CHAPTER 28

Nervous Systems

Objectives

Introduction Explain how spinal cords are injured and the approaches to repairing the damage.

Nervous System Structure and Function

28.1 Describe the structural and functional subdivisions of the nervous system.
28.2 Describe the structure and functions of neurons.

Nerve Signals and Their Transmission

28.3 Define a resting potential and explain how it is caused.
28.4 Describe the changes that are associated with an action potential.
28.5 Explain how an action potential propagates itself along a neuron.
28.6 Compare the structures, functions, and locations of electrical and chemical synapses.
28.7 Describe the types of inputs a single neuron can receive and note the nature of the neuron's response.
28.8 Describe the types and functions of neurotransmitters known in humans.
28.9 Explain how drugs can alter chemical synapses.

Nervous Systems

28.10 Describe, with examples, the diversity of animal nervous systems.
28.11 Describe the general structure of the brain, spinal cord, and associated nerves.
28.12 Compare the functions of the sensory and motor divisions of the peripheral nervous system. Distinguish between the somatic and autonomic divisions of the nervous system.
28.13 Compare the functions of the parasympathetic and sympathetic divisions of the peripheral nervous system.
28.14 Describe two trends in the evolution of the vertebrate brain. Explain how the human forebrain changes during development.

The Human Brain

28.15, 28.16 Describe the parts and functions of the human brain. Note the detailed structures and functions of the cerebral cortex.
28.17 Explain how injuries, illness, and surgery provide insight into the functions of the brain.
28.18 Explain how the brain regulates sleep and arousal.
28.19 Describe the functions of the limbic system.
28.19 Describe the properties of short-, long-term, and skill memories.
28.20 Explain the causes of long-term depression and long-term potentiation.

Key Terms

nervous system
neuron
sensory input
integration
motor output
effector
central nervous system (CNS)
peripheral nervous system (PNS)
nerve
ganglion
sensory neuron
interneuron
motor neuron
cell body
dendrite
axon
supporting cell
myelin sheath
node of Ranvier
synaptic knob
resting potential
sodium-potassium pump
stimulus
action potential
threshold potential
synapse
synaptic cleft
neurotransmitter
summation
acetylcholine
biogenic amine
nerve net
cephalization
centralization
nerve cord
spinal cord
brain
blood-brain barrier
ventricle
central canal
cerebrospinal fluid
meninges
white matter
gray matter
cranial nerve
spinal nerve
sensory division
referred pain
motor division
somatic nervous system
autonomic nervous system
parasympathetic division
sympathetic division
forebrain
midbrain
hindbrain
cerebrum
medulla oblongata
pons
brainstem
cerebellum
thalamus
biological clock
cerebrum
cerebral hemisphere
corpus callosum
basal ganglia
cerebral cortex
lateralization
reticular formation
electroencephalogram (EEG)
REM sleep
limbic system
amygdala
hippocampus
short-term memory
long-term memory
long-term depression (LTD)
long-term potentiation (LTP)

Word Roots

auto- = self (*autonomic nervous system:* a subdivision of the motor nervous system of vertebrates that regulates the internal environment)

bio- = life; **-genic** = producing (*biogenic amines:* neurotransmitters derived from amino acids)

cephalo- = head (*cephalization:* the clustering of sensory neurons and other nerve cells to form a small brain near the anterior end and mouth of animals with elongated, bilaterally symmetrical bodies)

dendro- = tree (*dendrite:* one of usually numerous, short, highly branched processes of a neuron that conveys nerve impulses toward the cell body)

inter- = between (*interneurons:* an association neuron; a nerve cell within the central nervous system that forms synapses with sensory and motor neurons and integrates sensory input and motor output)

neuro- = nerve; **trans-** = across (*neurotransmitter:* a chemical messenger released from the synaptic terminal of a neuron at a chemical synapse that diffuses across the synaptic cleft and binds to and stimulates the postsynaptic cell)

para- = near (*parasympathetic division:* one of two divisions of the autonomic nervous system)

soma- = body (*somatic nervous system:* the branch of the motor division of the vertebrate peripheral nervous system composed of motor neurons that carry signals to skeletal muscles in response to external stimuli)

syn- = together (*synapse:* the locus where a neuron communicates with a postsynaptic cell in a neural pathway)

Lecture Outline

Introduction *Can an Injured Spinal Cord Be Fixed?*

A. The nervous system is basic to the functioning of any animal.
   1. In order to survive and reproduce, an animal must respond appropriately to environmental stimuli, both internal and external.
   2. The nervous system coordinates immediate responses to stimuli with long-term responses from the endocrine system (Chapter 26).

