Fundamentals of the Nervous System and Nervous Tissue Outline

11.1 The nervous system receives, integrates, and responds to information (pp. 389–390; Figs. 11.1–11.3)

A. The nervous system has three basic functions: gathering sensory input from sensory receptors; processing and interpreting sensory input to decide an appropriate response (integration); and using motor output to activate effector organs, muscles and glands, to cause a response. (p. 389; Fig. 11.1)

B. The central nervous system (CNS) consists of the brain and spinal cord and is the integrating and control center of the nervous system. (p. 389; Figs. 11.1–11.3)

C. The peripheral nervous system (PNS) is outside the central nervous system. (pp. 389–390; Figs. 11.2–11.3)

1. The sensory, or afferent, division of the peripheral nervous system carries impulses toward the central nervous system from sensory receptors located throughout the body.
   a. Somatic sensory fibers carry impulses from receptors in the skin, skeletal muscles, and joints.
   b. Visceral sensory fibers carry impulses from organs within the ventral body cavity.
2. The motor, or efferent, division of the peripheral nervous system carries impulses from the central nervous system to effector organs, which are muscles and glands.
   a. The somatic nervous system consists of somatic motor nerve fibers that conduct impulses from the CNS to skeletal muscles and allow conscious (voluntary) control of motor activities.
   b. The autonomic nervous system (ANS) is an involuntary system consisting of visceral motor nerve fibers that regulate the activity of smooth muscle, cardiac muscle, and glands.

11.2 Neuroglia support and maintain neurons (pp. 391–392; Fig. 11.4; Table 11.1)

A. Neuroglia, or glial cells, are closely associated with neurons, providing a protective and supportive network. (pp. 391–392; Fig. 11.4)

1. Neuroglia of the CNS include:
   a. Astrocytes regulate the chemical environment around neurons and exchange between neurons and capillaries.
   b. Microglial cells monitor health and perform defense functions for neurons.
   c. Ependymal cells line the central cavities of the brain and spinal cord and help circulate cerebrospinal fluid.
   d. Oligodendrocytes wrap around neuron fibers, forming myelin sheaths.
2. Neuroglia in the PNS include:
   a. Satellite cells are glial cells of the PNS whose function is largely unknown. They are found surrounding neuron cell bodies within ganglia.

b. Schwann cells, or neurolemmocytes, are glial cells of the PNS that surround nerve fibers, forming the myelin sheath.

11.3 Neurons are the structural units of the nervous system (pp. 392–397; Figs. 11.5–11.6; Table 11.1)

A. Neurons are specialized cells that conduct messages in the form of electrical impulses throughout the body. (pp. 392–397; Figs. 11.5–11.6; Table 11.1)

1. Neurons function optimally for a lifetime, are mostly amitotic, and have an exceptionally high metabolic rate requiring oxygen and glucose.
2. The neuron cell body, also called the perikaryon or soma, is the major biosynthetic center containing the usual organelles except for centrioles.
3. Neurons have arm-like processes that extend from the cell body.
    a. Dendrites are cell processes that are the receptive regions of the cell and provide surface area for receiving signals from other neurons.
    b. Each neuron has a single axon, the conducting region of the cell, that arises from the axon hillock and generates and transmits nerve impulses away from the cell body to the axon terminals.
        i. Axon terminals, the secretory region of the cell, release neurotransmitters that either excite or inhibit other neurons or effector cells.
        ii. Axons may have a myelin sheath, a whitish, fatty, segmented covering that protects, insulates, and increases conduction velocity of axons.
        iii. Myelin sheaths in the PNS are formed by Schwann cells that wrap themselves around the axon, forming discrete areas separated by myelin sheath gaps, called nodes of Ranvier.
        iv. Myelin sheaths in the CNS are formed by oligodendrocytes that have processes that wrap around the axon.
        v. Axons within the CNS that have myelin sheaths are called white matter, while those without are called gray matter.
4. There are three structural classes of neurons.
    a. Multipolar neurons, the most common type of neuron, have three or more processes.
    b. Bipolar neurons have a single axon and dendrite, and are located within the retina of the eye, and olfactory mucosa.
    c. Unipolar neurons have a single process extending from the cell body that is associated with sensory receptors at the distal end.
5. There are three functional classes of neurons.
    a. Sensory, or afferent, neurons conduct impulses toward the CNS from receptors.
    b. Motor, or efferent, neurons conduct impulses from the CNS to effectors.
    c. Interneurons, or association neurons, conduct impulses between sensory and motor neurons, or in CNS integration pathways.

11.4 The resting membrane potential depends on differences in ion concentration and permeability (pp. 398–401; Figs. 11.9–11.9; Focus Figure 11.1)

A. Basic Principles of Electricity (p. 398; Fig. 11.7)

1. Voltage is a measure of the amount of difference in electrical charge between two points, called the potential difference.

