Nervous System

- The master controlling and communicating system of the body
- Functions:
  - Sensory input – monitoring stimuli occurring inside and outs1ide the body

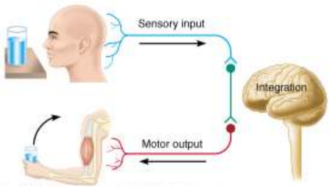


Figure 11.1

Nervous System

- Integration – interpretation of sensory input
- Motor output – response to stimuli by activating effector organs

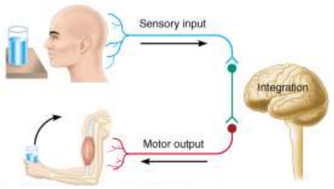


Figure 11.1

Organization of the Nervous System

- Central nervous system (CNS)
  - Brain and spinal cord
  - Integration and command center
- Peripheral nervous system (PNS)
  - Paired spinal and cranial nerves
  - Carries messages to and from the spinal cord and brain

Peripheral Nervous System (PNS): Two Functional Divisions

- Sensory (afferent) division
  - Sensory afferent fibers – carry impulses from skin, skeletal muscles, and joints to the brain
  - Visceral afferent fibers – transmit impulses from visceral organs to the brain
- Motor (efferent) division
  - Transmits impulses from the CNS to effector organs

Motor Division: Two Main Parts

- Somatic nervous system
  - Conscious control of skeletal muscles
- Autonomic nervous system (ANS)
  - Regulate smooth muscle, cardiac muscle, and glands
  - Divisions – sympathetic and parasympathetic

Histology of Nerve Tissue

- The two principal cell types of the nervous system are:
  - Neurons – excitable cells that transmit electrical signals
  - Supporting cells – cells that surround and wrap neurons

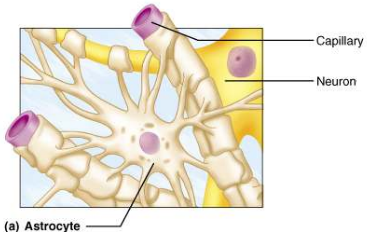
Supporting Cells: Neuroglia

- The supporting cells (neuroglia or glia):
  - Provide a supportive scaffolding for neurons
  - Segregate and insulate neurons
  - Guide young neurons to the proper connections
  - Promote health and growth

Astrocytes

- Most abundant, versatile, and highly branched glial cells
- They cling to neurons and cover capillaries
- Functionally, they:
  - Support and brace neurons
  - Anchor neurons to their nutrient supplies
  - Guide migration of young neurons
  - Control the chemical environment

Astrocytes



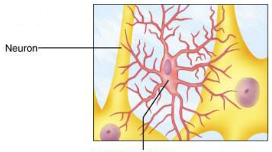
(a) Astrocyte

Figure 11.3a

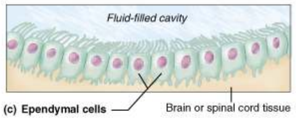
Microglia and Ependymal Cells

- Microglia – small, ovoid cells with spiny processes
  - Phagocytes that monitor the health of neurons
- Ependymal cells – squamous- to columnar-shaped cells
  - They line the central cavities of the brain and spinal column

Microglia and Ependymal Cells



(b) Microglial cell



(c) Ependymal cells

Figure 11.3b, c

Oligodendrocytes, Schwann Cells, and Satellite Cells

- Oligodendrocytes – branched cells that wrap CNS nerve fibers
- Schwann cells (neurolemmocytes) – surround fibers of the PNS
- Satellite cells surround neuron cell bodies with ganglia

Oligodendrocytes, Schwann Cells, and Satellite Cells

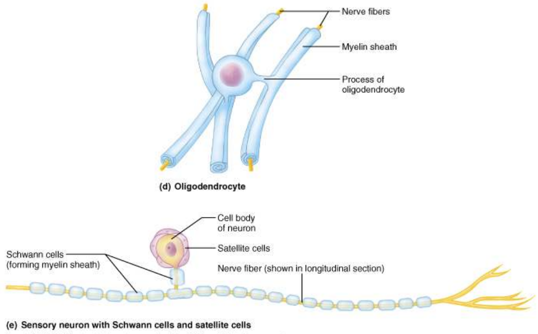


Figure 11.3d, e

Neurons (Nerve Cells)

- Structural units of the nervous system
  - Composed of a body, axon, and dendrites
  - Long-lived, amitotic, and have a high metabolic rate
- Their plasma membrane functions in:
  - Electrical signaling
  - Cell-to-cell signaling during development

Neurons (Nerve Cells)