B. The spinal cord acts as a conduit for information flow between the brain and the rest of the body. But what happens if the spinal cord is injured?
   1. Minor injuries to the spinal cord can be healed; however, severe injuries can be devastating monetarily and emotionally to the victim and the victim's family.
   2. Previously, patients suffering a severe injury to the spinal cord were often left paralyzed and without hope for a cure.
   3. Recently, with the advances in stem cell research, the possibility of a cure has become closer to a reality (Module 11.5).

C. Structure, function, and evolution of the nervous system are reviewed in this chapter. Emphasis will be placed on the vertebrate nervous system and on the human brain.

I. Nervous System Structure and Function

Module 28.1 Nervous systems receive sensory input, interpret it, and send out appropriate commands.

A. A cubic centimeter of human brain tissue contains several million **neurons,** each communicating with several others.

B. The **nervous system** is organized with three interconnecting functions (Figure 28.1A):
   1. **Sensory input** is triggered by stimulation of receptors and involves the conduction of signals from the receptors to integration centers.
   2. **Integration** is the interpretation of these signals and the formulation of responses by the processing centers.
   3. **Motor output** is the conduction of signals from the processing center to **effectors** (muscles or glands) that respond to the stimuli.

C. The two main divisions of nervous systems are the **central nervous system (CNS)** and the **peripheral nervous system (PNS).** The CNS consists of the brain and (in vertebrates) spinal cord. The PNS carries information from sensory receptors to the CNS and from the CNS to effectors.

D. The functional unit of the nervous system is the neuron (Module 28.2). **Nerves** are made of bundles of neurons. PNS nerves that convey information from sensory

receptors to the CNS are called **sensory neurons.** PNS nerves that convey information from the CNS to effectors are called **motor neurons.** Nerves that convey information from one region of the CNS to another are called **interneurons.**

E. Clusters of nerve cell bodies within the PNS are called **ganglia.**
NOTE: Clusters of nerve cell bodies within the CNS are called *nuclei.*

F. A simple reflex originates with the stimulation of a receptor. The impulse is then conveyed along a sensory neuron (PNS) to the CNS (where integration occurs), to a motor neuron (PNS), and to an effector (Figure 28.1B).

Module 28.2 Neurons are the functional units of nervous systems (Figure 28.2).

A. Each neuron consists of the following components:
   1. The **cell body** houses the nucleus and most of the organelles.
   2. **Dendrites** are short, numerous, and highly branched; they convey signals toward the cell body.
   3. **Axons** are long and usually unbranched (except at the very end); they convey signals away from the cell body toward other neurons or effector cells. Each axon ends in a **synaptic knob** that relays the signal.

B. Neurons are found with **supporting cells.** There may be as many as 50 supporting cells for every neuron. These cells protect, insulate, or reinforce the neurons.
NOTE: These supporting cells are called *neuroglia* (or *glial cells*). There are six major types of neuroglia. For example, astrocytes are supportive cells within the CNS that connect neurons to blood vessels. Astrocytes have many functions, including neurotransmitter metabolism and K^+ balance. Recent studies have implicated astrocytes in learning and memory. Oligodendrocytes form the myelin sheath of the CNS. However, unlike Schwann cells, which form the myelin sheath of the PNS, oligodendrocytes do not guide the regrowth of damaged neurons. Microglia are phagocytic cells found within the CNS. There is evidence that microglia play a role in Alzheimer's disease. Ependymal cells are ciliated cells that aid in the circulation of cerebrospinal fluid (CSF). Satellite cells support clusters of nerve cell bodies (ganglia) in the PNS.

C. Those nerves in the PNS that convey signals very quickly are enveloped by special supporting cells (Schwann cells) that form a **myelin sheath.** The Schwann cells are arranged like beads on a string, wrapped around the axon but leaving periodic, unmyelinated **nodes of Ranvier.** On axons of this type, the myelin sheath insulates the axon and the nodes of Ranvier are the only places on the axon where signals are transmitted (where the plasma membrane of the axon is depolarized).
NOTE: Schwann cells are also called neurolemmocytes. Nodes of Ranvier are also called neurofibral nodes.

