydra. In the protozoa, digested food in the food vacuole passes by simple diffusion into the cell cytoplasm. The hydra absorbs extracellularly digested nutrients into its body cells; some nondigested material is also taken up into the cells and digested intracellularly.

Annelida and Arthropoda. The earthworm (annelida) and grasshopper (arthropoda) absorb nutrients in similar ways. Soluble food passes by diffusion through the walls of these creatures' small intestines into the blood. The infolding (typholosole) of the digestive canal increases the absorptive surface.



Absorption in Annelida

Humans. As for humans, most absorption of nutrients occurs in the small intestine, which is adapted for absorption. *Villi* are microscopic projections from the lining of the intestine. The villi increase the surface area of the intestine, significantly increasing the area that is involved in absorption.

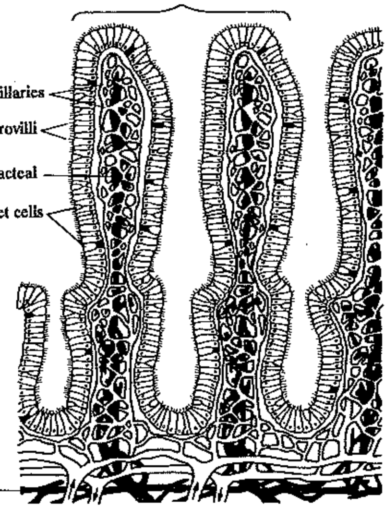
Villi contain capillaries and lacteals (projections of the lymphatic system) and are also covered with microvilli, "hairs" that further increase surface area and aid in absorption. The capillaries are in close proximity to the contents of the intestine, helping the movement of food molecules into the blood for transport through the body. Amino acids, small fatty acids, and glucose pass through the villi walls into the capillary system. Many nutrients, such as glucose and amino acids, are actively transported into cells using energy, against a concentration gradient, while others are passively absorbed, flowing down a gradient into cells and the circulation.

SITES OF ABSORPTION

Amino acids and monosaccharides are absorbed into the bloodstream by the microvilli of the small intestine.

Lipid molecules, however, are picked up by the lymphatic system via lacteals.

Fats are not generally transported through capillaries. Triglycerides are broken down in the intestinal interior into fatty acids and glycerol; these are absorbed by cells lining the intestine, then reformulated as triglycerides in fat-containing particles called chylomicrons. Chylomicrons pass into the lymphatic system in the villi to be transported eventually into the blood.



Absorption in Humans

CIRCULATION

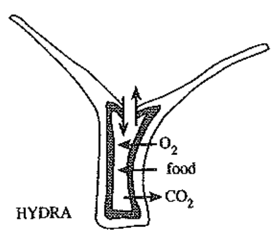
As we saw earlier, organisms make nutrients available to cells through absorption. But these nutrients, along with gases and wastes, must also be transported throughout the body to be used. The system involved in transport of these materials to different parts of the body is called the *circulatory system*. Small animals have their cells either directly in contact with the environment or in close enough proximity that diffusion alone is sufficient to provide for the movement of gases, wastes, and nutrients, making a specialized system for circulation unnecessary. Larger, more complex organisms require circulatory systems to move material within the body.

Circulation in Protozoans and Cnidarians

Protozoans are single-celled organisms, and cnidarians often have only two cell layers, with both layers in contact with the environment. Materials pass by simple diffusion across the plasma membrane between the cytoplasm and external environment. In hydra, for example, water circulates into and out of the body cavity, and all cells are in direct contact with the external environment.

A SIMPLE LIFE

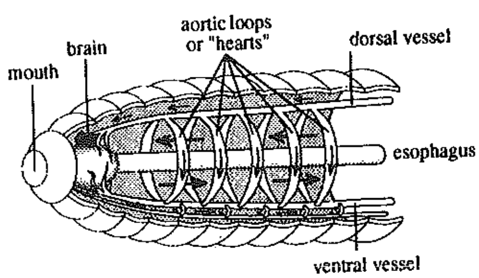
Note that in simple organisms, circulation occurs mainly through the process of simple diffusion.



Circulation in Hydra

Circulation in Annelida

Annelids are larger and more complex animals than cnidarians and most of their cells are not in direct contact with the external environment. A closed circulatory system moves food, water, and oxygen throughout the body, always within defined blood vessels. In annelids blood travels forward to the head (anterior) through dorsal blood vessels. Five aortic loops or "hearts" force blood down to the ventral vessel, which carries blood to the posterior and up to complete the circuit (see figure).



Circulation in Annelida

Annelids have no red blood cells, unlike vertebrates, but have hemoglobin-like pigment dissolved in their blood. Nourishment in the form of food and gases diffuses into the cells from the capillaries.

Circulation in Arthropoda

Arthropods, such as grasshoppers, utilize an open circulatory system. In an open circulatory system, blood flows within vessels some of the time, but in some areas of the body, the blood is not contained, flowing instead through open spaces called sinuses. Arthropods have a simple beating tube for a heart, which moves blood through a dorsal vessel and then out into sinuses. In these sinuses, blood is not enclosed in blood vessels but directly bathes cells, and exchange of food takes place (air exchange, meanwhile, is accomplished through a tracheal system of air tubes). Blood then reenters blood vessels. Mollusks also have an open circulatory system.

DON'T MIX THESE UP ON TEST DAY

Right ventricle → pumps blood to the lungs in the pulmonary artery

Left ventricle → pumps blood through the aorta to the rest of the body

Circulation in Vertebrates

Vertebrates have closed circulatory systems, with a chambered heart that pumps blood through arteries into tiny capillaries in the tissues. Blood from capillaries passes into veins that return to the heart. The chambers of vertebrate hearts include atria and ventricles. *Atria* are chambers where blood from veins collects and is pumped into ventricles, while *ventricles* are larger, more muscular chambers that pump blood out to the body.

Fish have a two-chambered heart with one atrium and one ventricle, in which the sole ventricle pumps blood into capillaries in the gills to collect oxygen. From the capillaries in the gills the blood is collected in arteries that move toward a second set of capillaries in the rest of the tissues of the body to deliver oxygen and nutrients. From there the blood passes back to the heart.

The problem with this setup is that it takes a lot of pressure to pump blood through the first set of capillaries in the gills, and there is little pressure left afterward to pump the blood through the rest of the body. This setup is not sufficient for the greater metabolic needs of terrestrial vertebrates. Amphibians have a three-chambered heart, and birds and mammals have four-chambered hearts, with two atria and two ventricles. The right ventricle pumps deoxygenated blood to the lungs through the pulmonary artery. Oxygenated blood returns through the pulmonary vein to the left atrium. From there it passes to the left ventricle and is pumped through the aorta and arteries to the rest of the body. Valves in the chambers of the heart keep blood from moving backward. There are, in effect, two separate circulations: one for the lungs, called the pulmonary circulation, and the systemic circulation for the rest of the body. Using a four-chambered heart to split the pumping of blood through the lungs from the pumping of the blood to the rest of the body allows much greater pressure in the systemic circulation than would be possible with a two-chambered heart.

The human heartbeat a doctor hears through a stethoscope is the sound of the chambers of the heart contracting in a regular pattern called the *cardiac cycle*. The heart is composed of specialized muscle tissue called *cardiac muscle*. Cardiac muscle cells are connected together in an electrical network that transmits nervous impulses throughout the muscle to stimulate contraction. The transmission and spreading of the signal is highly controlled to coordinate the beating of the chambers. During each cardiac cycle, the signal to contract initiates on its own in a special part of the heart called the *sinoatrial node*, or the pacemaker region. Cells from this region fire impulses in regular intervals all on their own, without stimulation from the nervous system. Once the signals start, they spread through both atria, which then contract, forcing blood into the ventricles. The signal then passes into the ventricles and spreads throughout their walls, causing contraction of the ventricles and the movement of blood into the major arteries. The ventricular contraction occurs during the *systole* part of the cardiac cycle, and the atria contract as the ventricles relax during the *diastole* part of the cardiac cycle.

DON'T MIX THESE UP ON TEST DAY

Atria → receive blood from veins

Ventricles → pump blood out of arteries

The signal that causes the beating of the heart originates spontaneously within the heart without nervous stimulation, but the heart rate can be altered by nervous stimulation. The most important nervous stimulation of the heart is the vagus nerve of the parasympathetic system, which acts to slow the heart rate. The vagus nerve is more or less always stimulating the heart and can increase the heart rate simply by stimulating the heart less than usual. The sympathetic nervous system and epinephrine increase the heart rate.

Arteries. The *arteries* carry blood from the heart to the tissues of the body. They repeatedly branch into smaller muscular arteries (arterioles) until they reach the capillaries, where exchange with tissues occurs. Arteries are thick-walled, muscular, and elastic; conduct blood at high pressure; and have a pulse caused by periodic surges of blood from the heart. Arterial blood is oxygenated except for blood in the pulmonary artery, which carries deoxygenated blood from the heart to the lungs to renew the oxygen supply.

Veins. *Veins* carry blood back to the heart from the capillaries. Blood flows fom capillaries to *venules* (small veins) to veins. Veins are relatively thin-walled, conduct at low pressure because they are at some distance from the pumping heart, and contain many valves to prevent backflow. Veins have no pulse; they usually carry dark red, deoxygenated blood (except for the pulmonary vein, which carries recently oxygenated blood from the lungs). The movement of blood through veins is assisted by the contraction of skeletal muscle around the veins, squeezing blood forward. Once it moves forward in this way, valves keep the blood from going back.

DON'T MIX THESE UP ON TEST DAY

Arteries:

- Are thick-walled
- Usually carry oxygenated blood
- Conduct blood at high pressure
- Have a pulse
- Have no valves

Veins:

- Are thin-walled
- Usually carry deoxygenated blood
- Conduct blood at low pressure
- Have no pulse
- Have valves to prevent backflow

Capillaries. *Capillaries* are thin-walled vessels that are very small in diameter. In fact, their walls are only one endothelial cell thick and red blood cells must pass through capillaries in single file. Capillaries, not arteries or veins, permit exchange of materials between the blood and the body's cells. Their small size and thin walls assist in the diffusion of material through their walls. Also, some of the liquid component of blood seeps from capillaries to directly bathe cells with nutrients. Proteins and cells are too large to pass into the tissues and stay in the blood within the capillary walls. Some of the fluid that enters tissues passes directly back into the blood at the other end of the capillary, and the rest can circulate back in the lymphatic system. If the capillaries are too permeable or too much liquid stays in the tissues, swelling results.

At different times, different tissues require differing blood flow. The body regulates much of blood flow in tissues locally. Arterioles that feed capillaries in a tissue have smooth muscle in their walls that can relax or constrict to allow more or less blood into a specific area of tissue. Factors that are affected by metabolic activity (such as the levels of oxygen and carbon dioxide in the blood) also act on the arteriole smooth muscle to match the blood flow to the metabolic needs of the tissue.

Lymphatic system. *Lymph vessels* are a separate system independent of the blood system. This system carries extracellular fluid (at this stage known as lymph) at very low pressure, without cells. The *lymph nodes* are responsible for filtering lymph to rid it of foreign particles, for maintaining the proper balance of fluids in the tissues of the body, and for transporting chylomicrons as part of fat metabolism. The system ultimately returns lymph to the blood system via the largest lymph vessel, the thoracic duct, which empties lymph back into the circulation shortly before it enters the heart.

The blood. The fluid moved through the body by the circulatory system is the blood. The blood is composed of a liquid component, the plasma, and cells. The cells include red blood cells (*erythrocytes*), platelets, and white blood cells (*lymphocytes*). Each of these types of cells has specific functions.

PARTS OF BLOOD

Plasma: fluids, proteins, solutes

Platelets: clotting

Erythrocytes: red blood cells, carry O_2

Lymphocytes: nonspecific immunity

B cells: make antibodies

Helper T cells: coordinate immune response

Cytotoxic T cells: kill infected cells

The *plasma* is composed of water, salts, proteins, glucose, hormones, lipids, and other soluble factors. The main salts in plasma are NaCl and KCl, in a composition that has been noted as similar to the composition of salt in sea water, our evolutionary origin. Calcium is another important salt in the extracellular fluid, including blood. The body regulates the blood volume and salt content through water intake and through excretion of urine. Oxygen is dissolved as a gas to a small extent in blood, although most oxygen is transported bound to hemoglobin in red blood cells. Carbon dioxide is converted to carbonic acid in the blood. Not only does this increase the solubility of carbon dioxide in the blood, but it also creates a pH buffer that protects the body against large changes in the pH of blood. The glucose in blood is transported as a dissolved sugar for cells to take up as needed. Hormones, both steroid hormones and peptide hormones, are transported in blood from one tissue where they are secreted to other tissues where they exert their actions. The protein component of plasma consists of antibodies for immune responses, fibrinogen for clotting, and serum albumin. The protein component of blood helps to draw water into the blood in the capillaries and prevent loss of fluid from the blood into the tissues, which would cause swelling.

Red blood cells are the most abundant cells in blood, and their primary function is to transport oxygen. After they are formed in the bone marrow, mature red blood cells (*erythrocytes*) lose their nuclei and become biconcave discs. They live for about four months in circulation before they are worn out and are destroyed in the spleen. Without a nucleus, mature red blood cells cannot make new proteins to repair themselves. Red blood cells also lose mitochondria, which renders them incapable of performing aerobic respiration. If they were able to carry on this form of respiration, they would themselves use up the oxygen that they carry to the tissues of the body. Instead, they produce energy in the form of ATP without using oxygen, through glycolysis.

The oxygen-carrying component of red blood cells is the protein *hemoglobin,* a tetrameric protein, in which each of the four polypeptide subunits has its own heme group with an iron that binds oxygen to form oxyhemoglobin. A given tetramer of hemoglobin protein can have from 0 to 4 oxygen molecules bound to it. The binding of oxygen to hemoglobin is reversible and cooperative, meaning that when one of the subunits in hemoglobin binds an oxygen molecule, this increases the affinity of the remaining subunits to bind oxygen, resulting in a sigmoidal curve for the binding of oxygen by hemoglobin. In the lungs, where the partial pressure of oxygen is high, hemoglobin readily picks up oxygen. In the tissues, where the partial pressure of oxygen is low, oxygen leaves hemoglobin to diffuse into the tissues. The hemoglobin molecule has evolved to deliver oxygen more efficiently in response to changes in the tissues. In periods of great metabolic activity in muscle, the pH of the blood can decrease and carbon dioxide increase, both of which tend to reduce the affinity of hemoglobin for oxygen and cause it to leave more oxygen in the tissue.

Blood Types. Red blood cells manufacture two prominent types of antigens, antigen A (associated with blood type A) and antigen B (blood type B). In any given individual, one, both, or neither antigen may be present. The same pattern appears in every red blood cell.

The plasma of every individual also contains antibodies for the antigens that are not present in the individual's red blood cells (if an individual were to produce antibodies against his or her own red blood cells, the antibodies would bind to the cells and the blood would clump, or agglutinate). Type A individuals have anti-B antibody, and type B individuals have anti-A antibody. Type O individuals, who have neither A nor B antigens, have both anti-A and anti-B antibodies. Type AB individuals have neither type of antibody. These relationships are depicted in the graph below.

	Blood Type	Antigen on Red Blood Cells	Antibodies Found in Plasma
	A	A	anti-B
	B	B	anti-A
Universal Recipient	AB	A, B	none
Universal Donor	O	none	anti-A, anti-B

Clotting of blood involves soluble proteins and small fragments of cells called platelets. Platelets are fragments of cells released into the circulation from cells called megakaryocytes. Platelets in an open wound release the enzyme thromboplastin, which initiates a series of reactions that ultimately lead to the formation of a fibrin clot. Thromboplastin, with the aid of calcium and vitamin K as cofactors, leads, in several steps, to the conversion of the inactive plasma prothrombin to its active form, thrombin. Thrombin then converts fibrinogen (dissolved in plasma) into the fibrinous protein called fibrin. Threads of fibrin trap red blood cells to form clots. As the blood clots, serum is the liquid left over. Thus serum is essentially plasma, minus fibrinogen and other clotting factors.

IMMUNE SYSTEM

VACCINE PROTECTION

When you are vaccinated, you are injected with weakened or dead pathogens. Your body has a protective immune response to these pathogens, stimulating B cells and T cells, so that when the real pathogen comes along, you're already protected!

The interior of the body is an ideal growth medium for some pathogenic organisms like disease-causing bacteria and viruses. To prevent this, the body has defenses that either prevent organisms from getting into the interior of the body or stop them from proliferating if they are within the body. The system that plays this protective role is called the *immune system*. The trick for the immune system is to be able to mount aggressive defenses, and, at the same time, to distinguish foreign bodies to avoid attacking one's own tissues and causing disease. This is exactly what happens in autoimmune disorders; the immune system attacks one's own tissues as if they were foreign invaders.

Passive immune defenses are barriers to entry. These include the skin and the linings of the lungs, mouth, and stomach. The skin is a very effective barrier to most potential pathogens, but if wounded, the barrier function of skin is lost. This is why burn patients are very susceptible to infection. The lungs are a potential route of entry, but are patrolled by immune cells, and have mucus to trap invaders and cilia lining the respiratory tract to remove the trapped invaders. The spleen plays a role in the immune system in adults, and in embryos plays a role in blood cell development.

Active immunity is conferred by the cellular part of the immune system. White blood cells are actually several different cell types that are involved in the defense of the body against foreign organisms in different ways. White blood cells include *phagocytes* that engulf bacteria with amoeboid motion and various types of *lymphocytes* (B and T cells) that are involved in the immune response. B cells produce *antibodies*, or *immunoglobins*, which are secreted proteins specific to foreign molecules such as viral or bacterial proteins. Helper T cells coordinate the immune response, and killer T cells directly kill cells that are infected with intracellular pathogens like viruses or cells that are aberrant like malignant cells. A given B or T cell responds to a specific antigen. Since the body does not know what antigens or pathogens may attack it, the immune system creates a varied population of B and T cells in which each cell recognizes only one antigen, but the population of cells contains a huge range of specificities. If a B cell or T cell encounters an antigen that matches its specificity, then it is stimulated to proliferate and create more cells with the same specificity. This amplification of a clone of cells that respond to the invading antigen helps the body to respond and to remain immune to infection in the future by the same pathogen. When a B cell encounters an antigen that it recognizes, it proliferates to make more B cells that produce antibody. The stimulated B cells also produce memory cells that do not make antibody but have the same specificity and will lie dormant for many years, ready to respond if the body is challenged again with the same antigen.

