11 Fundamentals of the Nervous System and Nervous Tissue

WHY THIS MATTERS

In this chapter, you will learn that

Neurons send electrical signals along their length, and communicate using chemical signals

by first asking

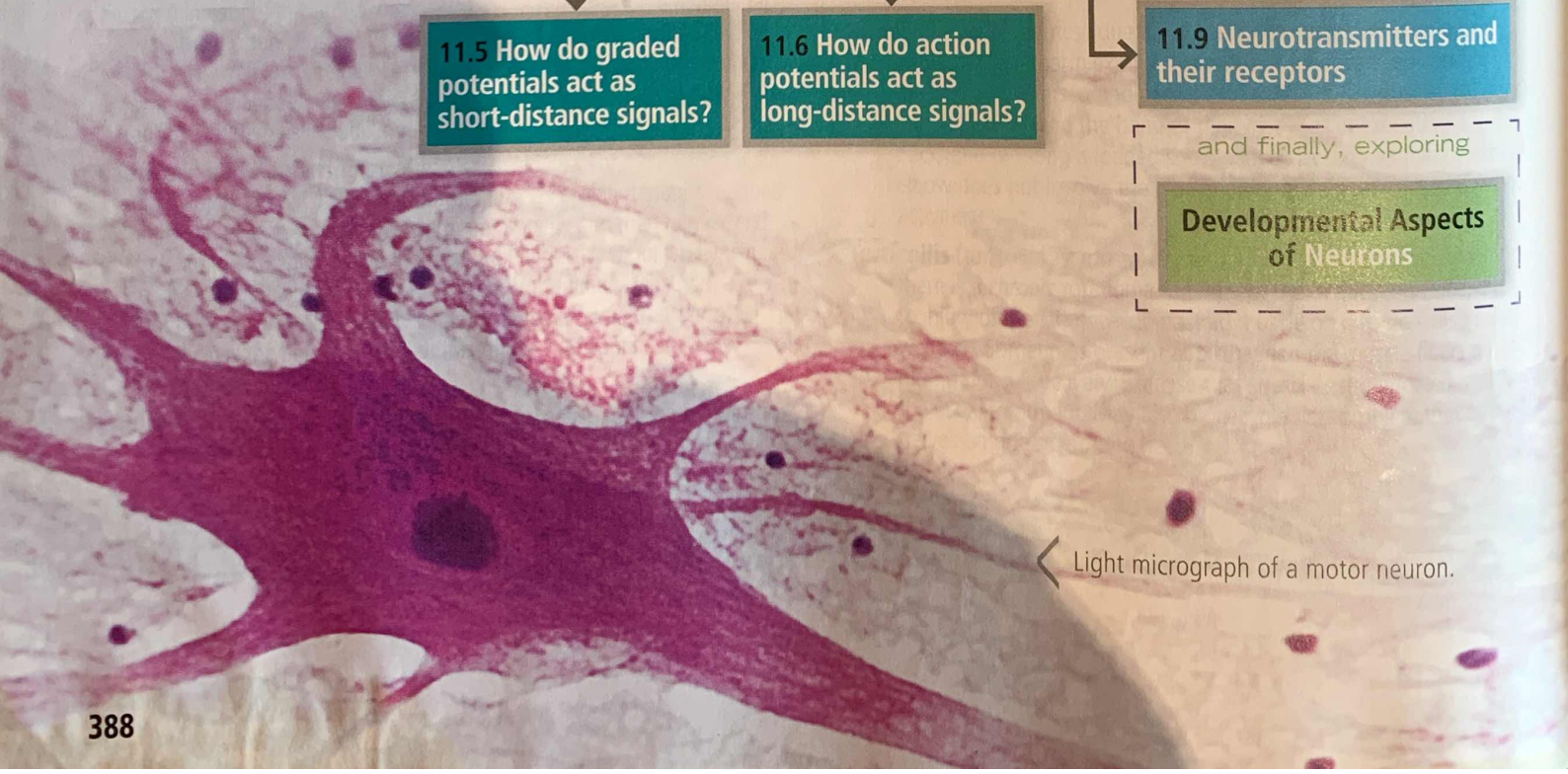
11.1 What does the nervous system do, and how is it organized?