D. In the human nervous system, impulses travel along myelinated axons at about 100 m/sec and along nonmyelinated axons at about 5 m/sec.

E. In people who have the debilitating autoimmune disease multiple sclerosis, the myelin sheaths are gradually degraded by the person's immune system.
Review: Autoimmune diseases are discussed in Module 24.16.

II. Nerve Signals and Their Transmission

Module 28.3 A neuron maintains a membrane potential across its membrane.

A. Like a battery, a neuron maintains potential energy (Module 5.1) as a difference in electrical charge across the plasma membrane. Cells in general have a negative resting

potential, with more negative charges inside the cell than outside. A neuron has a **resting potential** of −70 millivolts (mV) (Figure 28.3A).
NOTE: Remind the students that this is a localized charge and that the cell, as a whole, is not negatively charged; moreover, the interstitial fluid, as a whole, is not positively charged (ask your students if they stick to magnets).

B. The resting potential is maintained by negatively charged, large organic molecules remaining inside the cell and an excess of K^+ ions inside and Na^+ ions outside the cell. The K^+ ions are free to diffuse in both directions through K^+ channels across the membrane. Na^+ ions are actively transported out of the cell as K^+ ions are transported in by the **sodium-potassium pump** (Figure 28.3B).
Review: Active transport (Module 5.18).

Module 28.4 A nerve signal begins as a change in the membrane potential.

A. In the 1940s, Hodgkin and Huxley worked out the details of nerve signal transmission using squid giant axons (fibers).

B. A **stimulus** is any factor (electric shock, pressure, sudden temperature change, etc.) that results in the triggering of a nerve signal. A nerve signal involves the progressive formation of the **action potential** along a nerve.

C. The graph traces the electrical changes over time at one point along an axon. These changes can lead to an action potential (Figure 28.4).

D. A typical action potential shows the following changes relative to the resting potential of −70 mV. Following a stimulus, the voltage rises in 2–3 milliseconds (msec) to the **threshold potential,** the minimum rise that will generate an action potential (in this case, to −50 mV). The threshold potential triggers the action potential, causing a reversal in the membrane potential, a rapid upswing to about 35 mV within 3–4 msec from the initial stimulus. The voltage then drops slightly below the resting potential (hyperpolarization), and returns to it about 7 msec after the stimulus.
NOTE: It is only the axon that can achieve an action potential. The potentials that travel along dendrites and nerve cell bodies are graded potentials. Graded potentials travel only a short distance before dying out. However, graded potentials can be added together (summation) to result in an action potential.

E. The specific ion movements that generate this action potential are controlled by the opening and closing of voltage-gated channels. The stimulus triggers the opening of Na^+ channels. At first a few Na^+ ions move into the axon. If enough ions move in to reach the threshold potential, the increasingly positive charge within causes more and more Na^+ channels to open. The peak voltage triggers the closing of Na^+ channels and the opening of K^+ channels, allowing K^+ to diffuse out rapidly, thereby balancing the inward movement of Na^+. Next, there is a brief period during which the membrane potential is below −70 mV (due to slow closure of the K^+ channels), followed by a return to the resting potential.
NOTE: This hyperpolarization prior to a return to the resting potential is due to the slow closure of the K^+ channels. Also, keep in mind that the activity at a point on the axon is being described here; this is not a description of the actual conduction of a nerve impulse.

Module 28.5 The action potential propogates itself along the neuron.

A. The local spreading of the electrical changes is caused by inflowing Na^+ (Figure 28.5).

B. These changes trigger the opening of Na^+ channels just ahead of the action potential, generating a second action potential a little farther on.

C. But the changes cannot be induced in the region behind the action potential where K^+ ions are moving out, so the action potential travels in just one direction.

D. Action potentials are all-or-none events. A signal with higher intensity reaches no higher peak voltage, but instead consists of an increase in the number of action potentials per millisecond.

Module 28.6 Neurons communicate at synapses.

A. A **synapse** is the junction between two neurons, or between a neuron and an effector cell.

B. At electrical synapses, action potentials travel directly from one cell to another. In humans, electrical synapses are common in the heart and digestive tract, associated with cardiac and smooth muscle cells.