2. The flow of electrical charge from point to point is called current, and is dependent on voltage and resistance (hindrance to current flow).
3. In the body, electrical currents are due to the movement of ions across cellular membranes.
4. Gated ion channels, each of which is selective to a certain type of ion, play an important role in membrane potentials.
   a. Chemically gated (ligand-gated) channels open when the appropriate chemical binds.
   b. Voltage-gated channels open in response to a change in membrane potential.
   c. Mechanically gated channels open when a membrane receptor is physically deformed.
5. When ion channels are open, ions diffuse across the membrane along their electrochemical gradients, creating electrical currents.

B. Generating the Resting Membrane Potential (pp. 398–401; Focus Figure 11.1; Figs. 11.8–11.9)
1. The membrane of a resting neuron is polarized, and the potential difference of this polarity (approximately −70 mV) is called the resting membrane potential. The resting membrane potential exists only across the membrane and is mostly due to two factors: differences in ionic makeup of intracellular and extracellular fluids, and differential membrane permeability to those ions.
   a. The cytosol has a lower concentration of Na^+ and higher concentration of K^+ than extracellular fluid.
   b. Anionic proteins balance the cations inside the cell, while chloride ions mostly balance cations outside the cell.
   c. Potassium ions (K^+) play the most important role in generating a resting membrane potential, since the membrane is roughly 25 times more permeable to K^+ than Na^+.

C. Changing the resting membrane potential (p. 401)
1. Neurons use changes in membrane potential as communication signals and can be brought on by changes in membrane permeability to any ion, or alteration of ion concentrations on the two sides of the membrane.
2. Changes in membrane potential can produce either graded potentials, usually incoming signals that travel short distances, or action potentials, long-distance signals on axons.
3. Relative to the resting state, potential changes can be depolarizations, in which the inside of the membrane becomes less negative, or hyperpolarizations, in which the inside of the membrane becomes more negatively charged.

11.5 Graded potentials are brief, short-distance signals within a neuron (pp. 401-402; Fig. 11.10; Table 11.2)

A. Graded potentials are short-lived local changes in membrane potentials, can either be depolarizations or hyperpolarizations, and are critical to the generation of action potentials. (pp. 401-402; Fig. 11.10; Table 11.2)
1. Graded potentials occurring on receptors of sensory neurons are called receptor potentials, or generator potentials.
2. Graded potentials occurring in response to a neurotransmitter released from another neuron are called postsynaptic potentials.

11.6 Action potentials are brief, long-distance signals within a neuron (pp. 402–409; Figs. 11.11–11.14; Focus Figure 11.2; Table 11.2)

A. Generation of an Action Potential. (pp. 402–403; Focus Figure 11.2; Fig. 11.11)
   1. At rest, all gated Na^+ and K^+ channels are closed.
   2. Local currents depolarize the axon, and voltage-gated Na^+ channels open, allowing Na^+ ions to enter the cell. As the depolarization reaches threshold, this behavior becomes self-generating.
   3. Repolarization, which restores resting membrane potential, occurs as Na^+ channels inactivate, and K^+ channels open.
   4. Hyperpolarization occurs when some K^+ channels remain open, allowing excessive efflux of K^+ produces a slight dip following the spike.

B. A critical minimum, or threshold, depolarization is defined by the amount of influx of Na^+ that at least equals the amount of efflux of K^+. (pp. 403–404)

C. Action potentials are all-or-none phenomena: they either happen completely, in the case of a threshold stimulus, or not at all, in the event of a subthreshold stimulus. (p. 406; Table 11.2)

D. Higher-stimulus intensity is coded in the increased frequency of action potentials, not greater magnitude of an action potential. (p. 407; Fig. 11.12)

E. The refractory period of an axon is related to the period of time required so that a neuron can generate another action potential. (p. 407; Fig. 11.13)
   1. During the absolute refractory period, extending from the opening of the Na^+ channels to their closing, the cell cannot respond to another stimulus, regardless of how strong.
   2. During the relative refractory period, the Na^+ channels are mostly reset, the cell is repolarizing, and an exceptionally strong stimulus may reopen Na^+ channels and generate another action potential

11.7 Synapses transmit signals between neurons (pp. 409–413; Figs. 11.15–11.16; Focus Figure 11.3; Table 11.2)

A. A synapse is a junction that mediates information transfer between neurons or between a neuron and an effector cell. (p. 407; Fig.11.15)

B. Chemical synapses, the most common type of synapse, are specialized for release and
reception of chemical neurotransmitters, and have two parts: (pp. 407–410; Figs. 11.16–11.17).
   1. Axon terminals from presynaptic neurons have numerous synaptic vesicles that store and secrete neurotransmitters.
   2. A neurotransmitter receptor region on the postsynaptic neuron's membrane, usually located on a dendrite or the cell body.