QUICK QUIZ

What do *B cells* do?

(A) They produce antibodies.
(B) They lyse infected cells.
(C) They produce proteins that stimulate killer T and B cells to mature.

(*Answer* = (A))

Neutrophils are phagocytic cells that are the first cells to arrive at a site of inflammation to eat bacteria and other foreign particles. They are the primary component of pus. *Macrophages* and *monocytes* are also phagocytic cells and present foreign components, such as bacteria and viruses, to B cells and T cells to stimulate these parts of the immune system to respond.

ANTIGEN RESPONSE

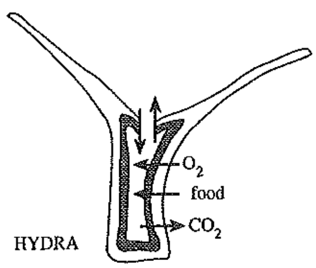
The body creates B and T cells with random antigen recognition. Cells that recognize foreign antigen proliferate to produce antigen-specific immune responses.

RESPIRATION

Cells performing aerobic respiration need oxygen and need to eliminate carbon dioxide (CO_2). To do this, organisms must exchange gases with the environment. The respiratory system provides oxygen and removes CO_2. The oxygen is used to drive electron transport and ATP production, and CO_2 is produced from burning glucose in the Krebs cycle. Even the most expert pearl divers cannot live without breathing for more than a few minutes. Gas exchange is accomplished via a variety of efficient ways, which range from simple diffusion to complex systems of respiration. The following sections describe the adaptations employed by a range of organisms.

Respiration in Protozoa and Cnidarians

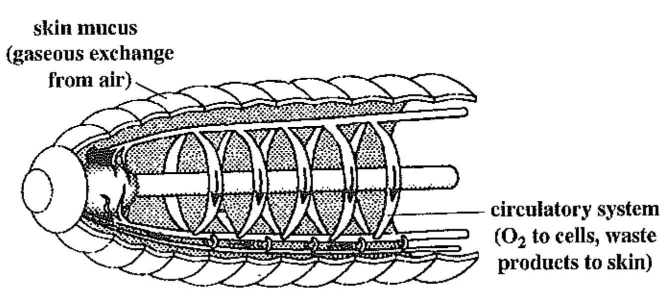
Since every cell of these types of primitive organisms is in contact with the external environment (in this case, water), respiratory gases can be easily exchanged between the cell and the outside by direct diffusion of these gases through the cell membrane. Lipid bilayer membranes are fully permeable to oxygen and carbon dioxide.



Respiration in Hydra

Respiration in Annelida

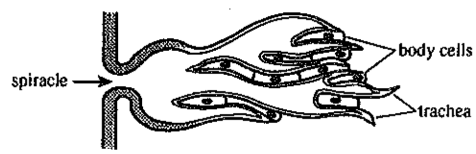
Mucus secreted by cells at the external surface of the annelid's body provides a moist surface for gaseous exchange from the air to the blood through diffusion. The annelid's circulatory system then brings O_2 to the cells and waste products such as CO_2 back to the skin, excreting them into the outside environment.



Respiration in Annelida

Respiration in Arthropoda

The arthropod respiratory system consists of a series of respiratory tubules called *tracheae*. These tubules open to the outside as pairs of openings called *spiracles*. Inside the body, the tracheae subdivide into smaller and smaller branches, enabling them to achieve close contact with most cells. In this way, this system permits the direct intake, distribution, and removal of respiratory gases between the air and the body cells. No oxygen carrier is needed and specialized cells for this purpose are not found. Since a blood system does not intervene in the transport of gases to the body's tissues, this system is very efficient and rapid, enabling most arthropods to produce large amounts of energy relative to their weights. The direct diffusion of air through tracheae is one factor that limits body size in arthropods.



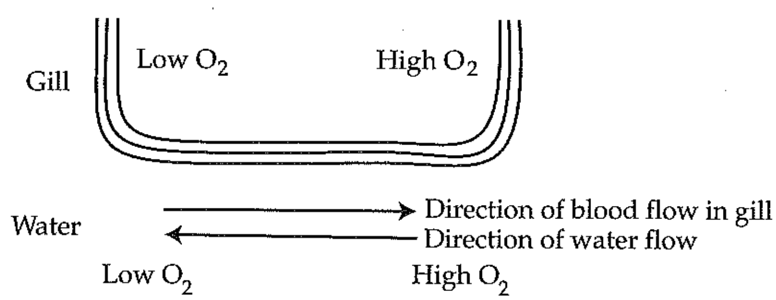
Respiration in Arthropoda

Respiration in Fish

Water entering a fish's mouth travels over numerous thin-walled, thread-like *gill* filaments that are well fed by capillaries. As water passes over these gill filaments, O_2 diffuses into the blood while CO_2 leaves the blood to enter the water. Arteries then transport the oxygenated blood through the body. The blood in the gills and the water moving over the gills move in opposite directions, creating what is known as a countercurrent exchange mechanism for the exchange of gases between the blood and the environment, a very efficient mechanism for exchange. After passing over the gills, water passes out of the body through openings on either side of the head, taking the discarded carbon dioxide with it. Marine invertebrates also have gills to exchange gases with their water environment.

COUNTERCURRENT EXCHANGE

Respiration in fish is very efficient, due to a process called countercurrent exchange. Blood in the gills flows in the opposite direction of water flowing around the gills, making the exchange of O_2 and CO_2 efficient.



Respiration in Fish

Respiration in Humans

Humans have developed a complex system of respiration to transport oxygen to their cells and to rid their bodies of waste products like carbon dioxide. First, the *lungs* are designed to move air between the exterior atmosphere and an interior air space that is in close contact with capillaries. Here, oxygen and carbon dioxide diffuse between the blood and air, while blood circulates through the body to exchange gases with the tissues and then returns to the lungs.

The lungs are found in a sealed cavity in the chest, bound by the ribs and chest wall and by the muscular *diaphragm* on the bottom. A membrane called a *pleura* surrounds the lungs and is held tightly against another membrane in the chest by a thin layer of liquid. The diaphragm is curved upward when released, and flattens when contracted, expanding the chest cavity. During inspiration, or inhalation, chest muscles move the ribs up and out as the diaphragm moves down; this creates both a larger chest cavity and a lower pressure that draws air into the respiratory passages. The reverse process decreases the size of the chest cavity and forces air out of the lungs (exhalation). Exhalation is largely a passive process that does not require muscle contraction. During exhalation the elasticity of the lungs draws the chest and diaphragm inward when the muscles relax, decreasing the volume of the lungs and causing air to be forced out.

DON'T SMOKE

Emphysema is a disease characterized by the destruction of the alveolar walls. This results in reduced elasticity of the lungs, making exhalation difficult. Most cases can be traced to cigarette smoking.

The breathing rate is controlled by a part of the brain, the *medulla oblongata,* that monitors carbon dioxide content in the blood. Excess CO_2 in the blood stimulates the medulla to send messages to the rib muscles and the diaphragm to increase the frequency of respiration.

The air passages involved in respiration consist of the *nose, pharynx, larynx, trachea, bronchi, bronchioles*, and *alveoli*. The *nose* adds moisture and warmth to inhaled air and helps to filter it, removing particulates and organisms. The *pharynx* is involved in diverting ingested material into the esophagus and away from the lungs to prevent choking. The *larynx* contains a membrane that vibrates in a controlled manner with the passage of air to create the voice. The *trachea* carries air through the vulnerable throat, protected by flexible but strong rings of cartilage. At the end of the trachea, the respiratory passage splits into the two lungs and into smaller and smaller passages that terminate in the *alveoli,* tiny air sacs that are the site of gas exchange in the lungs.

TAKE A DEEP BREATH

When the diaphragm contracts, it increases the chest's volume, creating a lower pressure that draws air into the lungs.

The alveoli have thin, moist walls and are surrounded by thin-walled capillaries. Oxygen passes from the alveolar air into the blood by diffusion through the alveolar and capillary walls. CO_2 and H_2O pass out in the same manner. Note that all exchanges at the alveoli involve passive diffusion.

Since passive diffusion drives gas exchange, both in the lungs as well as the tissues, gases always diffuse from higher to lower concentration. In the tissues, O_2 diffuses into tissues and CO_2 leaves, while in the lungs this is reversed due to high oxygen pressure and low CO_2. CO_2 is carried in blood mainly as dissolved carbonate ions.

DON'T MIX THESE UP ON TEST DAY

Osmoregulation is the regulation of water and salt levels within an organism.

Thermoregulation is the regulation of an organism's temperature.

THERMOREGULATION AND THE SKIN

The external temperature is part of the abiotic environment that life contends with and adapts to. Temperature affects organisms' rate of metabolic activity and rate of water loss. Extremes of temperature retard most life, although there are organisms that live only in boiling hot springs or at subfreezing temperatures.

Organisms must also develop ways to regulate heat. Cellular respiration transfers only some of the energy derived from the oxidation of carbohydrates, fats, and proteins into the high-energy bonds of ATP. Roughly 60 percent of the total energy is not captured; most of this is transformed to heat. The vast majority of animals are *cold-blooded*, or *ectothermic*—most of their heat energy escapes to the environment. Consequently, the body temperature of ectotherms, also known as *poikilotherms*, is very close to that of their surroundings. Since an organism's metabolism is closely tied to its body temperature, the activity of ectothermic animals such as snakes is radically affected by environmental temperature changes. As the temperature rises (within limits, since very high temperatures would be lethal), these organisms become more active; as temperatures fall, they become sluggish.

Some animals, notably mammals and birds, are endotherms; they are *warm-blooded*, or *homeothermic*. They have evolved physical mechanisms that allow them to make use of the heat produced as a consequence of respiration. Physical adaptations like fat, hair, and feathers actually retard heat loss. Homeotherms maintain constant body temperatures higher than the environment around them. Hence they are less dependent upon environmental temperature than poikilothermic animals, and are able to inhabit a comparatively greater range of variable conditions as a result.

EXTRA SENSITIVE

People who are albinos cannot synthesize the pigment melanin. This autosomal recessive disease results in an exquisite sensitivity to the sun.

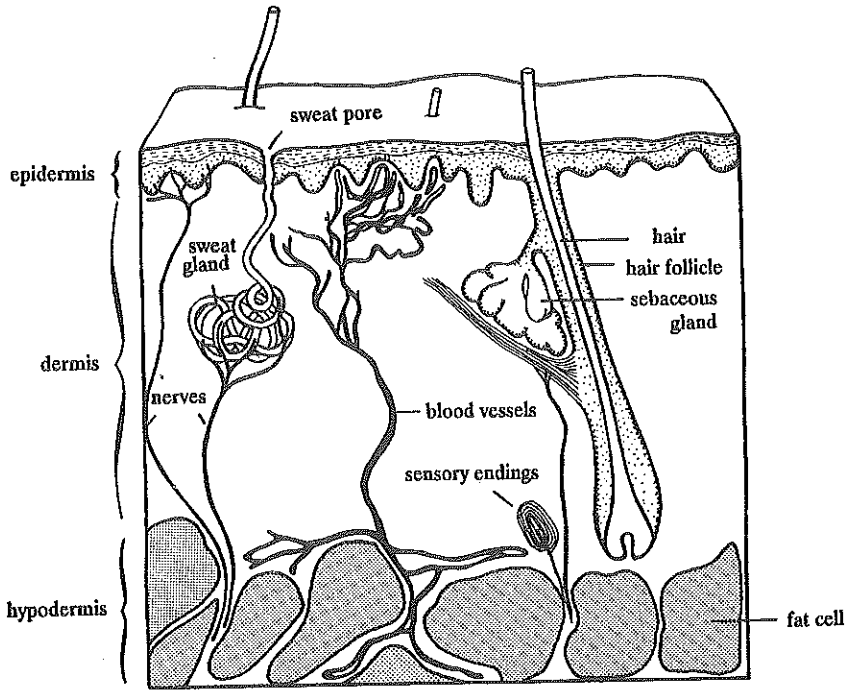
In humans, the *skin* protects the body from microbial invasion and from environmental stresses like dry weather and wind. Specialized epidermal cells called *melanocytes* synthesize the pigment *melanin,* which protects the body from ultraviolet light. The skin is a receptor of stimuli, such as pressure and temperature; is an excretory organ (removing excess water and salts from the body); and also is a thermoregulatory organ (helping control both the conservation and release of heat).

WHY THE CAMEL HAS A HUMP

The camel can tolerate a wide range of body temperatures because of its hump. This protective fat layer is strategically located on the animal's back, an area especially vulnerable to solar radiation. The hump does not contain water, despite popular belief.

Sweat glands secrete a mixture of water, dissolved salts, and urea via sweat pores. As sweat evaporates, the skin is cooled. Thus, sweating has both an excretory and a thermoregulatory function. Sweating is under autonomic (involuntary) nervous control.

Subcutaneous fat in the *hypodermis* insulates the body. Hair entraps and retains warm air at the skin's surface. Hormones such as epinephrine can increase the metabolic rate, thereby increasing heat production. In addition, muscles can generate heat by contracting rapidly (shivering). Heat loss can be inhibited through the constriction of blood vessels (*vasoconstriction*) in the *dermis*, moving blood away from the cooling atmosphere. Likewise, dilation of these same blood vessels (*vasodilation*) dissipates heat.



Human Skin

> **DON'T MIX THESE UP ON TEST DAY**
>
> *Ectoderms* warm their bodies by absorbing heat from their surroundings.
>
> *Endoderms* derive their body heat from their own metabolism.

Alternate mechanisms are used by some mammals to regulate their body temperature. For example, *panting* is a cooling mechanism that evaporates water from the respiratory passages. Most mammals have a layer of fur that traps and conserves heat. Some mammals exhibit varying states of torpor in the winter months to conserve energy; their metabolism, heart rate, and respiration rate greatly decrease during these months. *Hibernation* is a type of intense or extreme torpor during which the animal remains dormant over a period of weeks or months with body temperature maintained below normal.

EXCRETION

Excretion is the term given to the removal of metabolic wastes produced in the body. (Note that it is to be distinguished from elimination, which is the removal of indigestible materials.) Sources of metabolic waste include:

Waste	Metabolic Activity Producing the Waste
Carbon dioxide	Aerobic respiration
Water	Aerobic respiration, dehydration synthesis
Nitrogenous wastes (urea, ammonia, uric acid)	Deamination of amino acids
Mineral salts	All metabolic processes

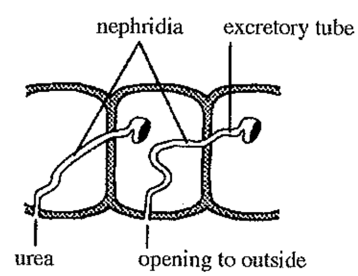
Our select group of organisms has developed various types of adaptations for excretion:

Excretion in Protozoa and Cnidarians

Remember that in these simple organisms, all cells are in contact with the external, aqueous environment. Water-soluble wastes such as the highly toxic ammonia produced by protein metabolism can therefore exit via simple diffusion through the cell membrane. Some freshwater protozoa, such as the paramecium, possess a contractile vacuole, an organelle specialized for water excretion by active transport. Excess water, which continually diffuses into the hyperosmotic cell from the hypo-osmotic environment (in this case, fresh water), is collected and periodically pumped out of the cell to maintain the cell's volume and pressure.

Excretion in Annelida

In annelids, two pairs of *nephridia* tubules in each body segment excrete water, mineral salts, and nitrogenous wastes in the form of *urea*. Fluid from the circulatory system is filtered out of the blood into fluid that fills the central body cavity. This fluid enters the nephridia tubules where some material is removed and other material is secreted into the urine before it is excreted from a pore with the nitrogenous wastes. Urine formation in this simple organism resembles to some extent the filtration and processing of urine that occurs in the mammalian kidney.



Excretion in Annelida

Excretion in Arthropods

Nitrogenous wastes are excreted in the form of solid uric acid crystals. The use of solid nitrogenous wastes is an adaptation that allows arthropods to conserve water. Mineral salts and uric acid accumulate in the *Malphigian tubules* and are then transported to the intestine to be expelled along with the solid wastes of digestion.

Osmoregulation

Osmoregulation may be defined as the ways in which organisms regulate the volume and salt content of their internal fluids. Saltwater fish, for example, live in a hyperosmotic environment that causes them to lose water and take in salt. In constant danger of dehydration, they must compensate by constantly drinking and actively excreting salt across their gills. Freshwater fish, in contrast, live in a hypo-osmotic environment that causes intake of excess water and excessive salt loss. These fish correct this condition by drinking infrequently, absorbing salts through the gills, and excreting dilute urine.

Human Excretory System

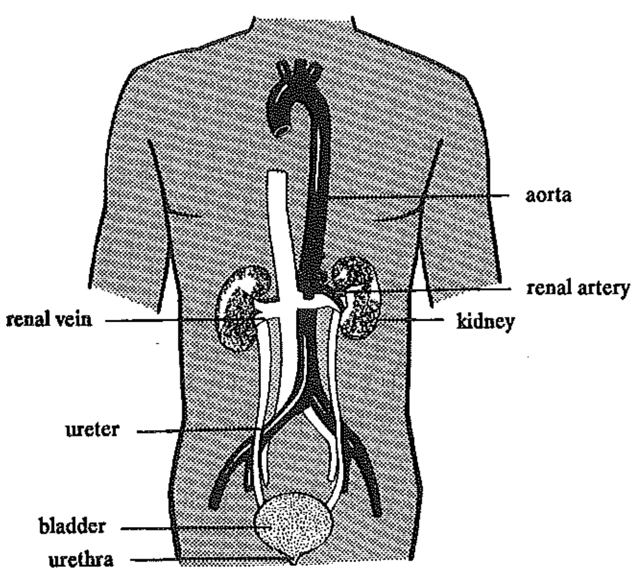
The principle organs of excretion in humans are the *kidneys*. The kidneys form urine to remove nitrogenous wastes in the form of urea as well as to regulate the volume and salt content of the extracellular fluids. From the kidney the urine passes into a tube-like *ureter* that connects to the *urinary bladder* where urine is stored until urination occurs. During urination, the urine leaves the bladder through the *urethra*.