C. At chemical synapses, action potentials are converted into a chemical signal. This chemical signal takes the form of **neurotransmitter** molecules that carry the message across a small gap **(synaptic cleft)** between the cells. The synaptic cleft prevents the spread of the action potential between cells.

D. In synaptic knobs at the ends of axons of transmitting neurons, neurotransmitters are stored in vesicles. The arrival of the action potential triggers the fusion of the vesicles with the plasma membrane, releasing the neurotransmitter into the cleft. The molecules diffuse across and bind to receptor molecules in the receiving cell's membrane. The neurotransmitters produce their effect by causing the opening of ion channels through which ions can diffuse and trigger a new action potential. The neurotransmitters are then broken down enzymatically or recycled back to the signaling cell for later use, and as a result the ion channels close (Figure 28.6).
NOTE: The fusion of the vesicles containing neurotransmitter with the plasma membrane requires an influx of Ca^{2+}.
Preview: These events are similar to those that occur at a neuromuscular junction (Module 30.10).

Module 28.7 Chemical synapses make complex information processing possible.

A. Neurotransmitters can either open ion channels in the receiving cell's plasma membrane or trigger a signal-transduction mechanism that will result in the opening of ion channels.
Review: The mechanism of signal transduction is discussed in Module 11.13.

B. Excitatory neurotransmitters open Na^+ channels and trigger a new action potential in the receiving cell.

C. Inhibitory neurotransmitters open Cl^- channels that decrease the tendency of the receiving cell to develop action potentials.

D. One cell receives input from numerous synaptic knobs from hundreds of neurons. The cell receives various magnitudes and numbers of both inhibitory and excitatory signals. The behavior of the receiving cell depends on the **summation** of all incoming signals (Figure 28.7).
NOTE: Temporal summation is when the signals impinging on the receiving cell are separated in time. Spatial summation occurs when the signals impinge on different regions (different dendrites) of the receiving cell.

Module 28.8 A variety of small molecules function as neurotransmitters.

A. A given neurotransmitter may be excitatory or inhibitory depending on the kind of receptor on the receiving cell.

B. Most neurotransmitters are small, nitrogen-containing molecules. For example, **acetylcholine** slows heart rate and causes muscle cells to contract.

C. Several neurotransmitters are **biogenic amines** (derived from amino acids) that also function as hormones: epinephrine, norepinephrine (increases heart rate), serotonin, and dopamine (affects sleep, mood, attention, and learning).

D. Biogenic amines are associated with various diseases. For example, Parkinson's disease is caused by a lack of dopamine, whereas schizophrenia has been linked to an excess of dopamine. Antidepressant drugs, such as Prozac®, function by affecting neurotransmitter activity (Prozac® acts by preventing the recycling of serotonin).
NOTE: Serotonin is also the target of prescription diet drugs.

E. Aspartate, glutamate, glycine, and gamma aminobutyric acid (GABA) are amino acids with neurosecretory functions in the brain. Aspartate and glutamate are excitatory. Glycine and GABA are inhibitory.
NOTE: Glutamate has been implicated in stroke-induced neuronal death.

F. Peptides (short chains of amino acids) such as endorphins (natural painkillers) and substance P (excitatory) are also neurotransmitters.

G. ATP, and the toxic gases NO (nitric oxide) and CO, have also been shown to serve as neurotransmitters. NO plays a role in penile erection and may play a role in learning.
NOTE: NO affects many other aspects of physiology, including playing a role in the regulation of blood pressure.

Module 28.9 Connection: Many drugs act on chemical synapses.

A. Drugs often produce their effect by altering the neurotransmitter or the receptor to the transmitter.

B. The effects of several commonly used drugs are as listed below:
1. Caffeine increases alertness by countering the effects of inhibitory signals.
2. Nicotine activates acetylcholine receptors and is a stimulant.
3. Alcohol may increase the inhibitory effects of GABA.

C. Prescription drugs also can act on the neurotransmitters and are used effectively in the treatment of psychological disorders.

D. Illegal drugs have a wide range of effects and include stimulants, depressants, and hallucinogenics. The problem with drugs that alter the effects of neurotransmitters is the addictive potential of the drugs.

III. Nervous Systems

Module 28.10 Nervous system organization usually correlates with body symmetry (Figure 28.10).

A. Neurons function in essentially the same way in all animals, but they are arranged in different patterns that provide different levels of integration and control.