and then asking

- **What are the cells of the nervous system?**
  - looking closer at
    - **11.2 Neuroglia**
    - **11.3 Neurons**
- **How do neurons send electrical signals?**
  - looking closer at
    - **11.4 How is the resting membrane potential generated?**
      - then asking
        - **11.5 How do graded potentials act as short-distance signals?**
        - **11.6 How do action potentials act as long-distance signals?**
- **How do neurons send and receive chemical signals?**
  - looking closer at
    - **11.7 The synapse**
    - **11.8 Postsynaptic potentials and synaptic integration**
    - **11.9 Neurotransmitters and their receptors**
- **11.10 How do neurons work together?**

and finally, exploring

Developmental Aspects of Neurons



Light micrograph of a motor neuron.

You are driving down the freeway, and a horn blares to your right. You immediately swerve to your left. Charlie leaves a note on the kitchen table: "See you later. Have the stuff ready at 6." You know the "stuff" is chili with taco chips. You are dozing but you awaken instantly when your infant son cries softly.

What do these three events have in common? They are all everyday examples of the functioning of your nervous system, which has your body cells humming with activity nearly all the time.

The **nervous system** is the master controlling and communicating system of the body. Every thought, action, and emotion reflects its activity. Its cells communicate by electrical and chemical signals, which are rapid and specific, and usually cause almost immediate responses.

We begin this chapter with a brief overview of the functions and organization of the nervous system. Then we focus on the functional anatomy of nervous tissue, especially the nerve cells, or *neurons*, which are the key to neural communication.

11.1 The nervous system receives, integrates, and responds to information

→ Learning Objectives

- ☐ List the basic functions of the nervous system.
- ☐ Explain the structural and functional divisions of the nervous system.

The nervous system has three overlapping functions, illustrated by the example of a thirsty person seeing and then lifting a glass of water (**Figure 11.1**):

1. **Sensory input.** The nervous system uses its millions of sensory receptors to monitor changes occurring both inside and outside the body. The gathered information is called **sensory input**.
2. **Integration.** The nervous system processes and interprets sensory input and decides what should be done at each moment—a process called **integration**.
3. **Motor output.** The nervous system activates *effector organs*—the muscles and glands—to cause a *response*, called **motor output.**

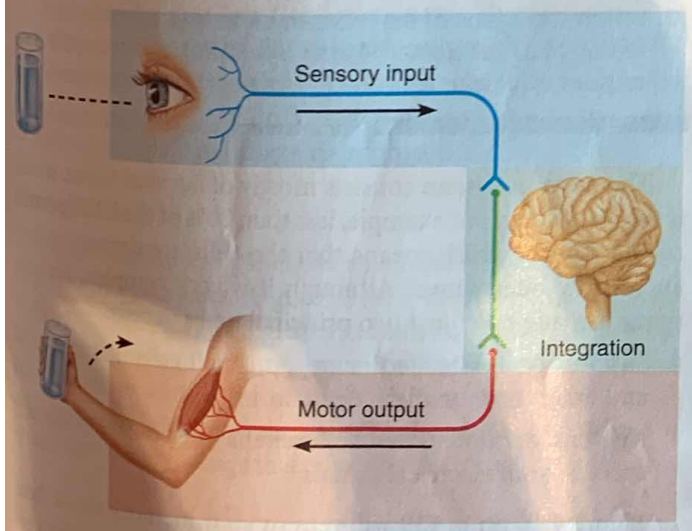


Figure 11.1 The nervous system's functions.

Here's another example: You are driving and see a red light ahead (sensory input). Your nervous system integrates this information (red light means "stop"), and your foot hits the brake (motor output).

We have one highly integrated nervous system. For convenience, it is divided into two principal parts, *central* and *peripheral* (**Figure 11.2**).

The **central nervous system (CNS)** consists of the *brain* and *spinal cord*, which occupy the dorsal body cavity. The CNS is the integrating and control center of the nervous system. It interprets sensory input and dictates motor output based on reflexes, current conditions, and past experience.