One of the main metabolic waste products that the kidneys remove is *urea*. When excess amino acids are present, or during a period of starvation when other energy sources are depleted, the body will break down amino acids from proteins and burn them for energy in the Krebs cycle. During this process, the nitrogen is enzymatically removed from the amino acid and released as ammonia, which is highly toxic. The liver converts the ammonia to urea, which is much less toxic than ammonia. The kidneys then remove the urea from the bloodstream.

FUNCTIONS OF THE KIDNEY

The kidney is involved in the following activities:

- Filtering of blood
- Reabsorption of amino acids, glucose, and salts
- Secretion of urea, uric acid, and other wastes

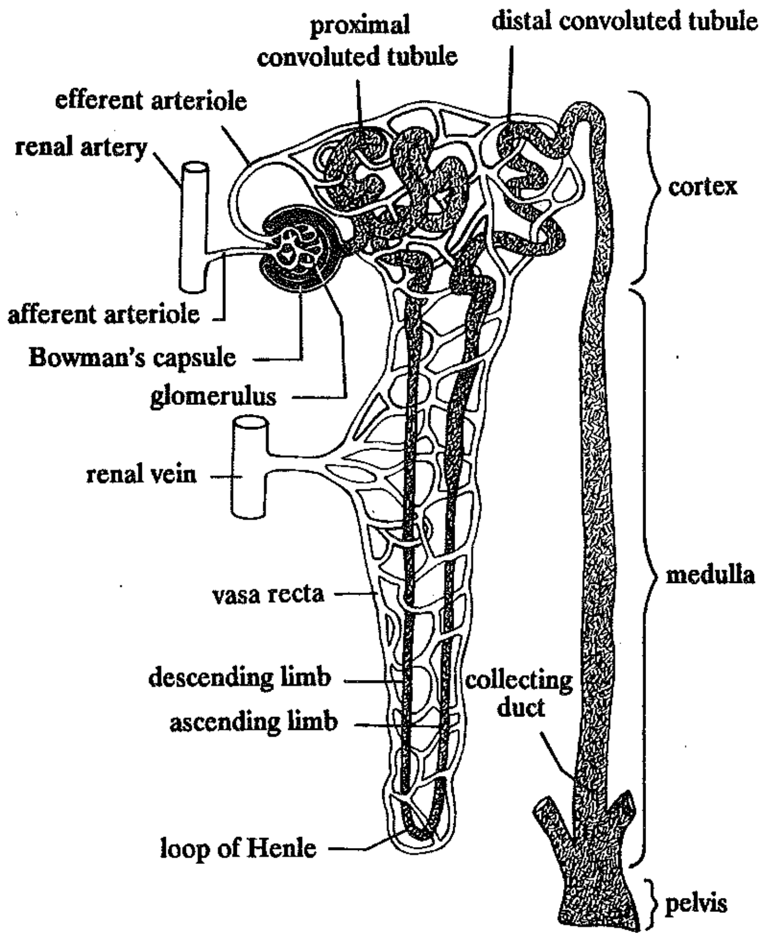


Human Excretory System

The basic functional unit of the kidney involved in urine formation is a small, tubelike structure called the *nephron* (see diagram on the next page) that first filters blood to form a filtrate fluid and then selectively modifies the filtrate to produce urine. The blood that is to be filtered enters each nephron in a ball-shaped cluster of capillaries called the *glomerulus*. The pressure of blood in the glomerulus squeezes the liquid portion of the blood out of the glomerulus through a sievelike filtering structure. Blood cells are too large to pass through the sieve and most proteins are retained in blood by their size and charged nature. Other small molecules such as salts, amino acids, glucose, water, and urea pass easily into the filtrate. The filtrate that leaves the blood enters a cup-shaped structure around the glomerulus called *Bowman's capsule*, which forms the starting end of the tubelike nephron.

VISUAL AID

Picture the *glomerulus* as a kind of sieve or colander. Small molecules, such as amino acids and glucose, can pass through (to be subsequently reabsorbed), while large molecules like proteins and blood cells cannot pass through.



Nephron

From Bowman's capsule, the urinary filtrate will move down the nephron tubule, becoming increasingly modified as it progresses. Before urine is ready to be excreted, it passes through 1) the *proximal convoluted tubule*, 2) the *loop of Henle*, 3) the *distal convoluted tubule*, and 4) the *collecting duct*. The first step in modifying the urinary filtrate occurs in the *proximal convoluted tubule*. In this region, active transport pumps glucose, amino acids, sodium, and proteins back out of the filtrate. Water follows these by osmosis, concentrating the urine and reducing the volume of filtrate. This step conserves necessary metabolites, which would otherwise be wasted in urine, at the same time that it concentrates the urinary filtrate. In diabetics with very high levels of glucose in blood, the reabsorption mechanism for glucose can be overwhelmed, leading to the loss of glucose in urine.

From the proximal tubule, the filtrate passes to the *loop of Henle*. While the glomerulus and Bowman's capsule of each nephron are located in the outer region of the kidney (the cortex), *the loop of Henle* dips down into the inner kidney region called the *medulla*.

The medulla has a very high concentration of extracellular sodium. As the filtrate passes down the loop of Henle, water is drawn out of the filtrate due to osmosis, passing from the low ion concentration in the filtrate to the high ionic strength of the extracellular fluid in the medulla. When the filtrate passes back up the loop of Henle, sodium is pumped out into the medulla. These two steps further reduce the volume of the urinary filtrate, drawing out the water along with the sodium, and help to preserve the high concentration of sodium in the medulla.

After passing through the *distal tubule*, the filtrate must pass through the *collecting duct* before passing out to the ureter and the urinary bladder. The collecting duct passes back down through the high-ionic-strength medulla. To make concentrated or dilute urine, the hormone *ADH* (antidiuretic hormone), also called vasopressin, regulates the permeability of the collecting duct walls.

When a person is dehydrated and his extracellular fluid volume is low, he will secrete ADH and excrete more concentrated urine, saving water. ADH acts on the walls of the collecting ducts to make them more permeable to water. Since the fluid of the medulla is very concentrated with ions, water will flow out of the collecting ducts if the walls of the collecting duct are water-permeable and allow osmosis, reabsorbing water from the urine as it forms. If no ADH is present, the walls of the collecting ducts do not permit osmosis, and the urine will remain dilute.

Another hormone that regulates urine formation is the steroid hormone *aldosterone*. Aldosterone is secreted in response to low extracellular sodium and acts on the distal tubule to increase the reabsorption of sodium from the urinary filtrate. The reabsorption of sodium causes water to be removed from the filtrate by osmosis as well, reducing the urine volume and increasing the volume of the extracellular fluids of the body. Thus, aldosterone is another means the body can use to conserve water as well as sodium.

DON'T MIX THESE UP ON TEST DAY

Antidiuretic hormone (ADH; vasopressin):

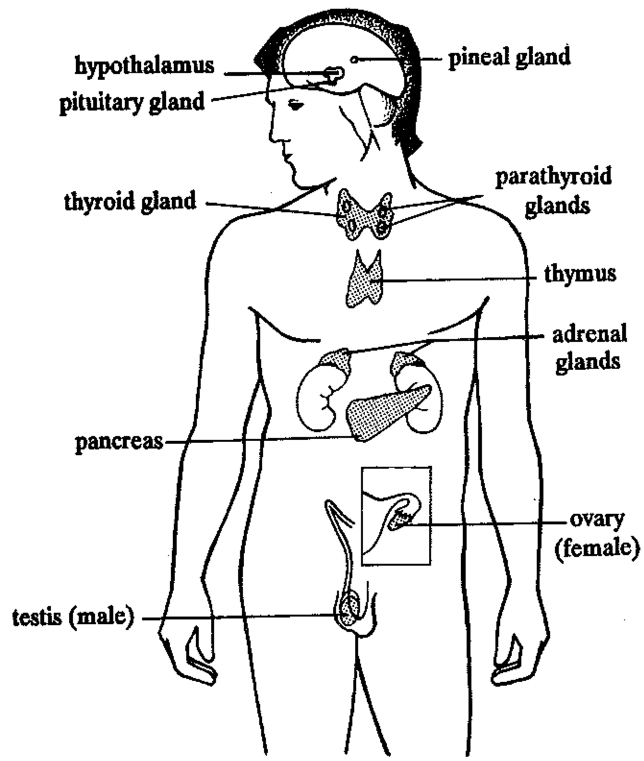
- Is produced by the hypothalamus and secreted by the posterior pituitary
- Makes the collecting duct more permeable to water
- Leads to a rise in blood volume

Aldosterone:

- Is produced by the adrenal cortex
- Stimulates the reabsorption of Na^+ and the secretion of K^+
- Leads to a rise in blood volume and blood pressure

ENDOCRINE SYSTEM

The body has two communication systems to coordinate the activities of different tissues and organs, the nervous system and the *endocrine system*. The endocrine system is the network of glands and tissues that secrete *hormones*, chemical messengers produced in one tissue and carried by the blood to act on other parts of the body. Compared to the nervous system, the signals conveyed by the endocrine system take much more time to take effect. A nervous impulse is produced in a millisecond and travels anywhere in the body in less than a second. Hormones require time to be synthesized, can travel no more quickly than the blood can carry them, and often cause actions through inducing protein synthesis or transcription, activities that require time. However, hormone signals will tend to be more long-lasting than nerve impulses. When the nerve impulse ends, a target such as skeletal muscle usually returns quickly to its starting state. When a hormone induces protein synthesis, the proteins can remain long after the hormone is gone. Often the two systems work together. The *endocrine glands*, such as the pancreas or the adrenal cortex, can be the direct targets (effectors) of the autonomic nervous system. The hormone adrenaline acts in concert with the sympathetic nervous system to produce a set of results similar to those produced directly by sympathetic neurons.



Human Endocrine System

DON'T MIX THESE UP ON TEST DAY

In the pancreas, the *exocrine function* secretes digestive enzymes and bicarbonate.

The *endocrine function* of the pancreas, meanwhile, secretes insulin and glucagon.

Endocrine glands secrete hormones directly into the bloodstream. This is in contrast to *exocrine secretions* that do not contain hormones and are released through ducts into a body compartment. An example of exocrine secretion is the secretion by the pancreas of digestive enzymes into the small intestine through the pancreatic duct. Both endocrine and exocrine functions can be found in the same organ. The pancreas simultaneously produces exocrine secretions (such as digestive enzymes) and endocrine secretions (such as insulin and glucagon) that are released into the blood to exert their effects throughout the body.

Two Types of Hormones: Steroid Hormones and Peptide Hormones

Based on their chemical nature, hormones can be classified into two groups: *steroid hormones* and *peptide hormones*. In both cases, the hormone must bind to a protein receptor on the target cell to affect that cell. The types of receptors they affect are different, however. Peptide hormones are large, hydrophilic, and charged, and cannot diffuse across the plasma membrane. As a result, the receptors they bind to are located on the cell surface. When a peptide hormone binds to its receptor on the surface of a target cell, it activates the receptor and causes it to transmit a signal into the cellular interior. The nature of this signal can be to turn on a protein kinase that phosphorylates certain proteins and changes their activity, or to release secondary messengers in the cell, such as calcium or cyclic AMP, that amplify the signal and alter many different cellular activities. This form of indirect signaling by a hormone is called a *signal transduction cascade* because of the amplification by downstream signaling factors.

Peptide hormones can be small peptides such as ADH, with just a few amino acid residues, or large, complex polypeptides like insulin. Peptide hormones are often produced as large, inactive precursors, or pro-hormones, that are cleaved by proteases into smaller active peptides before they are released. Since peptide hormones are secreted proteins, they are synthesized on the rough endoplasmic reticulum in the cell, then packaged and processed in the Golgi before they are delivered to the plasma membrane for secretion. Since hormone signaling is usually regulated, the release of hormones is usually regulated. The hormones are stored in secretory vesicles in the cytoplasm, waiting for the signal that fuses the vesicle with the plasma membrane, dumping the hormones into the extracellular fluid and blood and transporting them by the circulatory system to distant target tissues in the body.

DON'T MIX THESE UP ON TEST DAY

Peptide hormones, such as insulin and ADH, are proteins, have membrane receptors, act through intracellular secondary messengers, and can act quickly.

Steroid hormones, such as testosterone and estrogen, are cholesterol-derived, have intracellular receptors, act as primary messengers, affect transcription, and may take longer to produce a response.

Steroid hormones are small and hydrophobic, and most hormones of this class are derived from cholesterol, including estrogen, progesterone, testosterone, and cortisol. Since they are small and hydrophobic, they can diffuse through the cell membrane. These hormones bind to steroid hormone receptors after they have diffused into the cell through the plasma membrane. The hormone-bound receptors enter the nucleus and bind to target regions in genes that regulate transcription, turning the genes on or off. Steroid hormone signals are changes in gene transcription and protein expression caused by the steroid hormone receptors.

Since steroid hormones freely diffuse through membranes, they are not stored after production. They are usually secreted at a rate equal to their production. It is the rate of production for these hormones that is highly regulated, by controlling the activity of the enzymes that produce the hormones.

Endocrine Glands

Hormones are secreted by a variety of glands and organs, including the *hypothalamus, pituitary, thyroid, parathyroids, adrenals, pancreas, testes, ovaries, pineal, kidneys, heart,* and *thymus*. It is likely that additional tissues such as skin and fat, not traditionally considered glands, also have endocrine functions. Some hormones regulate a single type of cell or organ, while others have more widespread actions. The specificity of hormonal action is determined by the presence of specific receptors on or in the target cells.

A common principle that regulates the production and secretion of many hormones is the *feedback loop*. Often several hormones regulate each other in a chain. For example, the hypothalamic hormone corticotropin acts on the anterior pituitary to release adrenocorticotropic hormone (ACTH), which acts on the adrenal cortex to release cortisol. In a feedback loop, the level of the last hormone regulates the production of earlier hormones in the loop. When cortisol blood levels increase, cortisol acts on the pituitary to decrease further ACTH secretion, which leads to a decrease in cortisol production. Acting in this way, feedback loops act to maintain the body's internal state at a relatively constant level.

Hypothalamus and Pituitary Gland. The *hypothalamus,* a section of the posterior forebrain, is located above the pituitary gland and is intimately associated with it via a portal circulation system that carries blood directly from the hypothalamus to the pituitary. In most parts of the circulatory system, blood flows directly back to the heart from capillaries, but in a portal system blood flows from capillaries in one organ to capillaries in another. When the hypothalamus is stimulated (by feedback from endocrine glands or by neurons innervating it), it releases hormonelike substances called *releasing factors* into the anterior pituitary-hypothalamic portal circulatory system. These hormones are carried directly to the pituitary by the portal system. In turn, these releasing factors stimulate cells of the anterior pituitary to secrete the hormone indicated by the releasing factor.

The *pituitary gland* is a small gland with two lobes lying at the base of the brain. The two lobes, anterior and posterior, function as independent glands. The anterior pituitary secretes the following hormones:

- *Growth hormone* fosters growth in a variety of body tissues.
- *Thyroid-stimulating hormone* (TSH) stimulates the thyroid gland to secrete its own hormone, thyroxine.
- ACTH stimulates the adrenal cortex to secrete its corticoids.
- *Prolactin* is responsible for milk production by the female mammary glands.
- *Follicle-stimulating hormone* (FSH) spurs maturation of seminiferous tubules in males and encourages maturation of follicles in the ovaries.
- *Luteinizing hormone* (LH) induces interstitial cells of the testes to mature by beginning to secrete the male sex hormone testosterone. In females, a surge of LH stimulates ovulation of the primary oocyte from the follicle. LH then induces changes in the follicular cells and converts the old follicle into a yellowish mass of cells rich in blood vessels. This new structure is the corpus luteum, which subsequently secretes progesterone and estrogen.

MNEMONIC: FLAT PIG

The anterior pituitary gland secretes the following hormones:

FSH
LH
ACTH
TSH

Prolactin
I(gnore)
Growth

The *posterior pituitary* is a direct extension of nervous tissue from the hypothalamus. Nerve signals cause direct hormone release. The two hormones secreted by the posterior pituitary are ADH and oxytocin.

- *ADH* (vasopressin) acts on the kidney to reduce water loss.
- *Oxytocin* acts on the uterus during birth to cause uterine contraction.

Thyroid Gland. The thyroid hormone, *thyroxine*, is a modified amino acid that contains four atoms of iodine. It accelerates oxidative metabolism throughout the body. An abnormal deficiency of thyroxine causes goiter, decreased heart rate, lethargy, obesity, and decreased mental alertness. In contrast, hyperthyroidism (too much thyroxine) is characterized by profuse perspiration, high body temperature, increased basal metabolic rate, high blood pressure, loss of weight, and irritability.

Parathyroid Glands. The parathyroid glands are small, pealike organs located on the posterior surface of the thyroid. They secrete parathyroid hormone, which regulates the calcium and phosphate balance between the blood, bone, and other tissues. Increased parathyroid hormone increases bone formation. Plasma calcium must be maintained at a constant level for the function of muscles and neurons.

Pancreas. The pancreas is a multifunctional organ. It has both an *exocrine* and an *endocrine function.* The exocrine function of the pancreas secretes enzymes through ducts into the small intestine. The endocrine function, on the other hand, secretes hormones directly into the bloodstream.

The endocrine function of the pancreas is centered in the *islets of Langerhans*, localized collections of endocrine alpha and beta cells that secrete glucagon and insulin, respectively. *Insulin* stimulates the cells and muscles to remove glucose from the blood when glucose concentrations are high, such as after a meal. Insulin is also responsible for spurring both muscles and liver to convert glucose to glycogen, the storage form of glucose. The islets of Langerhans also secrete *glucagon*, which responds to low concentrations of blood glucose by stimulating the breakdown of glycogen into glucose, keeping the level of glucose in blood high enough to supply the body's tissues.

Adrenal Glands. The adrenal glands are situated on top of the kidneys and consist of the *adrenal cortex* and the *adrenal medulla.*

Adrenal cortex: In response to stress, ACTH stimulates the adrenal cortex to synthesize and secrete the steroid hormones collectively known as *corticosteroids.* The corticosteroids, derived from cholesterol, include glucocorticoids, mineralocorticoids, and cortical sex hormones.