B. Animals such as sponges do not have a nervous system.

C. Cnidarians have a **nerve net** (Figure 28.10A). The nerve net provides overall sensory function and control over limited muscular activity. The nerve net of hydra lacks central and peripheral divisions. The structure of the nervous system is suited to the hydra's radially symmetrical body plan and limited activity.

D. Like the hydra, radially symmetrical echinoderms have radially symmetrical nervous systems.
Review: At the phylum level, echinoderms are chordates' closest relatives (Chapter 18).

E. With bilateral symmetry comes the tendency for one end to encounter new environments first. The result of this is a concentration of nervous tissue at the head end, **cephalization,** and the presence of distinct central and peripheral nervous systems, **centralization.**

F. Flatworms are the first animal phylum to show cephalization and centralization. Their CNS is composed of a brain composed of ganglia and two **nerve cords** that communicate with smaller nerves of the PNS (Figure 28.10B). This CNS pattern is further developed in leeches (Figure 28.10C).

G. Insects have large, complex brains, integrating ganglia in each body segment, and many more complex sense organs (Figure 28.10D).

H. The nervous system of the squid parallels that of vertebrates and is well suited for a predatory lifestyle (Figure 28.10E).

Module 28.11 Vertebrate nervous systems are highly centralized and cephalized.

A. This system is highly centralized into **brain** and **spinal cord,** all protected inside bony skeletal elements (Figure 28.11A). The brain is the master control center, directing output through the spinal cord and including homeostatic centers, sensory centers, and centers of emotions and intellect.

B. The brain and spinal cord both include hollow regions that are filled with **cerebrospinal fluid (CSF).** These spaces in the brain, **ventricles,** are continuous with the **central canal** of the spinal cord (Figure 28.11B).
NOTE: This stems from the developmental source of the nervous system as an infolding of ectoderm into a hollow nerve tube (Modules 27.12, 27.13).

C. The brain is kept from direct contact with blood by the **blood-brain barrier.** The brain and spinal cord are also protected by the **meninges.** CSF flows between layers of the meninges and cushions the CNS.
NOTE: CSF also exchanges materials with the CNS and provides information, read by regions of the brain, on the status of the body.

D. The CNS is divided between **white matter,** with concentrations of myelinated axons and their synapses, and **gray matter,** with concentrations of neuron cell bodies. In the mammalian brain the cerebral cortex, the region of higher brain function, is gray matter.

E. Information is carried to and from the brain by **cranial nerves.** Information is carried to and from the spinal cord by **spinal nerves.**

Module 28.12 The peripheral nervous system of vertebrates is a functional hierarchy.

A. The ganglia and nerves of this system form a vast, intercommunicating network. Cranial nerves carry signals directly to the brain. Spinal nerves carry signals only to the spinal cord.

B. **Sensory division** neurons bring in information from either the external or the internal environment (Figure 28.12A). Spatial localization of this sensory information is not always accurate. An example of this is the **referred pain** associated with a heart attack (Figure 28.12B).
Preview: Sensory input and sensory transduction (Modules 29.1 and 29.2).

C. **Motor division** neurons are either under voluntary control (**somatic nervous system** carrying messages to skeletal muscles) or indirect, involuntary control (**autonomic nervous system** carrying messages mostly to glands and smooth muscles). The autonomic nervous system is divided into sympathetic and parasympathetic divisions (Module 28.13).

Preview: The somatic nervous system controls voluntary muscular movement (Module 30.10).

D. All spinal and most cranial nerves carry both sensory and motor neurons.

Module 28.13 Opposing actions of sympathetic and parasympathetic neurons regulate the internal environment.

A. The **parasympathetic division** of the autonomic nervous system primes the body for digesting food and resting, activities that gain and conserve the body's energy supply. These include stimulation of all digestive processes, and slowing the heart and breathing rates (Figure 28.13).
NOTE: The parasympathetic division is associated with " rest and repose."

B. Neurons from this system leave the basal part of the brain and the lower part of the spinal cord. Most neurons release the neurotransmitter acetylcholine to affect their target organs.

C. The **sympathetic division** prepares the body for intense, energy-consuming activities, such as fighting a competitor or fleeing a predator. These include inhibition of digestive activity, increasing the heart and breathing rates, and stimulating the liver to release glucose and the adrenal glands to release the fight-or-flight hormones epinephrine and norepinephrine.
NOTE: The sympathetic division is associated with " fight or flight."