The **peripheral nervous system (PNS)** is the part of the nervous system *outside* the CNS. The PNS consists mainly of nerves (bundles of axons) that extend from the brain and spinal cord, and *ganglia* (collections of neuron cell bodies). *Spinal nerves* carry impulses to and from the spinal cord, and *cranial nerves* carry impulses to and from the brain. These

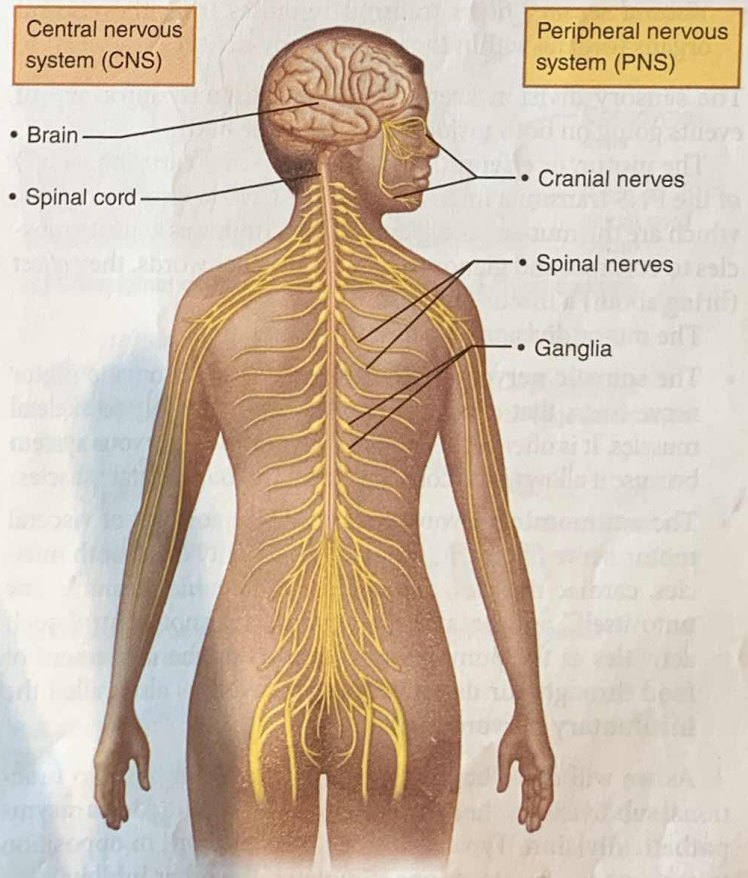


Figure 11.2 The nervous system. The brain and spinal cord (tan) make up the central nervous system. The peripheral nervous system (dark gold) mostly consists of pairs of cranial nerves, spinal nerves, and associated ganglia.