Glucocorticoids, such as cortisol and cortisone, are involved in glucose regulation and protein metabolism, and their presence is important to deal with stress. Glucocorticoids raise blood glucose levels by promoting gluconeogenesis. These hormones also act to decrease protein synthesis. They also reduce the body's immunological and inflammatory responses. ACTH from the pituitary induces cortisol production. Elevated cortisol represses ACTH expression and lowers cortisol levels, acting as a feedback loop to maintain relatively constant cortisol levels. Although cortisol is an important hormone to deal with stress, prolonged high levels of corticosteroids probably repress the immune system. Corticosteroids are effective anti-inflammatory medicines, but their use is limited by their alterations of fat metabolism and their repression of the immune system.

Mineralocorticoids, particularly aldosterone, regulate plasma levels of sodium and potassium, and consequently, the total extracellular water volume. Aldosterone causes active reabsorption of sodium and passive reabsorption of water in the kidney, a topic we dealt with in more detail earlier in this book.

> **FIGHT OR FLIGHT**
>
> Hormones such as *epinephrine* and *norepinephrine* are responsible for the body's physical reactions to stress. They temporarily increase heartbeat and blood supply to the active organs in what is known as "the fight or flight response."

The adrenal cortex also secretes small quantities of androgens (male sex hormones) in both males and females. Since most of the androgens in males are produced by the testes, the physiologic effect of the adrenal androgens is quite small. In females, however, overproduction of the adrenal androgens may have masculinizing effects, such as excessive facial hair.

Adrenal medulla: The secretory cells of the adrenal medulla can be viewed as specialized sympathetic nerve cells that secrete hormones into the circulatory system. This organ produces *epinephrine* (adrenaline) and *norepinephrine* (noradrenaline), both of which belong to a class of amino acid-derived compounds called *catecholamines.*

Epinephrine increases the conversion of glycogen to glucose in liver and muscle tissue, causing a rise in blood glucose levels and an increase in the basal metabolic rate. Both epinephrine and norepinephrine increase the rate and strength of the heartbeat, and dilate and constrict different blood vessels. These, in turn, increase the blood supply to skeletal muscle, the heart, and the brain, while decreasing the blood supply to the kidneys, skin, and digestive tract. These effects are known as the *"fight or flight response,"* and are elicited by sympathetic nervous stimulation in response to stress. Both of these hormones are also neurotransmitters.

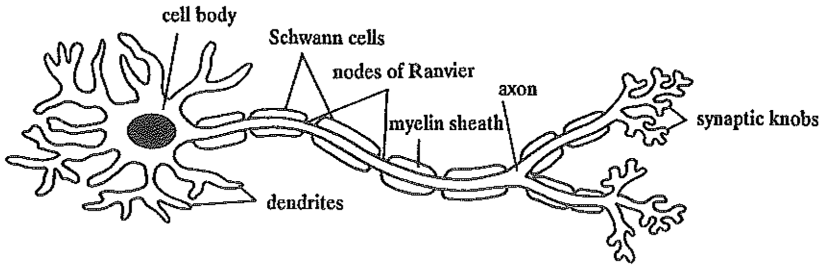
Ovaries and Testes. The gonads are important endocrine glands, with the testes producing testosterone in males and ovaries producing estrogen in females. See the section on reproduction earlier in this chapter for more details.

NERVOUS SYSTEM

The nervous system enables organisms to receive and respond to stimuli from their external and internal environments. Your brain and spinal column regulate your breathing and your movement, and provide perception of sight, sound, touch, smell, and taste. They allow organisms not only to perceive their environment but also to respond to their experience, and to alter their behavior over time through learning.

Functional Units of the Nervous System

To understand the nervous system, it is best to start with the basic functional unit of the nervous system—the *neuron.* The neuron is a specialized cell that is designed to transmit information in the form of electrochemical signals called *action potentials.* These signals are generated when the neuron alters the voltage found across its plasma membrane. The property of neurons that allows them to carry an action potential is an excitable membrane.



Neuron

The basic parts of the neuron's cell structure are the *cell body*, the *dendrites*, and the *axon* (see the figure above). The cell body contains the nucleus and most of the organelles and is the site of most protein synthesis and energy production in neurons. The dendrites receive chemical information from other neurons as changes in membrane potential, and carry this information to the cell body. The axon is a very long, slender projection of the neuron that transmits the action potential from the cell body to the target with which the neuron is to communicate. The axon can be as long as a meter when the cell body is located in the central nervous system and the axon must carry the action potential to a target in the extremities.

WATCH WHAT YOU EAT

The puffer fish is considered a delicacy in Japan, but it is not the kind of food you want to bolt down indiscriminately. This fish contains a poison called tetrodotoxin (TTX). TTX blocks the voltage-gated Na^+ channels of the body, which will block neuronal transmissions. Death follows soon after.

Resting Potential. The action potential involves manipulating the voltage across the plasma membrane to carry information. All cells have a voltage across their plasma membrane that is generated through the actions of a protein called the Na^+/K^+ ATPase. Using the hydrolysis of ATP for energy, this protein pumps sodium ions out of the cell and potassium into the cell and is essential to maintain the osmotic balance of cells. Some of the potassium leaks back out of the cell through an ion channel called the potassium leak channel. With more positive ions on the outside of the cell, a net negative voltage of about –70 mVolts is found across the plasma membrane of most cells and is called the resting potential.

ABOUT ACTION POTENTIALS

Action potentials are all-or-none and always the same size in a neuron. Larger signals cause more frequent action potentials, not larger action potentials.

Action Potential. Action potentials are a wave of electrochemical information that moves through axons and muscle tissue, creating a response in those target tissues. All cells have a resting potential, but not all cells have an excitable membrane that creates action potentials. The difference is that neurons, as well as muscle cells, have a protein in their plasma membrane that lets sodium ions through the membrane in response to a decrease in the membrane potential. This protein is called a voltage-gated sodium channel and gives neurons an excitable membrane. If the membrane voltage becomes less negative than the resting potential, changing from –70 mVolts to perhaps –50 mVolts, then the voltage-gated sodium channels in the neuron's plasma membrane will open. The voltage at which the voltage-gated channels open is called the *threshold potential.* When these channels are open, sodium will diffuse freely through the channel to cross the plasma membrane, flowing down a gradient from the outside of the cell into the cytoplasm. The opening of these channels in one region of the membrane and the entry of the sodium through the channels causes membrane *depolarization* (the membrane is less polarized, moving toward 0 potential).

ACTION!

Once an action potential starts, voltage-gated Na^+ channels open and close to move it down an axon.

After the voltage-gated sodium channels have opened and depolarization is complete, the channels close again, allowing the membrane voltage to return to its normal negative voltage. The return of the voltage to its normal negative state is called *repolarization.* At this point, the axon is ready to begin the process again and transmit a new action potential if necessary.

This, however, describes depolarization in only one section of membrane, not the length of a neuron. As the depolarization occurs in one section of membrane, the depolarization triggers the opening of voltage-gated sodium channels in the neighboring section of membrane further down the axon. The sodium channels further along the neuron then open, creating a new region of depolarization. Very rapidly, the region of depolarization moves along the neuron by triggering the opening of voltage-gated ion channels in one region after another, moving like a wave along the length of an axon in a neuron.

A substance called *myelin* allows action potentials to travel more quickly by surrounding the axons of most mammalian neurons. Myelin is an insulating agent that coats discrete patches of the plasma membrane. Small spaces between the myelin coating are called *nodes of Ranvier* (see the figure of the neuron). In a myelinated neuron, the action potential jumps from node to node, bypassing the insulated myelin regions where no ions cross the membrane. The action potential can travel much more rapidly this way in myelinated neurons, since it can jump forward instead of traversing the plasma membrane of the entire length of the axon. This method of jumping forward is called *saltatory conduction.* Another factor that affects the speed of an action potential is the size of the neuron: Larger neurons allow action potentials to travel more quickly.

MALFUNCTIONING MYELIN

When the body mounts a reaction against its own myelin, it begins to impede the conduction of action potentials. This results in weakness, lack of balance, vision problems, and/or incontinence. This condition is called multiple sclerosis (MS).

Size and Frequency of Action Potentials. There are two important characteristics of action potentials affecting the way nerves carry information. One factor is that every action potential in a neuron is the same size. Once the neuronal membrane reaches the threshold for depolarization, it will fully depolarize. Neurons do not have half of a depolarization or half of an action potential—the action potential is an all-or-nothing response. Either a neuron fires an action potential or it does not. The strength of a stimulus does not change the size of the action potential depolarization or the duration of the depolarization.

We do know from experience, though, that not all nervous signals are the same strength. A touch of a finger is different from a blow from a hammer, and the organism must recognize this. If the size of the action potential cannot carry this information, then what can? The answer is that all action potentials may be the same size, but the neuron carries action potentials more frequently to indicate a stronger stimulus. A weak signal like the touch of a finger may trigger one action potential in a second, while a strong stimulus like a hammer strike may trigger many more in the same period.

AT THE SYNAPSE

Neurotransmitters released at synapses bind to ligand-gated ion channels on the target cell. If the target cell is depolarized enough, an action potential will be triggered.

When an action potential has just passed through a section of membrane, it cannot fire an action potential again immediately. First it must finish depolarization and repolarization. This limit to the frequency of action potential firing in a neuron is called the *refractory period.* The refractory period places an upper limit on the frequency of action potentials that can pass through a neuron. The refractory period and the directional nature of the neuron also mean that neurons carry action potentials in only one direction, from the cell body out to the end of the axon. Action potentials do not move back up the axon to the cell body.

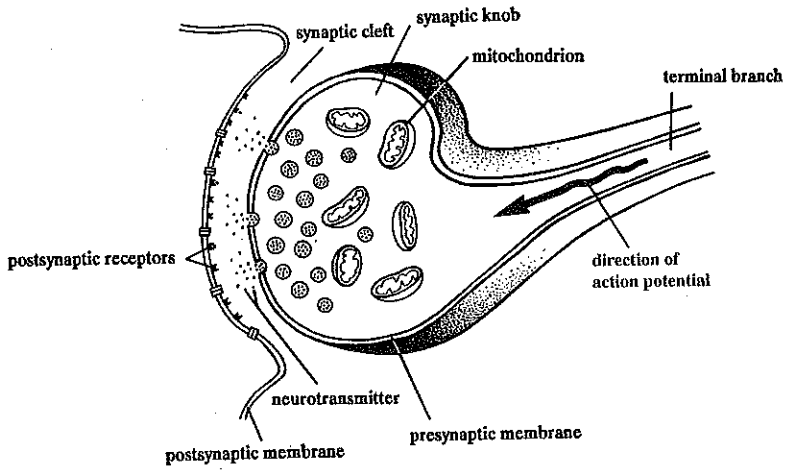
Synapses. The nervous system is not simply a network of electrical wires with the brain as the switchboard. There is a strong chemical component to the signals that neurons convey. Neurons do not usually directly carry the action potential all the way to the membrane of the target cell. When a neuron reaches a target cell, the axon ends in a synaptic terminal, with a gap called the *synapse* between the neuron and the target cell. At this point, the membrane potential is converted to a chemical signal, or *neurotransmitter,* that is released across a small gap between the neuron and the target cell. This gap between the neuron and the target cell is called the *synaptic cleft.* The target cell with which the neuron is communicating then receives the chemical signal by binding the neurotransmitter at a receptor on its surface and starting a signal of its own.

DRUGS AND NERVES

Many drugs modify processes that occur in the synapse. Cocaine, for example, blocks neuronal uptake carriers, prolonging the action of neurotransmitters. Nerve gases, meanwhile, are potent acetylcholinesterase inhibitors that cause rapid death by exaggerating the action of skeletal muscles (most importantly the diaphragm), which leads to respiratory arrest.

When an action potential travels down an axon to reach the synaptic terminal, it causes the neuron to release neurotransmitter into the synaptic cleft between the neuron and the target cell. This neurotransmitter will diffuse across the gap between the cells and bind to receptors on the target cell plasma membrane. The nature of the response on the target cell depends on the neurotransmitter released and the receptor that receives the signal. Some receptors open ion channels in response to binding neurotransmitter, allowing specific ions through the membrane in response to neurotransmitter. An excitatory neurotransmitter is one that binds to a receptor that allows sodium to flow through a channel into the cell. When the sodium enters, it depolarizes the plasma membrane of the target cell. If the depolarization of the target reaches the threshold to open voltage-gated sodium channels, an action potential will be initiated in the target cell. A neurotransmitter can also allow chloride to enter the postsynaptic membrane, causing a hyperpolarization, with the membrane potential moving away from the threshold for triggering an action potential. An inhibitory neurotransmitter therefore makes it more difficult for an action potential to start in the target cell.

Neurons do not usually exist with only one neuron forming a single synapse with another neuron. Neurons in the central nervous system form a dense network of interactions in which each neuron receives information in its dendrites from synapses with many other neurons, and each neuron in turn sends out an axon that can terminate in synapses with many other neurons. The information from all of the synapses with which a neuron interacts is combined in the cell body of a neuron in a process called *summation.* Summation is the means that a single neuron uses to process information from all of the neurons that form synapses with it and decide whether or not to initiate an action potential itself. If all of the combined changes in the potential of the neuron cause it to reach the threshold depolarization to open the voltage-gated channels, then it will fire an action potential. If not, the neuron will remain silent (no action potential). The result is called summation since it is determined by adding up the contributions to the membrane potential created by many different synapses that stimulate any given neuron.



Synapse

There are many types of synapses of neurons with other neurons. For motor neurons in the somatic nervous system, a specialized synapse of motor neurons with skeletal muscle cells is called the *neuromuscular junction*. When an action potential reaches the neuromuscular junction, acetylcholine (ACh) is released into the synaptic cleft and binds to postsynaptic receptors in the muscle cell. These receptors open sodium channels, depolarizing the muscle cell membrane and triggering an action potential in the muscle cell that is propagated throughout the membrane of the cell, triggering contraction of the muscle cell. The greater the number of action potentials that reach the muscle and the more muscle cells involved, the stronger the muscle contraction.

TURNING IT OFF

A synaptic neurotransmitter is turned off by:

1. Diffusion
2. Enzymatic inactivation
3. Reuptake into cells by transporters

Turning off signals is as important as turning them on. At the neuromuscular junction, for example, if the ACh is not removed, the muscle cell will continue to contract uncontrollably. Once the neurotransmitter is released into the synaptic cleft, it will continue binding to the postsynaptic receptors unless it is removed from the synapse in some way. There are several ways to remove the neurotransmitter from the synapse. One mechanism is for the neurotransmitter to diffuse away into the surrounding fluid. The synapse is small, making diffusion fairly rapid, but in most cases other mechanisms are involved. Another way to remove neurotransmitter from the synapse is with an enzyme that degrades the neurotransmitter. At the neuromuscular junction, acetylcholinesterase is an enzyme that acts on ACh to degrade and inactivate it. Pesticides or nerve gas that inactivate this enzyme can be deadly. A third way to remove neurotransmitter is to take it back up into cells at the synapse. This occurs for adrenaline or serotonin at synapses. The drug Prozac prevents depression by blocking the reuptake of serotonin from synapses, elevating the level of serotonin found in the synaptic cleft.

Organization of the Nervous System

As organisms evolved and became more complex, their nervous systems underwent corresponding increases in complexity. Simple organisms can respond only to simple stimuli; while complex organisms like humans can discern subtle variations of a stimulus, such as a particular shade of color.

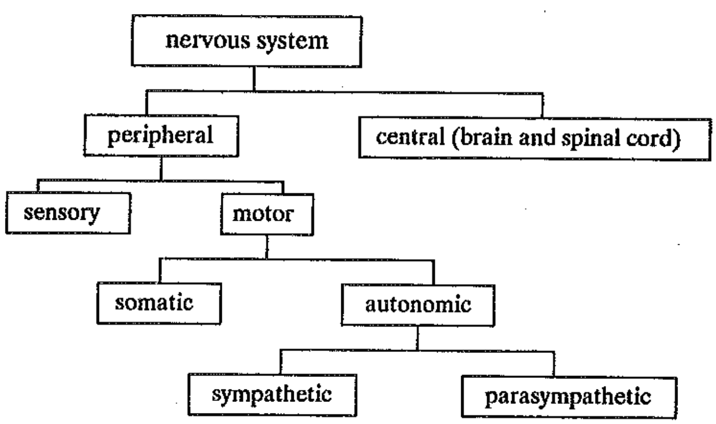
Invertebrates. Protozoa are single-celled and have no organized nervous system, although they do have receptors that respond to stimuli such as heat, light, and chemicals. Cnidarians have a nervous system consisting of a network of cells, the nerve net, located between the inner and outer layers of the cells of its body. With a limited network, the responses of cnidarians to their environment are limited to simple actions like retracting tentacles and stimulating swimming. Annelids possess a primitive central nervous system consisting of a solid ventral nerve cord and an anterior "brain" of fused ganglia. These clusters of cells allow a richer network of neurons than a simple nerve net, and more sophisticated information processing that results in more complex behavior. Arthropods also have ganglia and a more complex nervous system than annelids, with more specialized sense organs, including simple or complex eyes and a tympanum for detecting sound. The sensory input and information processing capability of arthropods allows for amazingly rich and complex behavior, like social behavior, in these small organisms.

INSENSITIVE

Simple organisms have very primitive nervous systems and can respond only to strong stimuli like touch, heat, light, and chemicals. Higher organisms like vertebrates, on the other hand, may respond to a wide range of stimuli.

Vertebrate Nervous System

Vertebrates have a *brain* enclosed within the *cranium* and a *spinal cord* that together form the *central nervous system* (CNS) that processes and stores information. Throughout the rest of the body is the *peripheral nervous system,* containing motor or efferent neurons that carry signals to effector organs such as muscles or glands to take action in response to nervous impulses. Sensory neurons in the peripheral nervous system convey information back to the CNS for processing and storage. The nervous system is also divided into the autonomic (involuntary) and the somatic (voluntary) components of the efferent (motor) pathways.



Organization of the Vertebrate Nervous System

The peripheral nervous system. The peripheral nervous system carries nerves from the CNS to target tissues of the body and includes all neurons that are not part of the CNS. The peripheral nervous system consists of 12 pairs of cranial nerves, which primarily innervate the head and shoulders, and 31 pairs of spinal nerves, which innervate the rest of the body. Cranial nerves exit from the brainstem and spinal nerves exit from the spinal cord. The peripheral nervous system has two primary divisions, the somatic and the autonomic nervous systems.