D. Neurons from this system leave the middle part of the spinal cord. Most neurons release the neurotransmitter norepinephrine to affect their target organs.

Module 28.14 The vertebrate brain develops from three anterior bulges of the neural tube.

A. Many vertebrate activities (e.g., finding food and mates, avoiding predators, and raising offspring) require far more integration and conscious control than that provided by the autonomic nervous system or by spinal cord reflexes.

B. The vertebrate brain evolved from three anterior bulges on the spinal cord: **forebrain, midbrain,** and **hindbrain.** These subdivisions can be distinguished in early stages of brain development in all vertebrates (Figure 28.14).

C. Three trends appeared during the course of evolution of the brains of animals:
1. An increase in relative brain size
2. Subdivision of the basic regions into subregions with specific roles
3. Increasing integrative power of the forebrain, particularly the **cerebrum**

D. Major changes of the forebrain occur during embryonic development. There is a rapid increase in size during the second and third trimesters that covers most of the brain. There is also an increase in the surface area due to extensive folding. The folds form the cerebral cortex.

E. In birds and mammals, the cerebral cortex is highly folded, increasing the surface area of gray matter. Porpoises and primates have a larger and more complex cerebral cortex than all other vertebrates. Of all animals, humans have the largest brain surface area relative to body size.

IV. The Human Brain

Module 28.15 The structure of a living supercomputer: The human brain.

NOTE: A great deal of the human brain is given over to relaying information.

A. The human brain is composed of around 100 billion neurons, with a much larger number of supporting cells.

B. The three ancestral lobes of the brain are present, but they are highly evolved (Figure 28.15A).

C. The hindbrain: The **pons** and **medulla oblongata** conduct information to and from the more forward portions through sensory and motor neurons. This region also controls such involuntary activities as breathing (Chapter 22), heart rates (Chapter 23), and digestion (Chapter 21), and helps coordinate whole-body movement (Chapter 30). The **cerebellum** coordinates muscular movement of the limbs and is responsible for learned motor responses (Chapter 29).

D. The midbrain integrates auditory information, coordinates visual reflexes, and relays sensory data to higher brain centers (Chapter 29). Together, the hindbrain and midbrain form the **brainstem.**

E. The brainstem filters sensory information sent on to higher brain centers, regulates sleep and arousal, and coordinates muscular movements and balance.

F. The forebrain is the site of the most sophisticated integration. The **thalamus** contains cell bodies of neurons that relay information to the cerebral cortex and filter signals that pass through it. The hypothalamus regulates homeostasis, particularly in controlling the hormonal output of the pituitary gland. The hypothalamus (Module 26.4) controls the pituitary gland, body temperature (Chapter 25), blood pressure (Chapter 23), hunger, thirst (Chapter 25), sexual urges, and responses to danger; it is involved in the experiences of emotions; and it contains a **biological clock** (regulating circadian rhythms; Module 37.9). It is particularly sensitive to some addicting drugs such as cocaine.
NOTE: Much of the brain functions in relaying information from one part of the brain to another in the process of integration.

G. The **cerebrum** is composed of two **cerebral hemispheres** connected by the **corpus callosum** (Figure 28.15B).

H. **Basal ganglia,** found beneath the corpus callosum, function in motor coordination. Degeneration of cells in the basal ganglia occurs in Parkinson's disease, a symptom that results in uncontrollable shaking.
NOTE: Current usage is " ganglia" when referring to the PNS and " nuclei" when referring to the CNS. Therefore, it is more appropriate to refer to the basal ganglia as basal nuclei.

Module 28.16 The cerebral cortex is a mosaic of specialized, interactive regions.

A. This region is a highly folded sheet of gray matter occupying over 80% of total brain mass. The **cerebral cortex** contains about 10 billion neurons and hundreds of billions of synapses. Its neural circuitry produces our most distinctive human traits: reasoning, language, imagination, artistic talent, and personality. It also creates our sensory perceptions by integrating sensory information with memory and analysis.

B. The cerebral cortex is split into a right and left side that communicate with each other through the corpus callosum. Interestingly, the right hemisphere of the cerebral cortex controls and receives information from the left side of the body and vice versa.