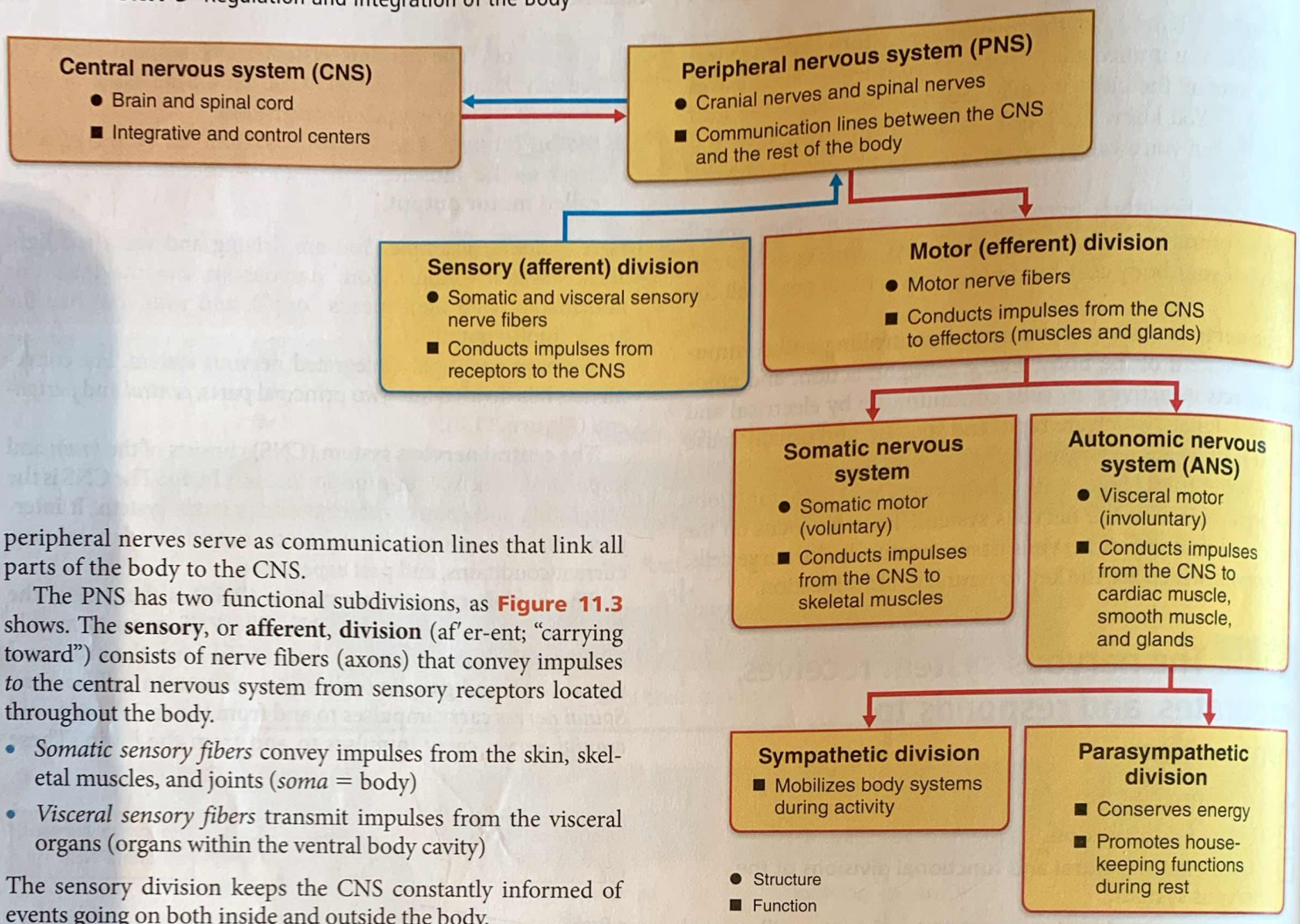


Figure 11.3 Organization of the nervous system. The human nervous system is organized into two major divisions, the central nervous system (CNS) and peripheral nervous system (PNS). Visceral organs (primarily located in the ventral body cavity) are served by visceral sensory fibers and by motor fibers of the autonomic nervous system. Motor fibers of the somatic nervous system and somatic sensory fibers serve the limbs and body wall (*soma* = body).

peripheral nerves serve as communication lines that link all parts of the body to the CNS.

The PNS has two functional subdivisions, as **Figure 11.3** shows. The **sensory**, or **afferent, division** (af′er-ent; "carrying toward") consists of nerve fibers (axons) that convey impulses *to* the central nervous system from sensory receptors located throughout the body.

- *Somatic sensory fibers* convey impulses from the skin, skeletal muscles, and joints (*soma* = body)
- *Visceral sensory fibers* transmit impulses from the visceral organs (organs within the ventral body cavity)

The sensory division keeps the CNS constantly informed of events going on both inside and outside the body.

The **motor**, or **efferent, division** (ef′er-ent; "carrying away") of the PNS transmits impulses *from* the CNS to effector organs, which are the muscles and glands. These impulses activate muscles to contract and glands to secrete. In other words, they *effect* (bring about) a motor response.

The motor division also has two main parts:

- The **somatic nervous system** is composed of somatic motor nerve fibers that conduct impulses from the CNS to skeletal muscles. It is often referred to as the **voluntary nervous system** because it allows us to consciously control our skeletal muscles.
- The **autonomic nervous system (ANS)** consists of visceral motor nerve fibers that regulate the activity of smooth muscles, cardiac muscles, and glands. *Autonomic* means "a law unto itself," and because we generally cannot control such activities as the pumping of our heart or the movement of food through our digestive tract, the ANS is also called the **involuntary nervous system**.