TWO SYSTEMS

Somatic—voluntary; acts on skeletal muscle

Autonomic—involuntary; targets glands, smooth muscle, and heart

The somatic motor nervous system. This system innervates skeletal muscle and is responsible for voluntary movement, generally subject to conscious control. Motor neurons release the neurotransmitter ACh onto ACh receptors located on skeletal muscle. This causes depolarization of the skeletal muscle, leading to muscle contraction. In addition to voluntary movement, the somatic nervous system is also important for reflex action.

The autonomic nervous system. The autonomic nervous system is neither structurally nor functionally isolated from the CNS or the peripheral system. Its function is to regulate the involuntary functions of the body including those of the heart and blood vessels, the gastrointestinal tract, urogenital organs, structures involved in respiration, and the intrinsic muscles of the eye. In general, the autonomic system innervates glands and smooth muscle but not skeletal muscle. It is made up of the sympathetic nervous system and the parasympathetic nervous system.

- *The sympathetic nervous system.* This system utilizes norepinephrine as its primary neurotransmitter. It is responsible for activating the body for emergency situations and actions (the fight-or-flight response), including strengthening of heart contractions, increases in the heart rate, dilation of the pupils, bronchodilation, and vasoconstriction of vessels feeding the digestive tract. One tissue regulated by the sympathetic system is the adrenal gland, which produces adrenalin in response to stimulation. Adrenalin produces many of the same fight-or-flight responses as the sympathetic system alone.
- *The parasympathetic nervous system.* Here, ACh serves as the primary neurotransmitter. One of this system's main functions is to deactivate or slow down the activities of muscles and glands (the rest-and-digest response). These activities include pupillary constriction, slowing of the heart rate, bronchoconstriction, and vasodilation of vessels feeding the digestive tract. The principal nerve of the parasympathetic system is the vagus nerve. Most of the organs innervated by the autonomic system receive both sympathetic and parasympathetic fibers, the two systems being antagonistic to one another.

DON'T MIX THESE UP ON TEST DAY

The *sympathetic nervous system*:

- Is associated with the fight-or-flight response
- Increases the heart rate
- Increases the breathing rate
- Lowers the digestive rate
- Causes pupil dilation

The *parasympathetic nervous system*:

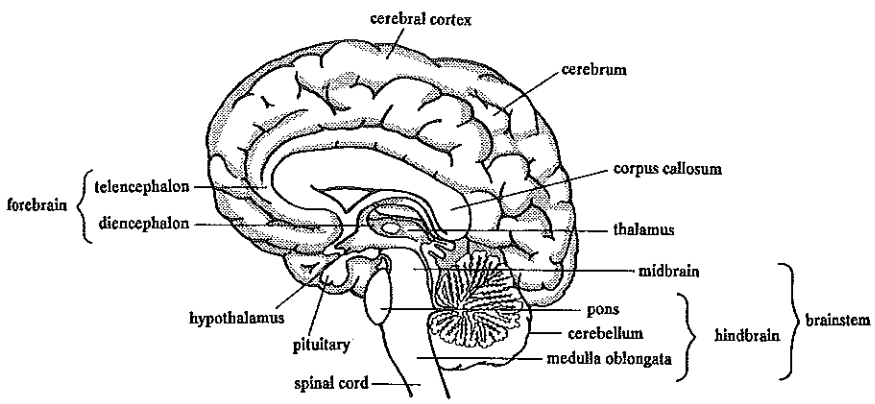
- Is associated with the rest-and-digest response
- Lowers the heart rate
- Does not affect the breathing rate
- Increases the digestive rate
- Does not cause pupil dilation

Human Brain

The human brain is divided into several anatomical regions with different functions, including the following regions:

- **Cerebral cortex.** The cerebral cortex controls all voluntary motor activity by initiating the responses of motor neurons present within the spinal cord. It also controls higher functions, such as memory and creative thought. The cortex is divided into hemispheres, left and right, with some specialization of function between them ("left-brain, right-brain"). The cortex consists of an outer portion containing mostly neuronal cell bodies (gray matter) and an inner portion containing mostly axons (white matter).
- **Olfactory bulb.** This serves as the center for reception and integration of olfactory input (swell).
- **Thalamus.** Nervous impulses and sensory information are relayed and integrated en route to and from the cerebral cortex by this region.

- **Hypothalamus.** Such visceral and homeostatic functions as hunger, thirst, pain, temperature regulation, and water balance are controlled by this center.
- **Cerebellum.** Muscle activity is coordinated and modulated here.
- **Pons.** This serves as the relay center for cerebral cortical fibers en route to the cerebellum.
- **Medulla oblongata.** This influential region controls vital functions such as breathing, heart rate, and gastrointestinal activity. It has receptors for carbon dioxide; when carbon dioxide levels become too high, the medulla oblongata forces you to breathe. This is why if you hold your breath until carbon dioxide levels rise so high in your blood that you pass out, you will breathe involuntarily to bring an influx of oxygen into your body.
- **Reticular activating system.** This network of neurons in the brainstem is involved in processing signals from sensory inputs and in transmitting these to the cortex and other regions. This system is also involved in regulating the activity of other brain regions, like the cortex, to alter levels of alertness and attention.



Human Brain

The *spinal cord* is also part of the CNS. The spinal cord acts as a route for axons to travel out of the brain. It also serves as a center for many reflex actions that do not involve the brain, such as the *knee-jerk reflex*. The spinal cord consists of two parts. The *dorsal horn* is the entrance point for sensory nerve fibers whose cell bodies are contained within the dorsal root ganglion. The *ventral horn*, on the other hand, contains the cell bodies of motor neurons. Fibers from the cerebral cortex synapse on the ventral horn motor neurons, thereby initiating muscular contractions.

DON'T MIX THESE UP ON TEST DAY

In the spinal cord, the *dorsal horn* serves as the entrance point for sensory nerve fibers or afferent neurons.

The *ventral horn*, meanwhile, contains the cell bodies of motor or efferent neurons.

Sensory Systems of the Nervous System

All complicated nervous systems are made more useful through input mechanisms that we know as our senses. Sight, hearing, balance, taste, smell, and touch provide an influx of data for the nervous system to assimilate. Other sensory information that we are not consciously aware of is also provided to the CNS, including internal conditions such as temperature and carbon dioxide content. All of these sensory detection systems use cells that are usually specialized, modified neurons to receive information and alter their membrane potential in response to this information. This altered membrane potential can then trigger an action potential to carry information back to the CNS. Some sensory cells detect chemical information (taste and smell), some detect electromagnetic energy (vision), and others detect mechanical information (sound, pressure). All sensation is caused by action potentials that are sent to the CNS by sensory cells. An action potential from the eye is the same as an action potential from the ear. The difference in perception, how we experience the information, is determined by how the information is received by the CNS and how it is processed. An action potential from the eye is perceived as sight because it passes to the visual center of the brain for processing.

DON'T MIX THESE UP ON TEST DAY

Cones are photoreceptors that respond to high-intensity illumination and color.

Rods, on the other hand, respond to low-intensity illumination (they are important in night vision) but do not detect color well.

Sight. The eye detects light energy and transmits information about intensity, color, and shape to the brain. The transparent *cornea* at the front of the eye bends and focuses light rays. These rays then travel through an opening called the *pupil,* whose diameter is controlled by the pigmented, muscular *iris.* The iris responds to the intensity of light in the surroundings (light makes the pupil constrict). The light continues through the *lens,* which is suspended behind the pupil. This lens focuses the image onto the *retina,* which contains photoreceptors that transduce light into action potentials. The image on the retina is actually upside down, but revision and interpretation in the cerebral cortex result in the perception of the image right-side up. The image from both eyes is also integrated in the cortex to produce the binocular vision with depth perception that allows us to throw, catch, and drive with improved ability. The shape of the lens is changed to focus images from nearby or far objects. To see nearby objects, the muscles attached to the lens are relaxed and the lens rounds up, focusing light more sharply. If the shape of the eye is either too short or too long, or if the lens becomes stiff with age, then the eye is unable to focus the image and corrective lenses may be required to bring images into focus.

MNEMONICS

These two mnemonics will help you to get a handle on the following concepts:

With the exceptions of sexual activity and digestion:

The **s**ympathetic nervous system **s**peeds things up.

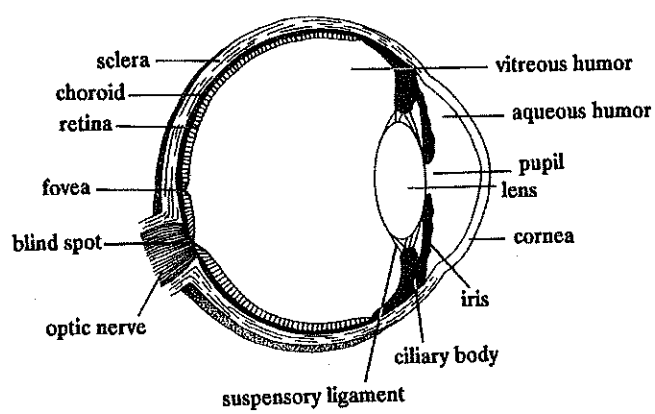
The parasympathetic nervous system slows things down.

and:

Cones respond to **c**olor.

Rods respond to black and white.

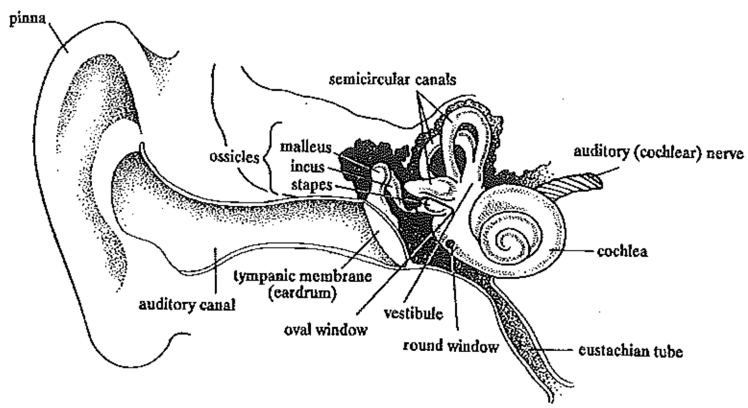
Cones and Rods. There are two types of specialized *photoreceptor cells* in the eye that respond to light: cones and rods. Cones respond to high-intensity illumination and are sensitive to color, while rods detect low-intensity illumination and are important in night vision. There are three different types of cones with different color sensitivities. The visual signal is received by the protein rhodopsin, which has a retinal group bound to it. This retinal group isomerizes when it is hit by a photon, starting the signal that leads to an action potential. The photoreceptor cells synapse onto bipolar cells, which, in turn, synapse onto ganglion cells. Axons of these cells bundle to form the *optic nerves,* which conduct visual information to the brain.



Human Eye

Hearing and Balance. The ear transduces sound energy into impulses that are perceived by the brain as sound. Sound waves pass through three regions as they enter the ear. First, they enter the outer ear, which consists of the *auricle* (pinna) and the *auditory canal.* Located at the end of the auditory canal is the *tympanic membrane* (eardrum) of the middle ear, which vibrates at the same frequency as the incoming sound. Next, three bones, or *ossicles* (malleus, incus, and stapes), amplify the stimulus and transmit it through the oval window, which leads to the fluid-filled inner ear.

This inner ear consists of the cochlea and semicircular canals. The *cochlea* contains the *organ of Corti,* which has specialized sensory cells called hair cells. Vibration of the ossicles vibrates the fluid inside the cochlea, causing specific regions of hair cells within the cochlea to vibrate depending on the frequency of the tone. Louder sounds increase the strength of the vibration and the response. The stimulation of a specific set of hair cells triggers the hair cells to transduce the mechanical pressure into action potentials, which travel via the auditory nerve to the brain for processing.



Human Ear

The *semicircular canals* are used for balance. Each of the three semicircular canals in the inner ear is perpendicular to the other two and is filled with a fluid called endolymph. At the base of each canal is a chamber with sensory hair cells; rotation of the head displaces endolymph in one of the canals, putting pressure on the hair cells in it. This changes the nature of the impulses sent by the vestibule nerve to the brain. The brain interprets this information to determine the position of the head.

IT'S TOO SPICY!

We lose taste buds as we age. This is why young children enjoy bland food such as macaroni and cheese, while adults tend to be more interested in spicier food.

Taste and Smell. *Taste buds* are chemical sensory cells located on the tongue, the soft palate, and the epiglottis. The outer surface of a taste bud contains a taste pore, from which microvilli, or taste hairs, protrude. Interwoven around the taste buds is a network of nerve fibers that are stimulated by the taste buds, and these neurons transmit impulses to the brainstem. There are four main kinds of taste sensations: sour, salty, sweet, and bitter.

Olfactory receptors are chemical sensors found in the olfactory membrane, which lies in the upper part of the nostrils over a total area of about 5 cm^2. The receptors are specialized neurons from which cilia project. When odorous substances enter the nasal cavity, they bind to receptors in the cilia, depolarizing the olfactory receptors. Axons from the olfactory receptors join to form the olfactory nerves, which project directly to the olfactory bulbs at the base of the brain.

MOTOR SYSTEMS

One of the key systems of the body is the system of muscles that are effectors for the CNS. To exert an effect, muscles also require something to act against, which is the skeletal system. Read on for explanations of the characteristic motor systems of members of the select group of organisms we have been discussing throughout this book.

Cilia and Flagella

Ciliates and *flagellates* are unicellular organisms that do not have discrete skeletal-muscular systems. Protozoans and primitive algae move by the beating of cilia or flagella. Amoebae, meanwhile, use cell extensions called *pseudopodia* for locomotion; the advancing cell membrane extends, and the cytoplasm flows into the pseudopods.

The cilia and flagella of all eukaryotic cells possess the same basic structure, which is different from prokaryotic structures. Each eukaryotic cilium and flagellum contains a cylindrical stalk of microtubules, with nine microtubule pairs arranged in a peripheral circle around two single microtubules in the center of the stalk. Movement is affected by means of the power stroke, a thrusting movement in which the microtubule cylinders slide past each other with work provided by protein motors. Return of the cilium or flagellum to its original position is called the recovery stroke.

Hydrostatic Skeletons

The muscles within the body wall of advanced flatworms such as planaria are arranged in two antagonistic layers, longitudinal and circular. As the muscles contract against the resistance of the incompressible fluid within the animal's tissues, this fluid functions as a hydrostatic skeleton. Contraction of the circular layer of muscles causes the incompressible interstitial fluid to flow longitudinally, lengthening the animal. Conversely, contraction of the longitudinal layer of muscles shortens the animal. This movement of muscle is similar to the peristaltic motion of the digestive system.

The same type of hydrostatic skeleton assists in the locomotion of annelids. Each segment of this animal can expand or contract independently. Annelids advance principally through the action of muscles on a hydrostatic skeleton, as well as through bristles in the lower part of each segment. These bristles, called *setae*, anchor the earthworm temporarily in earth while muscles push the earthworm ahead.

Exoskeleton

An *exoskeleton* is a hard external skeleton that covers all the muscles and organs of some invertebrates. Exoskeletons in arthropods are composed of chitin. In all cases, the exoskeleton is composed of noncellular material secreted by the epidermis. Although it serves the additional function of protection, an exoskeleton imposes limitations on growth. Periodic molting and deposition of a new skeleton are necessary to permit body growth. To cause movement, muscles attach to the interior of the exoskeleton. The giant insects that terrify us in monster movies could not possibly exist since the muscles in these monsters would not be strong enough to move the weight of the skeleton that would be required.

QUICK QUIZ

Match the numbered organism with the correct lettered motor system below.

1. Earthworm
2. Primitive algae
3. Bear

(A) Endoskeleton
(B) Hydrostatic skeleton
(C) Cilia and flagella

3. = (A)
2. = (C)
1. = (B)
Answers:

Endoskeleton

Vertebrates have an *endoskeleton* as a framework for the attachment of skeletal muscles, permitting movement when a muscle contracts by bringing two bones together. All voluntary movement involves muscle contraction bringing bones together. The endoskeleton also provides protection, since bones surround delicate vital organs. For example, the rib cage protects the thoracic organs (heart and lungs), while the skull and vertebral column protect the brain and spinal cord. The vertebrate skeleton contains *cartilage* and *bone,* both formed from connective tissue.

Cartilage, although firm, is also flexible and is not as hard or as brittle as bone. It makes up the skeletons of lower vertebrates, such as sharks and rays. In higher animals, cartilage is the principle component of embryonic skeletons and is replaced during development by the aptly termed *replacement bone.* Because cartilage has no vessels or nerves, it takes longer to heal than bone.

Bone makes up most of the skeleton of mature higher vertebrates, including humans, and is made of calcium and phosphate salts and strands of the protein *collagen.* Bones are produced as a balance between deposition of new bone by osteoblasts and reabsorption of old bone by osteoclasts that live in bone. *Osteoclasts* are cells that reabsorb bone and *osteoblasts* create new bone. Imbalance between these processes can lead to weakening of the bones, such as in osteoporosis. During growth, bone arises through the replacement of cartilage or through direct ossification. Bone produced through the latter process is called *dermal bone;* the bones of the skull are examples of this. In *replacement bone,* such as in the long bones of the legs and arms, osteoblasts replace the cartilage that has already formed. A hollow cavity within each long bone is subsequently filled with *bone marrow,* the site of formation of blood cells. The long bones originate as cartilage, with ossification beginning in the middle and the bones growing in the cartilaginous regions at the ends. As the bone grows, the region of ossification extends until growth ceases during adulthood and the bone becomes fully ossified.

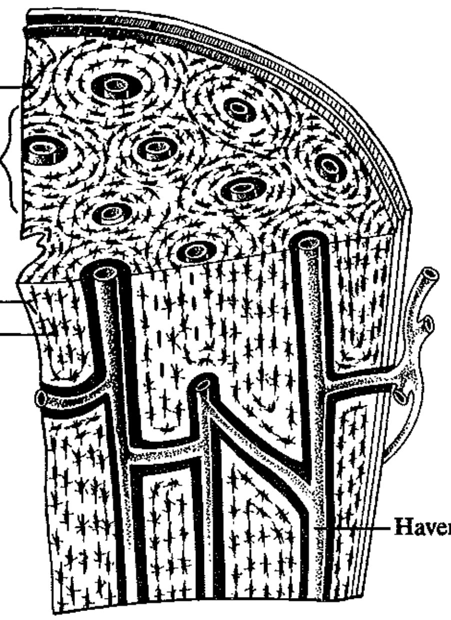
BUILD AND DESTROY

Bone tissue is made up of *osteoblasts,* which build bone, and *osteoclasts,* which destroy bone. The reason that the body builds bone is obvious; the reason it destroys it is less obvious. Bone acts as a calcium reservoir for the entire body. When the body needs calcium, bone is destroyed in order to provide it. The two cell types work together constantly to remodel bone.