C. Localization of function within the cortex comes mostly from studying the effects of tumors, strokes, and accidental damage; from studying direct stimulation during surgery; and from studying brain activity using PET scans (Figure 20.10D). The cortex has no pain sensors.

D. Both hemispheres are divided into four discrete lobes, each of which has several functional areas. Regions often combine centers that receive signals with association areas that help integrate our sensory perceptions. These association areas are the sites of higher mental activities: evaluating consequences, making judgments, and planning for

the future. Language also results from interactions among several areas, especially those areas associated with reading and speech (Figure 28.16).

E. **Lateralization** refers to the specialization of the hemispheres. " Right-brained" people are more artistic and musical, while " left-brained" individuals are more logical and adept at solving problems.

Module 28.17 Connection: Injuries and brain operations have provided insight into brain function.

A. The lack of appropriate animal models or computer simulations makes studying the human brain the most difficult task in anatomy and physiology. PET scans and MRIs have enhanced research efforts toward understanding brain function.

B. The practice of studying injured brains has also increased the understanding of normal brain function.

C. Much has been learned about the brain during surgery. Patients can be operated on awake, during which time they can be questioned while stimulated with electrical probes.

D. A radical procedure to alleviate the symptoms of severe epilepsy is a hemispherectomy. This procedure surgically removes half of the brain, with few long-term side effects other than partial paralysis on the opposite side of the body.

Module 28.18 Several parts of the brain regulate sleep and arousal.

A. Humans require sleep, a brain state in which stimuli are received and, in part, acted on, but without awareness of the stimuli, as is the case during arousal.

B. Sleep/wake cycles are regulated by the hypothalamus. Centers in the pons and medulla oblongata produce sleep when stimulated. A center in the midbrain causes arousal when stimulated.

C. Serotonin may be the key to why milk may induce sleepiness. Milk contains tryptophan, the precursor used to synthesize serotonin.

D. The **reticular formation** is a dispersed network that functions in sleep and arousal (Figure 28.18A). It filters familiar and repetitive stimuli, keeping them from impinging on consciousness. In general, the more active your reticular formation, the more aroused you are.

E. Brain waves (electrical signals on the head's surface recorded by an **electroencephalogram,** or **EEG**) depend on mental activity. The less the mental activity, the more regular the EEG (Figure 28.18B).

F. Alpha waves are characteristic of quiet, awake individuals. Beta waves are more agitated and characteristic of awake individuals solving complex mental problems (Figure 28.18B).

G. During sleep, activity cycles between two alternating types of sleep. Slow-wave (SW) sleep is characterized by delta waves and regular strong bursts of brain-wave activity. **REM (rapid-eye-movement) sleep** is characterized by rapid, less regular brain-wave activity than SW sleep. It is during REM sleep that most dreams occur. Both REM and SW sleep seem to play a role in memory and learning, with SW sleep playing a role in memory storage and REM sleep playing a role in the learning of repetitive skills.

Module 28.19 The limbic system is involved in emotions, memory, and learning.

A. The **limbic system** is a functional unit of several integrating centers and interconnecting neurons in the forebrain, including the thalamus, and parts of the hypothalamus and inner cerebrum (Figure 28.19).

B. Feelings of emotions, pleasure, and punishment are associated with the limbic system. Stimulation of these areas evokes intense reactions and is associated with basic survival mechanisms like feeding, aggression, and sexuality.
Preview: Part of the hypothalamus functions as a biological clock (Module 37.9).

C. The **hippocampus** is involved in memory formation, learning, and emotions. The hippocampus interacts closely with the **amygdala,** hypothalamus, brainstem, and prefrontal cortex. The amygdala appears to function as a memory filter, tying memory to a particular event or emotion. The prefrontal cortex functions in complex learning, reasoning, and personality.

D. The limbic system is closely associated with olfaction, as evidenced by the ability of odors to evoke both memories and emotions.

E. **Short-term memory** lasts only short periods of time (minutes).

F. **Long-term memory** requires the ability to store and retrieve information. The prefrontal cortex appears to be involved in the retrieval of stored information. Long-term memory can be improved with rehearsal and association with other long-term memories.

G. There is a difference between factual memories and skills. Skill memories involve muscular activities that have been learned by repeated use of a set of muscles. Overall, the process of memory formation and retrieval appears to be highly complex.