C. Steps in information transfer across chemical synapses (pp. 410–412; Focus Figure 11.3)
   1. An action potential arrives at the axon terminal.
   2. Voltage-gated Ca^{2+} channels open and Ca^{2+} enters the axon terminal.
   3. Ca^{2+} entry causes synaptic vesicles to release neurotransmitter by exocytosis.
   4. Neurotransmitter diffuses across the synaptic cleft and binds to specific receptors on the postsynaptic membrane.
   5. Binding of neurotransmitter opens ion channels, creating graded potentials.

6. Neurotransmitter effects are terminated.

D. Electrical synapses have neurons that are electrically coupled via protein channels and allow direct exchange of ions from cell to cell. (p. 407)

11.8 Postsynaptic potentials excite or inhibit the receiving neuron (pp. 414–417; Figs. 11.17–11.18)

A. Excitatory Synapses and EPSPs (p. 414; Figs. 11.17–11.18; Table 11.2)

1. At excitatory synapses, neurotransmitters bind to chemically gated ion channels, causing depolarization of the membrane, and generation of excitatory postsynaptic potentials (EPSPs), that can trigger action potentials at the axon hillock if they are of adequate strength.

B. Inhibitory Synapses and IPSPs (p. 414; Figs. 11.17–11.18; Table 11.2)

1. At inhibitory synapses, neurotransmitters hyperpolarize the membrane, by making it more permeable to K^+ or Cl^-, moving membrane potential away from threshold, and making generation of an action potential less likely.

C. Integration and Modification of Synaptic Events (p. 415–417)

1. Summation by the postsynaptic neuron is accomplished in two ways: temporal summation, which occurs in response to several successive releases of neurotransmitter, and spatial summation, which occurs when the postsynaptic cell is stimulated at the same time by multiple terminals.
2. Synaptic potentiation results when a presynaptic cell is stimulated repeatedly or continuously, resulting in an enhanced release of neurotransmitter.
3. Presynaptic inhibition results when another neuron inhibits the release of an excitatory neurotransmitter from a presynaptic cell.

11.9 The effect of a neurotransmitter depends on its receptor (pp. 417–422; Figs. 11.19–11.20; Table 11.3)

A. Neurotransmitters fall into several chemical classes: acetylcholine, the biogenic amines, amino acid derived, peptides, purines, and gases and lipids. (For a more complete listing of neurotransmitters within a given chemical class, refer to pp. 419–420; Table 11.3.)

B. Functional classifications of neurotransmitters consider whether the effects are excitatory or inhibitory and whether the effects are direct or indirect, including neuromodulators that affect the strength of synaptic transmission. (pp. 419–420; Table 11.3)

C. There are two main types of neurotransmitter receptors: Channel-linked receptors mediate fast synaptic transmission and result in brief, localized changes, and G protein–linked receptors mediate indirect transmitter action resulting in slow synaptic responses. (pp. 421–422; Figs. 11.19–11.20)

11.10 Neurons act together, making complex behaviors possible (pp. 423-424; Figs. 11.21–11.23)

A. Organization of Neurons: Neuronal Pools (p. 423; Fig. 11.21)

1. Neuronal pools are functional groups of neurons that integrate incoming information from receptors or other neuronal pools and relay the information to other areas.

B. Patterns of Neural Processing (pp. 423–424; Fig. 11.22)

1. Serial processing is exemplified by spinal reflexes and involves sequential stimulation of the neurons in a circuit.
2. Parallel processing results in inputs stimulating many pathways simultaneously and is vital to higher-level mental functioning.

C. Types of Circuits (p. 424; Fig. 11.23)

1. The patterns of synaptic connections in neuronal pools, called circuits, determine the pool's functional capabilities.

Developmental Aspects of Neurons (pp. 424–425; Fig. 11.24)

A. The nervous system originates from a dorsal neural tube and neural crest, which begin as a layer of neuroepithelial cells that ultimately become the CNS. (p. 425)

B. Differentiation of neuroepithelial cells occurs largely in the second month of development. (p. 425)

C. Growth of an axon toward its target appears to be guided by older "pathfinding" neurons and glial cells, nerve growth factor and cholesterol from astrocytes, and tropic chemicals from target cells. (p. 425)

D. The growth cone, or growing tip, of an axon takes up chemicals from the environment that are used by the cell to evaluate the pathway taken for further growth and synapse formation. (p. 425; Fig. 11.24)

E. Unsuccessful synapse formation results in cell death, and many neurons are lost through apoptosis before the final population of neurons is complete. (p. 425)