While the division between dermal and replacement bone is based on embryologic origin, the division between spongy and compact bone is based on function and internal structure. *Spongy bone* is located in the central portions of bone, and consists of a network of hard spicules separated by marrow-filled spaces. The low density and the ability to withstand lateral stress are characteristics of bone that may be attributed to this type of spongy bone. *Compact bone,* located on the outer surfaces and articular surfaces, is responsible for the hardness of bone and its ability to withstand longitudinal stress. It consists of cylindrical units called *Haversian systems,* with cells radiating around a central capillary within a Haversian canal.

MNEMONIC

Remember:
Osteo**b**lasts **b**uild **b**one!



Microscopic Bone Structure

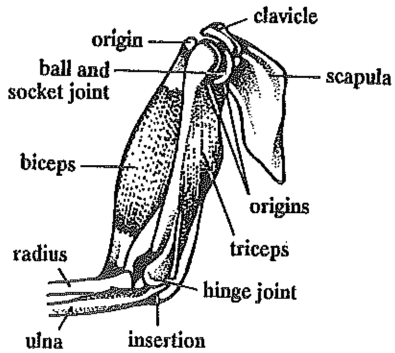
Bones are connected at joints, either immovable joints as in the skull or movable joints like the hip joint. In the latter type, ligaments serve as bone-to-bone connectors, while tendons attach skeletal muscle to bones and bend the skeleton at the movable joints. In the vertebrate skeleton, the *axial skeleton* is the midline basic framework of the body, consisting of the skull, vertebral column, and rib cage. The *appendicular skeleton,* on the other hand, includes the bones of the appendages and the pectoral and pelvic girdles.

EFFECTORS OF THE NERVOUS SYSTEM

Motor systems allow organisms to respond to stimuli from their nervous systems.

Muscle System

The muscle system serves as an effector of the nervous system. Muscles contract to implement actions after they receive nervous stimuli. For example, your arm muscles will automatically contract if you touch a hot stove. A skeletal muscle originates at a point of attachment to the stationary bone. The insertion of a muscle is the portion attached to the bone that moves during contraction. An *extensor* extends or straightens the bones at a joint—as in, straightening out a limb. A *flexor* bends a joint to an acute angle, as in bending the elbow to bring the forearm and upper arm together. Bones and muscles work together like a lever system.



Muscle Movement

Types of Muscles. Vertebrates possess three different types of muscle tissues: *smooth*, *skeletal*, and *cardiac*. In all three types, muscles cause movement by contraction, and the contraction is caused by the sliding of actin and myosin filaments past each other within cells. The differences between the types of muscle include where they are located, what they do, how they are controlled, and what the cells look like.

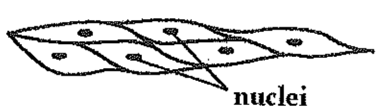
- *Smooth muscle*, or involuntary muscle, is generally found in visceral systems and is innervated by the autonomic nervous system. Each muscle fiber consists of a single cell with one centrally located nucleus. Smooth muscle is nonstriated, meaning it does not have clearly organized arrays of actin and myosin filaments. Smooth muscle is located in the walls of the arteries and veins, the digestive tract, the bladder, and the uterus. Smooth muscle contracts in response to action potentials, and the contraction is mediated by actin-myosin fibers like in other muscle, although the fibers do not have the clear organization they display in other muscle types. Smooth muscle cells in a tissue are connected to each other through junctions that allow electrical impulses to pass directly from one cell to the next without passing through chemical synapses.

DON'T MIX THESE UP ON TEST DAY

Smooth muscle is involuntary muscle in the arteries, the gastrointestinal tract, and elsewhere.

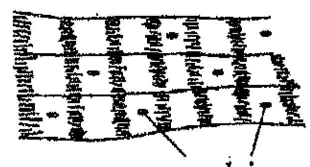
Skeletal muscles are voluntary muscles that cause body movement.

Cardiac muscle is the tissue that makes up the heart.



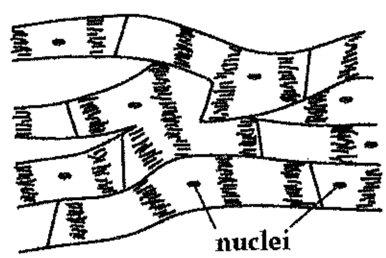
Smooth Muscle

- *Skeletal muscles*, or voluntary muscles, produce intentional physical movement. A skeletal muscle cell is a single large multinucleated fiber containing alternating light and dark bands called *striations*, caused by overlapping strands of thick myosin protein filaments that slide past thin actin protein filaments during muscle contraction. The actin and myosin filaments in skeletal muscle are organized into sections called *sarcomeres* that form contractile units within each muscle cell. The somatic nervous system innervates skeletal muscle. Each skeletal muscle fiber is stimulated by nerves through neuromuscular synapses. When a muscle cell is stimulated by a nerve, an action potential moves over the whole muscle fiber, releasing calcium in the cytoplasm of the cell. This calcium causes the actin and myosin to slide over each other, shortening the cell and the fibers. Many muscle cells are bundled together to create muscles.



Skeletal Muscle

- *Cardiac muscle* is the tissue that makes up the heart. It has characteristics of both skeletal and smooth muscle. Cardiac muscle cells have a single nucleus, like smooth muscle, and are striated, like skeletal muscle. Cardiac muscle cells are connected by gap junctions, like smooth muscle, so that cells can pass action potentials directly between cells throughout the heart and do not require chemical synapses. Cardiac muscle contraction is regulated by the autonomic nervous system, which increases the rate and strength of contractions through sympathetic stimulation and decreases their rate through the parasympathetic system. Cardiac muscle has an internal pacemaker responsible for the heartbeat that is modified by the nervous system but does not require the nervous system to maintain a regular heartbeat.



Cardiac Muscle

With that, we've covered the basics of the physiology you might be called upon to know on Test Day. The final topics associated with organismal biology that we need to discuss are those of animal behavior and plants.

ANIMAL BEHAVIOR

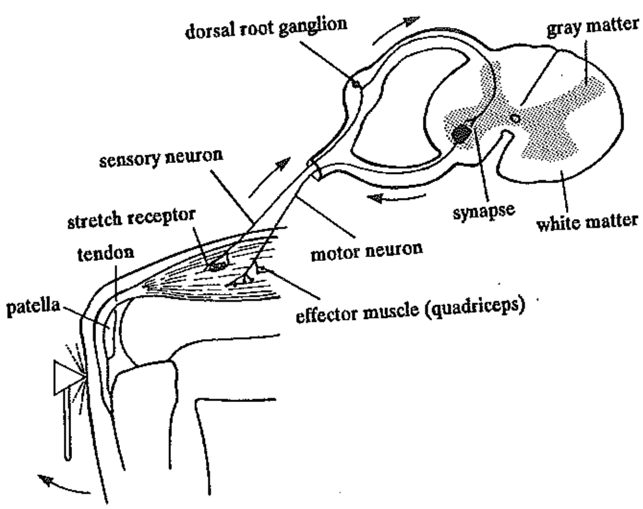
Animals respond to their environment in a great variety of ways to increase their ability to survive and reproduce. As animals have evolved more complex nervous systems and motor systems, they have also evolved more complex behaviors. Some of these behaviors are inherited genetically, while others are learned. Reflexes and fixed action patterns are examples of behaviors that are genetically determined, ingrained responses hardwired in the nervous system, which do not require any learning. Many behaviors are a mixture of learned and instinctive actions. Through behavioral experiments and genetics, scientists try to discern the role of "nature vs. nurture" in specific behaviors.

Patterns of Animal Behavior

Animal behavior is characterized by a number of different patterns. Simple organisms are capable only of simple, automatic responses to their environment, while more complex organisms are characterized by an increased reliance on mental processes such as learning.

Simple Reflexes

Reflexes are simple, automatic responses to simple stimuli. A simple reflex is controlled at the spinal cord level of a vertebrate, involving a direct pathway from the receptor (afferent nerve) to the efferent or motor nerve. The efferent nerve innervates the effector, a muscle or gland. Thus a simple reflex involves a two-neuron pathway. Monosynaptic reflex pathways have only one synapse between the sensory neuron and the motor neuron. The classic example is the knee-jerk reflex. When the tendon covering the patella (kneecap) is hit, stretch receptors sense this and action potentials are sent up the sensory neuron and into the spinal cord. The sensory neuron synapses with a motor neuron in the spinal cord, which, in turn, stimulates the quadriceps muscle to contract, causing the lower leg to kick forward. In polysynaptic (complex) reflexes, sensory neurons synapse with more than one neuron. A classic example of this is the withdrawal reflex: when a person steps on a nail, the injured leg withdraws in pain, while the other leg extends to retain balance.



Reflex Arc for Knee Jerk

DON'T MIX THESE UP ON TEST DAY

An example of a *simple reflex* is the knee-jerk reflex.

An example of a *complex reflex* is the withdrawal response.

Fixed-action patterns, meanwhile, are the characteristic movements of a herd or flock of animals.

Simple reflexes can be changed over time to become more or less sensitive to stimulation of sensory neurons. This is a simple form of learning that even very simple organisms like snails display, called *habituation*. The opposite of habituation, *sensitization,* occurs when a repeated stimulus creates a stronger reflex response over time.

Fixed-Action Patterns

Some behaviors, such as avoiding predators, are so important to survival that they cannot depend on learning. Learning is not possible in some circumstances where individuals grow without parents or adults and yet must immediately know how to eat, avoid predators, and reproduce. *Fixed-action patterns* are used for behaviors that are important and cannot depend on learning. A fixed-action pattern is a complex, coordinated behavioral response triggered by specific stimulation from the environment. The stimulus that elicits the behavior is referred to as the *releaser*. Fixed-action patterns are not learned and are not usually modified by learning. The particular stimuli that trigger a fixed-action pattern are readily modified, provided certain cues or elements of the stimuli are maintained.

An example of a fixed-action pattern is the retrieval-and-maintenance response of many female birds to an egg of their species. Certain kinds of stimuli are more effective than others in triggering a fixed-action pattern. Hence an egg with the characteristics of that species will be more effective in triggering the response than one that only crudely resembles the natural egg. The characteristic movements made by animals that herd or flock together (such as the swimming actions of fish and the flying actions of locusts) are fixed-action patterns, as is the spinning of webs by spiders.

Characteristics of the stimulus for the fixed-action pattern can be altered to determine what part of the stimulus is the most important factor. It can be the size of eggs, their shape, their color, or the pattern of speckling that elicits a bird's care for eggs. The characteristic of the stimulus that triggers the response can be artificially manipulated to create a larger-than-normal response.

Other physical factors such as hormones can exert important influences on behavior, particularly the influence of estrogen and testosterone on sex-specific behavior. Even if a behavior is learned, genetic biological components such as hormone expression and sexual maturation might be required for the behavior to be manifested. For example, hormones and sexual maturation play a key role in the ability of songbirds to perform their characteristic songs.

LEARNING AND NERVES

The capacity for learning adaptive responses is closely correlated with the degree of neurologic development of the organism—that is, the capacity and flexibility of its nervous system, particularly its cerebral cortex, to form new synapses.

Learning

Learned behavior involves a change in the way an animal behaves based on experience. Learning is a complex phenomenon that occurs, to some extent, in all animals. In lower animals, instinctual or innate behaviors are the predominant determinants of behavior patterns, and learning plays a relatively minor role in the modification of these predetermined behaviors. Higher animals, on the other hand, with their well-developed brains and neurological systems, learn the major share of their repertoire of responses to the environment.

Habituation

Habituation is a simple learning pattern in which a repeated stimulus creates a decreased responsiveness to that stimulus. If the stimulus is no longer regularly applied, the response tends to recover over time. If you poke a snail once, it retracts into its shell, but if you poke it repeatedly, it will learn to ignore the stimulus. The receptors and sensory neurons involved become down-regulated over time and no longer signal, causing the habituation. However, if you leave the snail alone for a while and then touch it again, its retraction response will return; the response neurons have recovered.

Classical Conditioning

Classical or *Pavlovian* conditioning involves the association of a physical response with an environmental stimulus. Russian physiologist Ivan Petrovich Pavlov studied the salivation reflex in dogs. In 1927, he discovered that if a dog was presented with an arbitrary stimulus (e.g., a bell) and then presented with food, the dog would eventually salivate on hearing the bell alone. Pavlov came up with the following terminology:

- An established (innate) reflex consists of an *unconditioned stimulus* (e.g., food for salivation), and the response that it naturally elicits is the *unconditioned response* (e.g., salivation).
- A *neutral stimulus* is a stimulus that will not by itself elicit a response prior to conditioning (e.g., a bell). During *conditioning* (the establishment of a new reflex), a neutral stimulus is presented with an unconditioned stimulus. When the neutral stimulus elicits a response in the absence of the unconditioned stimulus, it becomes the *conditioned stimulus.*
- The product of the conditioning experience is termed the *conditioned reflex* (e.g., salivation at the sound of a ringing bell).

Operant or Instrumental Conditioning. Instrumental conditioning involves conditioning responses to stimuli with the use of reward or reinforcement. When the organism exhibits a behavioral pattern that the experimenter would like to see repeated, the animal is rewarded, with the result that it exhibits this behavior more often. B.F. Skinner used the well-known "Skinner box" to show that animals in a cage could be conditioned to push down a lever to release food from a food dispenser. Instrumental conditioning can be performed through *positive reinforcement* (such as a food reward) or *negative reinforcement* (such as giving an animal a painful electric shock whenever it exhibits a certain unwanted behavior).

Modifications of Conditioned Behavior. Organisms eventually "unlearn" conditioned responses if they are not reinforced. *Extinction* is the gradual elimination of conditioned responses in the absence of reinforcement. The recovery of such a conditioned response after extinction is termed *spontaneous recovery.*

Limits of Behavioral Change

There are limits, however, to what an organism is capable of learning. These limits can be either neurologic (the organism simply doesn't have the brain power) or chronologic (learning must occur during a narrow window during the organism's development in order to be successful).

QUICK QUIZ

A dog is rapped hard on the nose with a newspaper every time he steals cinnamon buns from the kitchen table. Eventually, he stops stealing the buns. This is an example of

(A) imprinting.

(B) instrumental conditioning through negative reinforcement.

(C) a circadian rhythm.

(Answer = (B))

These are specific time periods called *critical periods* during an animal's early development when it is physiologically capable of developing specific behavioral patterns. If the proper environmental pattern is not present during this critical period, the behavioral pattern will not develop correctly. In some animals there is also a visual critical period; if light is not present during this period, visual effectors will not develop properly later on, no matter how much stimulus is given.

Imprinting

Imprinting is a process in which environmental patterns or objects presented to a developing organism during a brief critical period in early life become accepted permanently as an element of its behavioral environment. To put it another way, these patterns are "stamped in" and included in an animal's behavioral response. A duckling, for example, passes through a critical period in which it learns that the first large moving object it sees is its mother. In the natural environment, its mother usually is the first thing a duckling sees. However, if a large, moving object other than its mother is the first thing it sees, the duckling will follow it, as Konrad Lorenz discovered when he was pursued by newborn ducklings that assumed that he was their mother.

FOLLOW THE LEADER

The trailing behavior of ants is based on scent. Scout ants release scent trails to guide the other ants to food sources.

Intraspecific Interactions

Just as an organism communicates within itself via nervous and endocrine systems, it also requires methods to communicate with other members of its species. These methods include behavioral displays, pecking order, territoriality, and responses to chemicals. Pheromones can mark a territory or attract a mate, for example, creating a long-lasting message that can be detected over long distances in some cases. Visual communication between animals is quite common, since most animals have vision of some sort, and visual signals are a rapid way to communicate.

The olfactory sense is immensely important as a means of communication. Many animals secrete substances called pheromones that influence the behavior of other members of the same species. One type of pheromone, the releaser pheromone, triggers a reversible behavioral change in the recipient. For example, female silkworms secrete a very powerful attracting pheromone that will attract a male from a distance of two miles or more. In addition to their sex-attracting purposes, releaser pheromones are secreted as alarm and toxic defense substances.

Behavioral Displays

A *display* may be defined as an innate behavior that has evolved as a signal for communication between members of the same species. According to this definition, a song, a call, or an intentional change in an animal's physical characteristics is considered a display. Many animals have evolved a variety of complex actions that function as signals in preparation for mating. Agonistic displays are intended to appease the observer, such as a dog's display of appeasement when it wags its tail. Meanwhile, antagonistic displays are intended to imply hostility and to instill fear, as when a bear directs its face straight at its opponent and raises its body onto its hind legs.

Other displays include various dancing procedures exhibited by honeybees, especially the scout honeybee, which is able to convey information to workers in the hive concerning the quality, direction, and distance from the hive of food sources. Displays utilizing auditory, visual, chemical, and tactile elements are often used as a means of communication.

ROUND AND WAGGLE DANCING

Honeybees have developed a complex system of communication that involves a form of dancing. A "round dance" (rapid sideways movement in tight circles) indicates that food is near. A "waggle dance" (a half-circle swing in one direction, followed by a straight run and another half-circle swing in the other direction) indicates that food is farther away in a specified direction.

Pecking Order

Frequently, the relationships among members of the same species living as a contained social group become stable for a period of time. When food, mates, or territory are disputed, a dominant member of the species will prevail over a subordinate one. This social hierarchy is often referred to as the *pecking order.* This established hierarchy minimizes violent intraspecific aggressions by defining the stable relationships among members of the group; subordinate members only rarely challenge dominant individuals.

Territoriality

Members of most land-dwelling species defend a limited area or territory from intrusion by other members of the same species. These territories are typically occupied by a male or a male-female pair. The territory is frequently used for mating, nesting, and feeding.

Territoriality serves the adaptive function of distributing members of the species so that the environmental resources are not depleted in a small region. Furthermore, intraspecific competition is reduced. Although there is frequently a minimum size for a species' territory, that size varies with population size and density. The larger the population, and the scarcer the resources available to it, the smaller the territories are likely to be.