Module 28.20 The cellular changes underlying memory and learning probably occur at synapses.

Preview: Learning ranges from simple behavioral changes to complex problem solving (Module 37.4).

A. **Long-term depression (LTD)** is a type of learning whereby repeated, weak stimulation of a neuron leads to its decreased responsiveness to an action potential.

B. In contrast, **long-term potentiation (LTP)** is a type of learning whereby repeated stimulation of a neuron leads to its increased responsiveness to an action potential. LTP may be involved in memory storage and learning (Figure 28.20).

Class Activities

1. Compare two types of nervous systems by using the cnidarian *Hydra* and the planarian flatworm *Dugesia.* Place several individuals of each species in a watch glass on an overhead projector, and leave the preparation alone as you talk about the systems. The animals will (hopefully) demonstrate their capabilities very well. Add a few *Daphnia* to introduce an even more sophisticated system, and to induce additional behavior of *Hydra.*

2. An impromptu demonstration of the " all-or-nothing" and cascading nature of the transmission of action potentials can be done with chalkboard erasers (make sure you have plenty on hand). Line them up as though they were dominoes (you can also use dominoes, but erasers work better), with each eraser upright on its narrow end and with a space of about two-thirds of an eraser length between them. A slight push of the leading eraser will cause it to rock back and forth, but if it doesn't surpass the "threshold" push, the signal will not be passed further. A certain strength of push will surpass the "threshold potential" and induce the transmission of an " action potential" (the sequential tipping over of all the erasers).

3. There are numerous reflexes that are fun to demonstrate. For example, tapping the patellar tendon will cause the knee-jerk reflex, tapping the Achilles tendon will cause the foot to move, gently stroking the back of the hand will cause a change in the size of the pupils, and I am sure that there are many others you can think of.
4. Ask your students to consider the evolutionary advantages and disadvantages of cephalization. Have the class show how a particular type of nervous system reflects an organism's lifestyle.

Transparency Acetates

Figure 28.1A	Organization of a nervous system
Figure 28.1B	The knee-jerk reflex
Figure 28.2	Structure of a motor neuron
Figure 28.3A	Measuring a neuron's resting potential
Figure 28.3B	How the resting potential is generated
Figure 28.4	The action potential (Layer 1)
Figure 28.4	The action potential (Layer 2)
Figure 28.4	The action potential (Layer 3)
Figure 28.4	The action potential (Layer 4)
Figure 28.4	The action potential (Layer 5)
Figure 28.5	Propagation of the action potential along an axon
Figure 28.6	Neuron communication (Layer 1)
Figure 28.6	Neuron communication (Layer 2)
Figure 28.6	Neuron communication (Layer 3)
Figure 28.7	The multiple synaptic inputs that a neuron may receive
Figure 28.10	Invertebrate nervous systems
Figure 28.11A	A vertebrate nervous system (back view)
Figure 28.11B	Fluid-filled spaces of the vertebrate CNS
Figure 28.12A	Functional divisions of the vertebrate PNS
Figure 28.12B	Referred pain
Figure 28.13	The autonomic nervous system
Figure 28.14	Embryonic development of the vertebrate brain
Figure 28.15A	The main parts of the human brain
Figure 28.15B	A rear view of the brain
Table 28.15	Brain structure and function
Figure 28.16	Functional areas of the cerebrum's left hemisphere
Figure 28.18A	The reticular formation
Figure 28.18C	Brain waves recorded by an EEG
Figure 28.19	The limbic system (shown in shades of gold)
Figure 28.20	A possible cellular mechanism of memory storage

Media

See the beginning of this book for a complete description of all media available for instructors and students. Animations and videos are available in the Campbell Image Presentation Library. Media Activities and Thinking as a Scientist investigations are available on the student CD-ROM and web site.

Animations and Videos	File Name
Resting Potential Animation	28-03-RestingPotentialAnim.mov
Action Potential Animation	28-04-ActionPotentialAnim.mov
Synapse Animation	28-06-SynapseAnim.mov

Activities and Thinking as a Scientist	Module Number
Web/CD Activity 28A: *Neuron Structure*	28.2
Web/CD Thinking as a Scientist: *What Triggers Nerve Impulses?*	28.4
Web/CD Activity 28B: *Nerve Signals: Action Potentials*	28.5
Web/CD Activity 28C: *Neuron Communication*	28.6