As we will describe in Chapter 14, the ANS has two functional subdivisions, the **sympathetic division** and the **parasympathetic division**. Typically these divisions work in opposition to each other—whatever one stimulates, the other inhibits.

☑ Check Your Understanding

1. What is meant by "integration," and does it primarily occur in the CNS or the PNS?
2. Which subdivision of the PNS is involved in (a) relaying the feeling of a "full stomach" after a meal, (b) contracting the muscles to lift your arm, and (c) increasing your heart rate?

For answers, see Answers Appendix.

The nervous system consists mostly of nervous tissue, which is highly cellular. For example, less than 20% of the CNS is extracellular space, which means that the cells are densely packed and tightly intertwined. Although it is very complex, nervous tissue is made up of just two principal types of cells:

- Supporting cells called *neuroglia*, small cells that surround and wrap the more delicate neurons
- *Neurons*, nerve cells that are excitable (responsive to stimuli) and transmit electrical signals

Figure 4.10 on p. 139 will refresh your memory about these two kinds of cells before we explore them further in the next two modules.

14. Why does a myelinated axon conduct action potentials faster than a nonmyelinated axon?

15. If an axon receives two stimuli close together in time, only one AP occurs. Why?

For answers, see Answers Appendix.

11.7 Synapses transmit signals between neurons

Learning Objectives

- ☐ **Define synapse.**
- ☐ **Distinguish between electrical and chemical synapses by structure and by the way they transmit information.**

The operation of the nervous system depends on the flow of information through chains of neurons functionally connected by synapses (**Figure 11.15**). A **synapse** (sin′aps), from the Greek *syn*, "to clasp or join," is a junction that mediates information transfer from one neuron to the next or from a neuron to an effector cell—it's where the action is.

The neuron conducting impulses toward the synapse is the **presynaptic neuron**, and the neuron transmitting the electrical signal away from the synapse is the **postsynaptic neuron.** At a given synapse, the presynaptic neuron sends the information, and the postsynaptic neuron receives the information. As you might anticipate, most neurons function as both presynaptic and postsynaptic neurons. Neurons have anywhere from 1000

CHAPTER SUMMARY

MAP For more chapter study tools, go to the Study Area of MasteringA&P.

There you will find:

- Interactive Physiology iP
- A&PFlix A&PFlix
- Interactive Physiology 2.0 iP2
- PhysioEx PEx
- Practice Anatomy Lab PAL
- Videos, Practice Quizzes and Tests, MP3 Tutor Sessions, Case Studies, and much more!

11.1 The nervous system receives, integrates, and responds to information (pp. 389–390)

1. The nervous system bears a major responsibility for maintaining body homeostasis. It monitors, integrates, and responds to information in the environment.
2. The nervous system is divided anatomically into the central nervous system (brain and spinal cord) and the peripheral nervous system (mainly cranial and spinal nerves).
3. The major functional divisions of the PNS are the sensory (afferent) division, which conveys impulses to the CNS, and the motor (efferent) division, which conveys impulses from the CNS.
4. The efferent division includes the somatic (voluntary) system, which serves skeletal muscles, and the autonomic (involuntary) system, which innervates smooth and cardiac muscle and glands.

11.2 Neuroglia support and maintain neurons (pp. 391–392)

1. Neuroglia (supporting cells) segregate and insulate neurons and assist neurons in various other ways.
2. CNS neuroglia include astrocytes, microglial cells, ependymal cells, and oligodendrocytes. PNS neuroglia include Schwann cells (neurolemmocytes) and satellite cells.

11.3 Neurons are the structural units of the nervous system (pp. 392–397)

1. Neurons have a cell body and cytoplasmic processes called axons and dendrites.

Neuron Cell Body (p. 392)

2. The cell body is the biosynthetic (and receptive) center of the neuron. Except for those found in ganglia, cell bodies are found in the CNS.
3. A collection of cell bodies is called a nucleus in the CNS and a ganglion in the PNS.