Behavioral Cycles

Daily cycles of behavior are called *circadian rhythms.* Animals who exemplify these behavior cycles lose their exact 24-hour periodicity if they are isolated from the natural phases of light and dark. Cyclical behavior, however, will continue with approximate day-to-day phasing. The cycle is thus initiated intrinsically, but modified by external factors. Daily cycles of eating, maintained by most animals, provide a good example of cycles characterized by both internal and external control. The internal controls are the natural bodily rhythms of eating and satiation. External modulators include the elements of the environment that occur in familiar cyclic patterns, such as dinner bells and clocks, but most particularly the light of the sun. Sleep and wakefulness are the most obvious examples of cyclical behavior. These behavior patterns have been associated with particular patterns of brain waves.

EVEN PLANTS NEED TO SLEEP SOMETIMES

The first evidence noted for the existence of 24-hour circadian rhythms was the movements of bean plants.

PLANTS

Plants are so distinct in their body form and so important to life on earth that we present their physiology separately. Plants are multicellular autotrophs that use the energy of the sun, carbon dioxide, water, and minerals to manufacture carbohydrates through photosynthesis. The chemical energy plants produce is used for respiration by the plants themselves and is the source of all chemical energy in most ecosystems. The plant life cycle is distinct from animals, alternating between diploid and haploid forms in each generation.

Plant Organs

Although we may not usually think of plants having organs, the truth is that roots, stems, and leaves each have a defined function and are composed of tissues united around that function in the same manner as animal organs. The stems provide support against gravity and allow for the transport of fluid through vascular tissue. Water travels upward from the roots to the leaves, and nutrients travel from the leaves down through the rest of the plant. The roots provide anchoring support, and remove water and essential minerals from the soil. In some plants the roots have a symbiotic relationship with bacteria that fix nitrogen from the atmosphere into a biologically available form that plants can use. The leaves are the primary photosynthetic tissue, generating glucose that can be used to drive all of the plant's biochemical energy needs.

One of the key plant tissues is the *xylem*, which contains cells that carry water and dissolved minerals upward from the roots to the rest of the plant. The xylem is structured differently in flowering and nonflowering plants. In nonflowering plants, or *gymnosperms*, cells called *tracheids* in the stem form a connected network. It is not the cells themselves that conduct water, however. When the cells die, they leave behind their cell walls connected together in one long channel for water transport. Flowering plants, or *angiosperms*, also conduct water through their xylem using the cell walls of dead cells; but in angiosperms the cell walls are more tubelike, making water transport more efficient. In trees, older xylem cells at the innermost layer die, forming the heartwood used for lumber. The outer layer of xylem is alive and is called the sapwood.

Transport in plants, as in animals, encompasses both absorption and circulation. In plants, circulation is called *translocation* and mainly involves transporting water and carbohydrates. The rise of water up the xylem is caused by transpiration pull (as water evaporates from the leaves of plants, a vacuum is created), capillary action (the rise of any liquid in a thin tube because of the surface tension of the liquid), and root pressure exerted by water entering the root hairs.

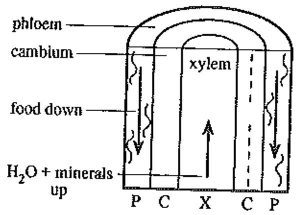
MNEMONIC

Remember:

Xylem cells transport water, and **ph**loem cells transport **f**ood!

Another important plant tissue is the *phloem*. The phloem transports nutrients from the leaves to the rest of the plant. This nutrient liquid is commonly called sap. In the phloem, cells are alive when they perform their transport function. The phloem cells are tube-shaped, moving the sap through the tube. Like terrestrial animals, plants need a protective coating provided by an external layer of epidermis cells. Another plant tissue is the *ground tissue*, involved in storage and support.

The cambium is located between the xylem and the phloem. Cambium cells divide to produce more xylem and phloem, which makes the plant grow wider.



Parts of the Plant

Plant Cells

Plant cells have all of the same essential organelles as other eukaryotic cells, including the mitochondria, endoplasmic reticulum (ER), Golgi, and nucleus. A major distinction of plant cells is the presence of the photosynthetic organelle, the *chloroplast* (see chapter 3, Cellular and Molecular Biology). Some plant cells contain large storage vacuoles not found in animal cells. Another distinct feature of plant cells is their cell wall. Each plant cell is surrounded outside of its plasma membrane by a stiff cell wall made of *cellulose.* The cellulose cell wall helps to provide structure and support for the plant. From grasses to trees, plants rely on cellulose cell walls to help support the plant against gravity.

Plant Phyla

Within the plant kingdom there are several major phyla. One of the major distinctions between these plant groups is whether or not a plant has vascular tissue for the transport of fluids. Plants without vascular tissue are small simple plants called *nontracheophytes,* also known as bryophytes or non-vascular plants, and include mosses. The *tracheophytes* are the rest of the plants, including pines, ferns, and flowering plants. The evolution of vascular tissue was an important step in the colonization of land by plants, since it increases the support of plants against gravity and increases their ability to survive dry conditions. Ferns, also known as *pterophytes,* are a phylum of tracheophytes that do not produce seeds, using spores instead for reproduction.

Gymnosperms

Gymnosperms represent the development of the seed, although they have no flowers, and angiosperms are the flowering plants, the dominant plants in many ecosystems today. Each of these represents major evolutionary steps. *Gymosperms* were the first plants to evolve the use of the seed in reproduction. Gymnosperms do not have flowers or fruit that enclose the seed, and so their name means "naked seed." Ginkgo trees are one example of gymnosperms, but by far the most common gymnosperms are the conifer trees such as pine, fir, and redwood. These trees have cones that are involved in reproduction, with one type of cone that produces male spores and separate cones that produce female spores. The female spores are enclosed in eggs that later develop into seeds after fertilization. Male spores are released as pollen that reaches female cones usually by wind dispersal. The seeds of gymnosperms, without a flower and not enclosed in a fruit, are quite small.

Angiosperms

Ferns were once dominant land plants, and gymnosperms were dominant after that. Today the flowering plants, the angiosperms, are dominant. Most of the following discussion of plant physiology focuses on the flowering plants due to their importance in ecosystems and the great number of species they represent. The two main groups of angiosperms are the *monocots* and the *dicots*. The monocots usually have narrow leaves and include the grasses, while dicots have broad leaves. Monocots and dicots differ in many other ways as well, such as seed structure.

Angiosperm Structure and Tissues

The stems of angiosperms are arranged in bundles of vascular tissues, separating the xylem and the phloem into organized layers. The *vascular bundles* in monocots are scattered through the stem cross section, while the vascular bundles in dicot stems are organized into a ring. Phloem cells are thin-walled and are found on the outside of the vascular bundle, while xylem cells are found on the inside. Additional stem tissues are the *pith* (involved in storage) and the cortex (to provide strength and structure). The *epidermis* on the outside of the stem protects tissues from the environment. Stems also have a layer of *cambium*, a tissue involved in growth. As cambium cells grow and divide, some of the cells differentiate to form xylem and others form phloem. This cambium contributes to growth of the plant, allowing stems to grow in thickness over time. Another layer of cambium lies beneath the bark of trees.

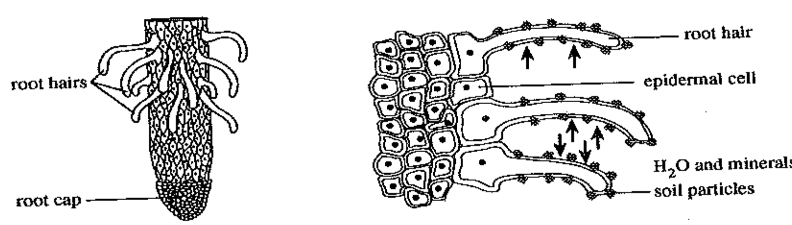
DON'T MIX THESE UP ON TEST DAY

Xylem cells are found in the center of the vascular bundle of the plant, and are responsible for transporting water and dissolved minerals **up** the stem.

Phloem cells are found outside the vascular bundle of the plant, and transport nutrients **down** the stem in actively photosynthesizing plants.

Cambium is undifferentiated tissue that can develop into either xylem or phloem.

Like the stem, the root has an epidermis, a cortex, phloem cells, xylem cells, and cambium cells. The epidermis contains the *root hair* cells. Root hairs are specialized cells of the root epidermis with thin-walled projections. They provide increased surface area for absorption of water and minerals from the soil through diffusion and active transport. The main functions of the root are absorption, which is accomplished through these root hairs, and anchorage of the plant in the ground. Some roots additionally function in the storage of food (such as the roots of turnips and carrots).

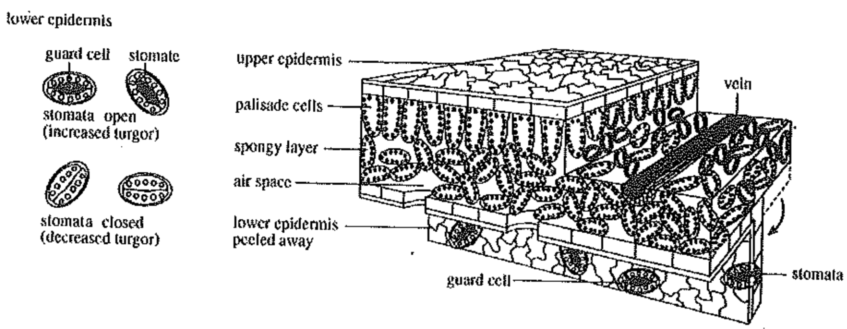


Root

Leaves are the other plant organ. To perform photosynthesis, leaves have adapted in various ways. First of all, the leaf has a waxy cuticle on top to conserve water. Its upper epidermis, the top layer of cells, has no openings, an adaptation which is also intended to inhibit water from being released. Another photosynthetic adaptation, the *palisade layer*, is the term given to elongated cells that are spread over a large surface area and contain chloroplasts. They are directly under the upper epidermis and are well exposed to light.

The leaf also possesses a *spongy layer,* where stomata open into air spaces that contact an internal moist surface of loosely packed spongy layer cells. Spongy cells contain chloroplasts. As in animals, this moist surface is necessary for diffusion of gases into and out of cells in both photosynthesis and respiration. Air spaces in leaves increase the surface area available for gas diffusion by the cells, allowing gaseous interchange of CO_2, H_2O, and O_2. The lower epidermis of the leaf is punctuated by *stomatal openings,* which further regulate the loss of water through transpiration and permit diffusion of carbon dioxide, water vapor, and oxygen between the leaf and the atmosphere. The size of these stomatal openings is controlled by guard cells. These cells open during the day to admit CO_2 for photosynthesis and close at night to limit loss of water vapor through transpiration.

One explanation for the mechanism by which the guard cells open and close is as follows: During the day, the guard cells, which contain chloroplasts, produce glucose. High glucose content in the cells causes them to swell up via osmosis. This condition is known as *turgor.* Because the inner wall of the guard cell is thickened, the swelling produces a curvature in the opening between the guard cells, and the stomatal opening increases. At night, photosynthesis ceases, cell turgor decreases, and the stomatal opening closes. During a drought, the stomata will also close during the day to prevent loss of water by transpiration. In this case, photosynthesis ceases because of a lack of CO_2.



Leaf

Growth of Tissues in the Developing Plant

Growth in higher plants is restricted to embryonic or undifferentiated cells called *meristem.* These tissues undergo active cell division. Gradually, the cells elongate and differentiate into cell types characteristic of the species. Different types of meristem include the *apical meristem,* which is found in the tips of roots and stems. These cells provide for growth in length, which occurs only at the root and stem tips. The *lateral meristem,* or cambium, is located between the xylem and phloem. This tissue permits growth in diameter. It is not an active tissue in monocots (grasses) or herbaceous dicots (alfalfa), but it is predominant in woody dicots (such as oak).

Control of Growth in Plants

The regulation of growth patterns is largely accomplished by plant hormones, which are almost exclusively devoted to this function. These hormones are produced by actively growing parts of the plant, such as the meristematic tissues in the apical region (apical meristem) of shoots and roots. They are also produced in young, growing leaves and developing seeds. Some of these hormones and their specific functions are discussed below.

Auxins

Auxins are an important class of plant hormone associated with several growth patterns, including *phototropism* (growth toward light) and *geotropism* (growth directed by gravity).

Auxins are responsible for phototropism, the tendency of the shoots of plants to bend toward light sources (particularly the sun). When light strikes the tip of a plant from one side, the auxin supply on that side is reduced. Thus the illuminated side of the plant grows more slowly than the shaded side. This asymmetrical growth in the cells of the stem causes the plant to bend toward the slower-growing light side; thus the plant turns toward the light. Indoleacetic acid is one of the auxins associated with phototropism.

Geotropism is the term given to the growth of portions of plants toward or away from gravity. With negative geotropism, shoots tend to grow upward, away from the force of gravity. If the plant is turned on its side (horizontally), the shoots will eventually turn upward again. Gravity itself increases the concentration of auxin on the lower side of the horizontally placed plant, while the concentration on the upper side decreases. This unequal distribution of auxins stimulates cells on the lower side to elongate faster than cells on the upper side. Thus the shoots turn upward until they grow vertically once again.

SUN WORSHIPPERS

When sunflowers bend to follow the sun, they are exhibiting phototropism.

With positive geotropism, roots (unlike shoots), grow toward the pull of gravity. In a horizontally placed stem, however, the effect on the root cells is the opposite. Those exposed to a higher concentration of auxin (the lower side) are inhibited from growing, while the cells on the upper side continue to grow. In consequence, the root turns downward.

Auxins produced in the terminal bud of a plant's growing tip move downward in the shoot and inhibit development of lateral buds. Auxins also initiate the formation of lateral roots, while they inhibit root elongation.

Gibberellins

This second class of hormones stimulates rapid stem elongation, particularly in plants that normally do not grow tall (for example, dwarf plants). *Gibberellins* also inhibit the formation of new roots and stimulate the production of new phloem cells by the cambium (where the auxins stimulate the production of new xylem cells). Finally, these hormones terminate the dormancy of seeds and buds and induce some biennial plants to flower during their first year of growth.

Cytokinins

Cytokinins make up another general class of hormone compounds that promote cell division. Kinetin is an important type of cytokinin and is involved in general plant growth, breaking seed dormancy, and expanding leaves. The action of kinetin is enhanced when auxin is present. The ratio of kinetin to auxin is of particular importance in the determination of the timing of the differentiation of new cells.

TREATING THE FRUIT YOU EAT

Ethylene and one of its most important inhibitors, abscissic acid, are commonly used to treat fruits for human consumption. Bananas, for example, are picked unripe, then treated with ethylene so that the ripening process will continue after the fruit is off the tree. As bananas are transported to markets and sold, they are treated with abscissic acid to prevent rotting and extend their shelf life.

Ethylene

Ethylene stimulates the ripening of fruit and induces aging. Its functioning is slowed by inhibitors, which block cell division as part of a number of important control mechanisms. Inhibitors are particularly important to the maintenance of dormancy in the lateral buds and seeds of plants during autumn and winter. The inhibitors break down gradually with time (and, in some cases, are destroyed by the cold) so that buds and seeds can become active in the next growing season.

Antiauxins

Antiauxins regulate the activity of auxins. For example, indoleacetic acid oxidase regulates the concentration of indoleacetic acid. An increase in the concentration of indoleacetic acid increases the amount of indoleacetic acid oxidase that is produced.

Asexual Reproduction in Plants

Many plants utilize asexual reproduction, such as *vegetative propagation*, to increase their numbers.

Undifferentiated tissue (*meristem*) in plants provides a source of cells from which new plants can develop. Vegetative propagation offers a number of advantages to plants, including speed of reproduction, lack of genetic variation, and the ability to produce seedless fruit. This process can occur either naturally or artificially.

Natural forms of vegetative propagation include:

- **Bulbs.** These are parts of the root that split to form several new bulbs (an example is the tulip).
- **Tubers.** These modified underground stems have buds, such as the eye of a potato, which develop into new plants.
- **Runners.** Runners are plant stems that run above and along the ground, extending from the main stem. Near the main plant, new plants develop which produce new roots, as well as upright stems at intervals (as in lawn grasses).

QUICK QUIZ

What kinds of vegetative propagation do the following plants utilize?

(1) Daffodil

(2) Strawberry

(3) Fern

(4) Yam

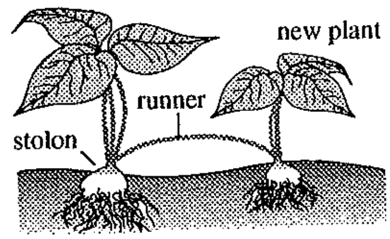
Answers:

(1) Bulb

(2) Runner

(3) Rhizome

(4) Tuber

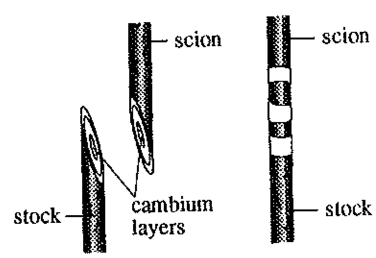


Runner

- **Rhizomes.** *Stolons* is another term used for these woody, underground stems. They reproduce through new upright stems that appear at intervals, eventually growing into independent plants. The iris is a rhizome.

Artificial forms of vegetative propagation include:

- **Cutting.** When cut, a piece of stem of some plants will develop new roots in water or moist ground. Examples include the geranium and the willow. Plant growth hormones such as auxins accelerate root formation in cuttings.
- **Layering.** The stems of certain plants, when bent into the ground and covered by soil, will take root. The connection between the main plant and this offshoot can then be cut, resulting in the establishment of a new plant. Blackberry and raspberry bushes reproduce in this manner.
- **Grafting.** Desirable types of plants can be developed and propagated using this method, in which the stem of one plant (*scion*) is attached to the rooted stem of another closely related plant (*stock*). One prerequisite for successful grafting is that the cambium (the tissue in stem that is not differentiated and allows stems to grow thicker) of the scion must be in contact with the cambium of the stock, since these two masses of undifferentiated cells must grow together to make one. Grafting does not allow for any mixing of hereditary characteristics, since the two parts of the grafted plant remain genetically distinct.



Grafting

Sexual Reproduction in Plants

Most plants are able to reproduce both sexually and asexually; some do both in the course of their life cycles, while others do one or the other. In the life cycles of mosses, ferns, and other vascular plants, there are two kinds of individuals associated with different stages of the life cycle: the *diploid* and the *haploid* individual.

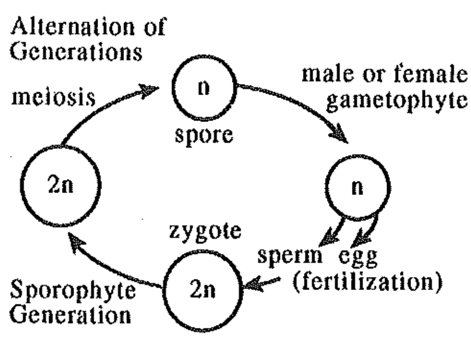
Diploid and Haploid Generation

In the diploid or *sporophyte* generation, the asexual stage of a plant's life cycle, diploid nuclei divide meiotically to form haploid spores (not gametes) and the spores germinate to produce the haploid or gametophyte generation.

The haploid or *gametophyte* generation is a separate haploid form of the plant concerned with the production of male and female gametes. Union of the gametes at fertilization restores the diploid sporophyte generation. Since there are two distinct generations, one haploid and the other diploid, this cycle is sometimes referred to as the *alternation of generations*. The relative lengths of the two stages vary with the plant type. In general, the evolutionary trend has been toward a reduction of the gametophyte generation and increasing importance of the sporophyte generation.

How do these generations express themselves in common plants? In moss, the gametophyte is the green plant that you see growing on the north side of trees. The sporophyte variety is smaller, nongreen (nonphotosynthetic), and short-lived. It is attached to the top of the gametophyte and is dependent upon it for its food supply. Spores from the sporophyte germinate directly into gametophytes.

In ferns, on the other hand, the reverse pattern may be observed, with the sporophyte of the species dominant. The gametophyte is a heart-shaped leaf the size of a dime. Fertilization produces a zygote from which the commonly seen green fern sporophyte develops. The sporophyte fern's leaves (the fronds) develop spores beneath the surface of the leaf. These spores germinate to form the next generation of gametophyte. In gymnosperms and angiosperms the haploid gametophyte is small, is not independent, and is orders of magnitude smaller and more transient than the diploid plants, continuing the evolutionary trend over time for the sporophyte to increase in dominance of the cycle.



Alternation of Generations

Sexual Reproduction in Flowering Plants

In flowering plants, or angiosperms, the evolutionary trend mentioned above continues; the gametophyte consists of only a few cells and survives for a very short time. The woody plant that is seen (for example, a rose) is the sporophyte stage of the species.

THE BIRDS, THE BEES, AND THE FLOWERS

We appreciate sexual reproduction in flowering plants when we admire blooming trees or eat fruits and vegetables. Flowering is the elaborate mechanism that plants have evolved to attract pollinators such as birds and bees, guaranteeing for themselves the genetic diversity that sexual reproduction provides.

DON'T MIX THESE UP ON TEST DAY

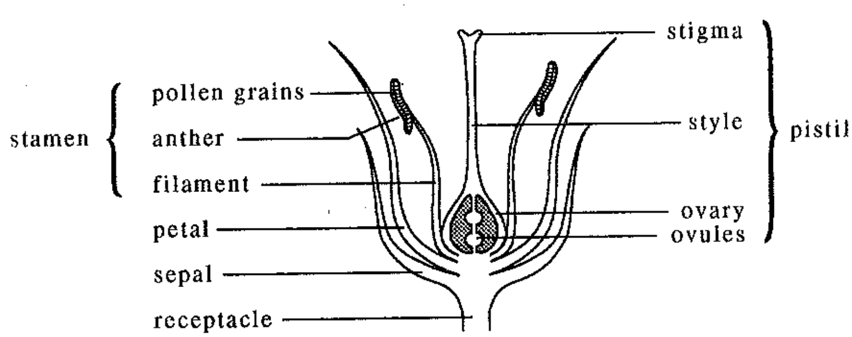
You will be expected to know that in sexual reproduction in animals, the haploid cell (gamete) is always unicellular while in the alternation of generations in plants, the haploid gametophyte is multicellular.

The Flower. The flower is the organ for sexual reproduction of angiosperms, and consists of male and female organs. The flower's male organ is known as the *stamen.* It consists of a thin, stalklike filament with a sac at the top. This structure is called the *anther,* and produces haploid spores. The haploid spores develop into pollen grains. The haploid nuclei within the spores will become the sperm nuclei, which fertilize the ovum.

Meanwhile, the flower's female organ is termed a *pistil.* It consists of three parts: the *stigma,* the *style,* and the *ovary.* The stigma is the sticky top part of the flower, protruding beyond the flower, which catches the pollen. The tubelike structure connecting the stigma to the ovary at the base of the pistil is known as the style; this organ permits the sperm to reach the ovules. The ovary, the enlarged base of the pistil, contains one or more ovules. Each ovule contains the haploid egg nucleus.

Petals are specialized leaves that surround and protect the pistil. They attract insects with their characteristic colors and odors. This attraction is essential for cross-pollination—that is, the transfer of pollen from the anther of one flower to the stigma of another (introducing genetic variability).

Note that some species of plants have flowers that contain only stamens ("male plants") and other flowers that contain only pistils ("female plants").



Parts of the Flower

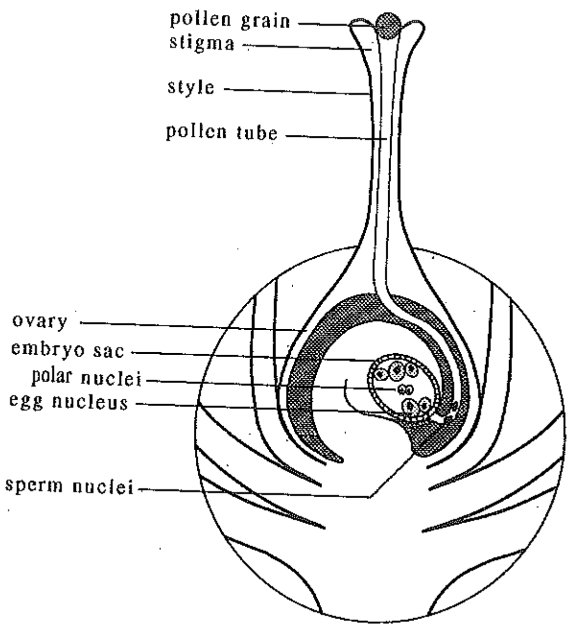
The Male Gametophyte (Pollen Grain). The pollen grain develops from the spores made by the sporophyte (for example, a rose bush). Pollen grains are transferred from the anther to the stigma. Agents of cross-pollination include insects, wind, and water. The flower's reproductive organ is brightly colored and fragrant in order to attract insects and birds, which help to spread these male gametophytes. Carrying pollen directly from plant to plant is more efficient than relying on wind-born pollen and helps to prevent self-pollination, which does not create genetic diversity. When the pollen grain reaches the stigma (pollination), it releases enzymes that enable it to absorb and utilize food and water from the stigma and to germinate a pollen tube. The pollen tube is the remains of the evolutionary gametophyte. The pollen's enzymes proceed to digest a path down the pistil to the ovary. Contained within the pollen tube are the tube nucleus and two sperm nuclei; all are haploid.

Female Gametophyte. The female gametophyte develops in the ovule from one of four spores. This embryo sac contains nuclei, including the two polar (*endosperm*) nuclei and an egg nucleus.

Fertilization. The gametes involved in this cycle of reproduction are nuclei, not complete cells. The sperm nuclei of the male gametophyte (pollen tube) enters the female gametophyte (embryo sac), and a double fertilization occurs. One sperm nucleus fuses with the egg nucleus to form the diploid zygote, which develops into the embryo. The other sperm nucleus fuses with the two polar bodies to form the endosperm (triploid or $3n$). The endosperm provides food for the embryonic plant. In dicotyledonous plants, the endosperm is absorbed by the seed leaves (*cotyledons*).

1 sperm nuclei + 1 egg nuclei = zygote = embryo

1 sperm nucleus + 2 polar nuclei = $3n$ endosperm



Fertilization in Angiosperms

Development of the Plant Embryo-Seed Formation. The zygote produced in the sequence described above divides mitotically to form the cells of the embryo. This embryo consists of the following parts, each with its own function:

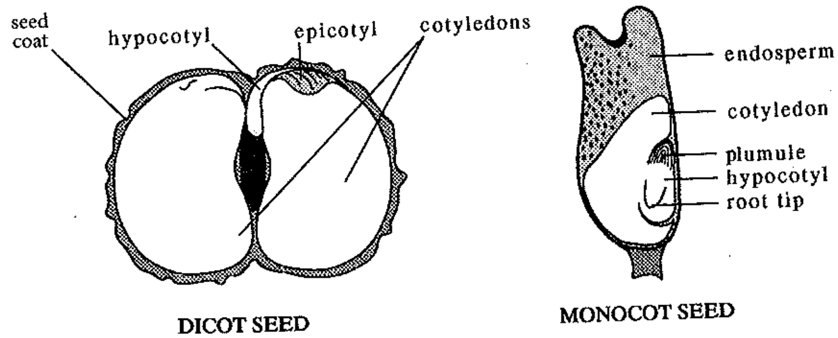
- The *epicotyl* develops into leaves and the upper part of the stem.
- The *cotyledons* or seed leaves store food for the developing embryo.
- The *hypocotyl* develops into the lower stem and root.
- The *endosperm* grows and feeds the embryo. In dicots, the cotyledon absorbs the endosperm.
- The *seed coat* develops from the outer covering of the ovule. The embryo and its seed coat together make up the seed. Thus, the seed is a ripened ovule.

DON'T MIX THESE UP ON TEST DAY

The *endosperm* is a nutrient-rich structure formed when a sperm nucleus fuses with two polar nuclei. This fusion provides nourishment for the developing *embryo*.

FRUIT OVARIES

Fruits may be thought of as ripened ovaries. They nourish their seed embryos until these can germinate under the right conditions.



Types of Plant Embryos

Seed Dispersal and Development of Fruit. The fruit, in which most seeds develop, is formed from the ovary walls, the base of the flower, and other consolidated flower pistil components. Thus, the fruit represents the ripened ovary. The fruit may be fleshy (as in the tomato) or dry (as in a nut). It serves as a means of seed dispersal: it enables the seed to be carried more frequently or effectively by air, water, or animals (through ingestion and subsequent elimination). Eventually, the seed is released from the ovary and will germinate under proper conditions of temperature, moisture, and oxygen.

THINGS TO REMEMBER

- Sexual and asexual reproduction
- Cell division
- Mitosis
- Meiosis
- Know the structure and function of the following systems in humans:
  - Digestive system
  - Circulatory system
  - Immune system
  - Respiratory system
  - Endocrine system
  - Nervous system
  - Motor system
- Animal behavior concepts
  - Simple and complex reflexes
  - Fixed-action patterns
  - Learned behavior
- Plant physiology concepts
  - Cell structure
  - Methods of reproduction
  - Vascular versus non-vascular
  - Gymnosperms and angiosperms

ORGANISMAL BIOLOGY QUIZ

1. Which enzyme breaks down starch to disaccharides?
   (A) Amylase
   (B) Gastrin
   (C) Secretin
   (D) Pepsin
   (E) Maltase

2. Of the choices below, which statement about the blastula stage of embryonic development is FALSE?
   (A) It consists of a solid ball of cells.
   (B) It contains a fluid-filled center called the blastocoel.
   (C) It is the stage of development that precedes the gastrula.
   (D) It is a more advanced stage than a morula.
   (E) It is a less advanced stage than a neurula.

3. Which of the following associations of germinal tissues and developed tissue is INCORRECT?
   (A) Mesoderm: heart
   (B) Ectoderm: nervous sytem
   (C) Endoderm: lining of intestinal tract
   (D) Mesoderm: pancreas
   (E) Ectoderm: epidermis of skin

4. To ensure survival of their species, animals that do not spend a large amount of time caring for their offspring must
   (A) have the ability to live in water and on land.
   (B) lay eggs.
   (C) produce many offspring.
   (D) have protective coloring.
   (E) have internal fertilization.

5. Basal metabolism disorders are most likely caused most directly by
   (A) impairment of the pituitary.
   (B) impairment of the gonads.
   (C) impairment of the thyroid.
   (D) impairment of the thymus.
   (E) impairment of the parathyroid.

6. In humans, the site of successful fertilization is most commonly the
   (A) ovary.
   (B) fallopian tube.
   (C) uterus.
   (D) cervix.
   (E) vagina.

7. Which of the following statements about skeletal muscle tissue is TRUE?
   (A) In the muscle fiber, actin is the thick filament.
   (B) The sarcoplasmic reticulum regulates the level of Ca^{2+} within a muscle cell.
   (C) Unlike a nerve cell, a muscle cell does not possess an excitable membrane.
   (D) In a muscle fiber, myosin is the thin filament.
   (E) Contraction of a muscle fiber can occur in the absence of Ca^{2+}.

8. Which of the following statements is NOT true of the digestive system?

   (A) Digestive enzymes from the pancreas are released via a duct into the duodenum.

   (B) Peristalsis is a wave of smooth-muscle contraction that proceeds along the digestive tract.

   (C) In the small intestine, villi absorb nutrients into both the lymphatic and circulatory systems.

   (D) The low pH of the stomach is essential in order for carbohydrate digestive enzymes to function.

   (E) The release of bile from the gallbladder is triggered by the hormone cholecystokinin.

9. Which of the following statements about blood is FALSE?

   (A) Mature red blood cells are not nucleated.

   (B) Blood platelets are involved in the clotting process.

   (C) The adult spleen is a site of red blood cell development.

   (D) White blood cells are capable of phagocytosing foreign matter.

   (E) New red blood cells are constantly developing in the bone marrow.

10. Which of the following is a normal pathway of blood flow?

   (A) Right ventricle to aorta

   (B) Pulmonary veins to left atrium

   (C) Inferior vena cava to left atrium

   (D) Pulmonary veins to left ventricle

   (E) Left ventricle to pulmonary artery

11. Which of the following associations of brain structure and function is FALSE?

   (A) Hypothalamus: appetite

   (B) Cerebellum: motor coordination

   (C) Cerebral cortex: higher intellectual function

   (D) Reticular activating system: sensory processing

   (E) Medulla: basic emotional drives

12. Which statement about the respiratory system is NOT true?

   (A) Ciliated nasal membranes warm, moisten, and filter inspired air.

   (B) Contraction of the diaphragm enlarges the thoracic cavity.

   (C) When the thoracic cavity enlarges, the pressure of air within the lungs falls.

   (D) When the pressure of air within the lungs is less than the atmospheric pressure, air will flow out of the lungs.

   (E) The respiratory process consists of inspiratory and expiratory acts following one another.

13. Which of the following statements about hormones is NOT true?

   (A) They are transported by the circulatory system.

   (B) They bind to receptors on target cells.

   (C) They must be present in large quantities to have an effect.

   (D) They are secreted by endocrine glands.

   (E) They can affect organs of the body that are far removed from their site of synthesis.

14. Which of the following is an INCORRECT pairing of an endocrine gland and hormone secretion?
    (A) Posterior pituitary: LH
    (B) Adrenal cortex: aldosterone
    (C) Anterior pituitary: TSH
    (D) Adrenal medulla: epinephrine
    (E) Hypothalamus: GnRH

15. Which of the following statements about acetylcholine (ACh) is NOT true?
    (A) ACh is released at the neuromuscular junction.
    (B) ACh binds to specific receptors on the postsynaptic membrane.
    (C) In a synaptic cleft, there are enzymes that degrade ACh.
    (D) ACh diffuses through the presynaptic membrane after its synthesis.
    (E) A synapse that is subjected to many action potentials may be depleted of ACh granules.

16. The sympathetic nervous system causes which of the following?
    (A) Constriction of the pupil
    (B) Decreased heart rate
    (C) Increased gastric secretion
    (D) Reduction of adrenaline secretion
    (E) Increased respiration

17. In the simple reflex arc
    (A) the sensory neuron synapses directly with the motor neuron.
    (B) sensory and motor neurons can synapse outside of the spinal cord.
    (C) sensory neurons synapse in the brain.
    (D) the motor response occurs without synaptic delay.
    (E) a minimum of three neurons must participate.

18. Hyperthyroidism is ALWAYS associated with
    (A) low blood pressure.
    (B) severely diminished mental activity.
    (C) high metabolic rate.
    (D) low body temperature.
    (E) decreased heart rate.

19. Geotropism is
    (A) the growth of parts of plants toward or away from gravity.
    (B) the tendency of plants to bend toward light.
    (C) the tendency of plants to have branched roots.
    (D) the formation of new phloem cells.
    (E) None of the above

20. Gibberellins
    (A) inhibit lateral buds.
    (B) stimulate fruit ripening.
    (C) maintain seed dormancy.
    (D) stimulate rapid stem elongation.
    (E) All of the above

21. Rhizomes are
    (A) underground stems with buds.
    (B) stems running above and along the ground.
    (C) spores.
    (D) the result of sexual reproduction.
    (E) woody, underground stems.

22. After Konrad Lorenz swam in a pond with newly hatched ducklings separated from their mother, they followed him around as if he were their mother. This is an example of
    (A) discrimination.
    (B) response to pheromones.
    (C) imprinting.
    (D) instrumental conditioning.
    (E) None of the above

Honors Bio Essay Response

Respond to ONE of the following prompts using complete sentences. Diagrams, flow charts, sketches and images should only be used to enhance your written response.

A. Homeostasis, or the maintenance of a steady-state environment, is a characteristic of all living organisms. Choose **three** of the following physiological parameters and describe how homeostasis is maintained for each
   a. Blood glucose levels
   b. Body temperature
   c. Blood pH
   d. Osmotic concentration of the blood
   e. Blood calcium levels
B. Angiosperms have a wide distribution in the biosphere and include the largest number of species in the plant kingdom. Answer all four of the following prompts
   a. Describe common characteristics shared by angiosperms and discuss evolutionary changes that were vital to their development and survival.
   b. Discuss how the anatomy and reproductive strategies of bryophytes limit their distribution
   c. Explain alternation of generations in mosses and angiosperms
   d. Discuss the impact of hormones on plant growth and development.