Neuron Processes (pp. 393–395)

4. A bundle of nerve fibers is called a tract in the CNS and a nerve in the PNS.
5. Most neurons have many dendrites, receptive processes that conduct signals from other neurons toward the nerve cell body. With few exceptions, all neurons have one axon, which generates and conducts nerve impulses away from the nerve cell body. Axon terminals release neurotransmitter.
6. Bidirectional transport along axons uses ATP-dependent motor proteins moving along microtubule tracks. It moves vesicles, mitochondria, and cytosolic proteins toward the axon terminals and conducts substances destined for degradation back to the cell body.
7. Large nerve fibers (axons) are myelinated. The myelin sheath is formed in the PNS by Schwann cells and in the CNS by oligodendrocytes. The myelin sheath gaps are also called nodes of Ranvier. Nonmyelinated fibers are surrounded by supporting cells, but the membrane-wrapping process does not occur.

Classification of Neurons (pp. 395–397)

8. Anatomically, neurons are classified according to the number of processes issuing from the cell body as multipolar, bipolar, or unipolar.
9. Functionally, neurons are classified according to the direction of nerve impulse conduction. Sensory neurons conduct impulses toward the CNS, motor neurons conduct away from the CNS, and interneurons (association neurons) lie between sensory and motor neurons in the neural pathways.

iP Nervous System I; Topic: Anatomy Review, pp. 1–12.

11.4 The resting membrane potential depends on differences in ion concentration and permeability (pp. 398–401)

Basic Principles of Electricity (p. 398)

1. The measure of the potential energy of separated electrical charges is called voltage (V) or potential. Current (I) is the flow of electrical charge from one point to another. Resistance (R) is hindrance to current flow. Ohm's law gives the relationship among these: $I = V/R$.
2. In the body, ions provide the electrical charges; cellular plasma membranes provide resistance to ion flow. The membranes contain leakage channels (nongated, always open) and gated channels.

iP Nervous System I; Topic: Ion Channels, pp. 1–10.

Generating the Resting Membrane Potential (pp. 398–401)

3. A resting neuron exhibits a resting membrane potential, which is −70 mV (inside negative). It is due both to differences in sodium and potassium ion concentrations inside and outside the cell and to differences in permeability of the membrane to these ions.
4. The ionic concentration differences result from the operation of the sodium-potassium pump, which ejects 3 Na^+ from the cell for each 2 K^+ transported in.

Changing the Resting Membrane Potential (p. 401)

5. Depolarization is a reduction in membrane potential (inside becomes less negative); hyperpolarization is an increase in membrane potential (inside becomes more negative).

iP2 Resting Membrane Potential.

11.5 Graded potentials are brief, short-distance signals within a neuron (pp. 401–402)

1. Graded potentials are small, brief, local changes in membrane potential that act as short-distance signals. The current produced dissipates with distance.

11.6 Action potentials are brief, long-distance signals within a neuron (pp. 402–409)

1. An action potential (AP), or nerve impulse, is a large, but brief, depolarization signal (and polarity reversal) that underlies

long-distance neural communication. It is an all-or-none phenomenon.

2. In the AP graph, an AP begins and ends at resting membrane potential. Depolarization to approximately +30 mV (inside positive) is caused by Na^+ influx. Depolarization ends when Na^+ channels inactivate. Repolarization and hyperpolarization are caused by K^+ efflux.
3. If threshold is reached, an AP is generated. If not, depolarization remains local.
4. In nerve impulse propagation, each AP provides the depolarizing stimulus for triggering an AP in the next membrane patch. Regions that have just generated APs are refractory; for this reason, the nerve impulse propagates in one direction only.
5. APs are independent of stimulus strength: Strong stimuli cause APs to be generated more frequently but not with greater amplitude.
6. During the absolute refractory period, a neuron cannot respond to another stimulus because it is already generating an AP. During the relative refractory period, the neuron's threshold is elevated because repolarization is ongoing.
7. In nonmyelinated fibers, APs are produced in a wave all along the axon, that is, by continuous conduction. In myelinated fibers, APs are generated only at myelin sheath gaps and are propagated more rapidly by saltatory conduction.

iP2 Generation of an Action Potential.

11.7 Synapses transmit signals between neurons (pp. 409–413)

1. A synapse is a functional junction between neurons. The information-transmitting neuron is the presynaptic neuron; the information-receiving neuron is the postsynaptic neuron.

Chemical Synapses (pp. 410–412)

2. Chemical synapses are sites of neurotransmitter release and binding. When the impulse reaches the presynaptic axon terminals, voltage-gated Ca^{2+} channels open, and Ca^{2+} enters the cell and mediates neurotransmitter release. Neurotransmitters diffuse across the synaptic cleft and attach to postsynaptic membrane receptors, opening ion channels. After binding, the neurotransmitters are removed from the synapse by diffusion, enzymatic breakdown, or reuptake into the presynaptic terminal or astrocytes.

Electrical Synapses (pp. 412–413)

3. Electrical synapses allow ions to flow directly from one neuron to another; the cells are electrically coupled.

iP Nervous System II; Topics: Anatomy Review, pp. 1–9, Ion Channels, pp. 1–8, Synaptic Transmission, pp. 1–7.

11.8 Postsynaptic potentials excite or inhibit the receiving neuron (pp. 414–417)

1. Binding of neurotransmitter at excitatory chemical synapses results in local graded potentials called EPSPs, caused by the opening of channels that allow simultaneous passage of Na^+ and K^+.
2. Neurotransmitter binding at inhibitory chemical synapses results in hyperpolarizations called IPSPs, caused by the opening of K^+ or Cl^- channels. IPSPs drive the membrane potential farther from threshold.
3. EPSPs and IPSPs summate temporally and spatially. The membrane of the axon hillock acts as a neuronal integrator.
4. Synaptic potentiation, which enhances the postsynaptic neuron's response, is produced by intense repeated stimulation. Ionic calcium appears to mediate such effects, which may be the basis of learning.
5. Presynaptic inhibition is mediated by axoaxonal synapses that reduce the amount of neurotransmitter released by the inhibited neuron.

iP Nervous System II; Topic: Synaptic Potentials and Cellular Integration, pp. 1-10.

11.9 The effect of a neurotransmitter depends on its receptor (pp. 417–422)

1. The major classes of neurotransmitters based on chemical structure are acetylcholine, biogenic amines, amino acids, peptides, purines, dissolved gases, and lipids.
2. Functionally, neurotransmitters are classified as (1) inhibitory or excitatory (or both) and (2) direct or indirect action. Direct-acting neurotransmitters bind to and open ion channels. Indirect-acting neurotransmitters act through second messengers. Neuromodulators also act indirectly presynaptically or postsynaptically to change synaptic strength.
3. Neurotransmitter receptors are either channel-linked receptors that open ion channels, leading to fast changes in membrane potential, or G protein–linked receptors that oversee slow synaptic responses mediated by G proteins and intracellular second messengers. Second messengers can act directly on ion channels or activate kinases, which in turn activate or inactivate other proteins, causing a variety of effects.

iP Nervous System II; Topic: Synaptic Transmission, pp. 6–15.

11.10 Neurons act together, making complex behaviors possible (pp. 423–424)

1. CNS neurons are organized into several types of neuronal pools, each with distinguishing patterns of synaptic connections called circuits.
2. In serial processing, one neuron stimulates the next in sequence, producing specific, predictable responses, as in spinal reflexes. A reflex is a rapid, involuntary motor response to a stimulus.
3. Reflexes are mediated over neural pathways called reflex arcs. The minimum number of elements in a reflex arc is five: receptor, sensory neuron, integration center, motor neuron, and effector.
4. In parallel processing, which underlies complex mental functions, impulses travel along several pathways to different integration centers.
5. The four basic circuit types are diverging, converging, reverberating, and parallel after-discharge.

Developmental Aspects of Neurons (pp. 424–425)

1. Neuron development involves proliferation, migration, and the formation of interconnections. The formation of interconnections involves axons finding their targets and forming synapses, and the synthesis of specific neurotransmitters.
2. Axon outgrowth and synapse formation are guided by other neurons, glial cells, and chemicals (such as N-CAM and nerve growth factor). Neurons that do not make appropriate synapses die, and approximately two-thirds of neurons formed in the embryo undergo programmed cell death.