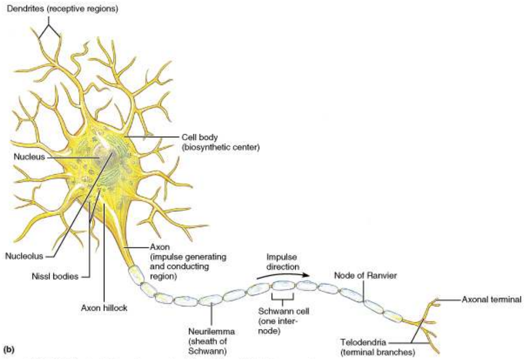


Figure 11.4b

Nerve Cell Body (Perikaryon or Soma)

- Contains the nucleus and a nucleolus
- Major biosynthetic center
- Focal point for the outgrowth of neuronal processes
- There are no centrioles (hence its amitotic nature)
- Well-developed Nissl bodies (rough ER)
- Axon hillock – cone-shaped area from which axons arise

Processes

- Armlike extensions from the soma
- Called tracts in the CNS and nerves in the PNS
- There are two types: axons and dendrites

Dendrites of Motor Neurons

- Short, tapering, and diffusely branched processes
- They are the receptive, or input, regions of the neuron
- Electrical signals are conveyed as graded potentials (not action potentials)

Axons: Structure

- Slender processes of uniform diameter arising from the hillock
- Long axons are called nerve fibers
- Usually there is only one unbranched axon per neuron
- Rare branches, if present, are called *axon collaterals*
- Axonal terminal – branched terminus of an axon

Axons: Function

- Generate and transmit action potentials
- Secrete neurotransmitters from the axonal terminals

Myelin Sheath

- Whitish, fatty (protein-lipid), segmented sheath around most long axons
- It functions in:
  - Protection of the axon
  - Electrically insulating fibers from one another
  - Increasing the speed of nerve impulse transmission

Myelin Sheath and Neurilemma: Formation

- Formed by Schwann cells in the PNS
- A Schwann cell:
  - Envelopes an axon in a trough
  - Encloses the axon with its plasma membrane
  - Concentric layers of membrane make up the myelin sheath
- Neurilemma – remaining nucleus and cytoplasm of a Schwann cell

Myelin Sheath and Neurilemma: Formation

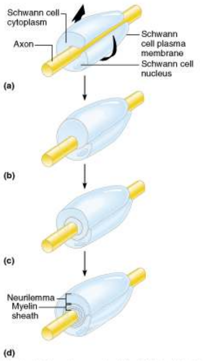


Figure 11.5a-d

Nodes of Ranvier (Neurofibral Nodes)

- Gaps in the myelin sheath between adjacent Schwann cells
- They are the sites where collaterals can emerge

Unmyelinated Axons

- A Schwann cell surrounds nerve fibers but coiling does not take place
- Schwann cells partially enclose 15 or more axons

Axons of the CNS

- Both myelinated and unmyelinated fibers are present
- Myelin sheaths are formed by oligodendrocytes
- Nodes of Ranvier are widely spaced
- There is no neurilemma

Regions of the Brain and Spinal Cord

- White matter – dense collections of myelinated fibers
- Gray matter – mostly soma and unmyelinated fibers

Neuron Classification

- Structural:
  - Multipolar
  - Bipolar
  - Unipolar
- Functional:
  - Sensory (afferent)
  - Motor (efferent)
  - Interneurons (association neurons)

Comparison of Structural Classes of Neurons

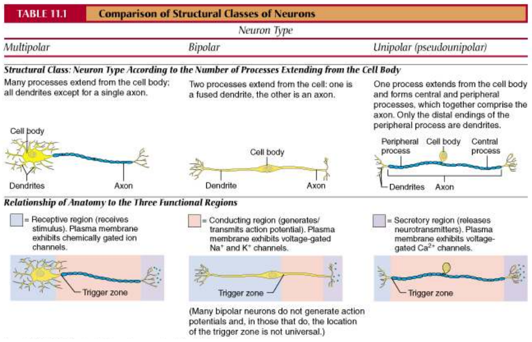


TABLE 11.1 **Comparison of Structural Classes of Neurons**

	Neuron Type	
Multipolar	*Bipolar*	*Unipolar (pseudounipolar)*
Structural Class: Neuron Type According to the Number of Processes Extending from the Cell Body		
Many processes extend from the cell body; all dendrites except for a single axon.	Two processes extend from the cell: one is a fused dendrite, the other is an axon.	One process extends from the cell body and forms central and peripheral processes, which together comprise the axon. Only the distal endings of the peripheral process are dendrites.
Relationship of Anatomy to the Three Functional Regions		
▨ = Receptive region (receives stimulus). Plasma membrane exhibits chemically gated ion channels.	▨ = Conducting region (generates/transmits action potential). Plasma membrane exhibits voltage-gated Na^+ and K^+ channels.	▨ = Secretory region (releases neurotransmitters). Plasma membrane exhibits voltage-gated Ca^{2+} channels.
	(Many bipolar neurons do not generate action potentials and, in those that do, the location of the trigger zone is not universal.)	

Table 11.1

Comparison of Structural Classes of Neurons

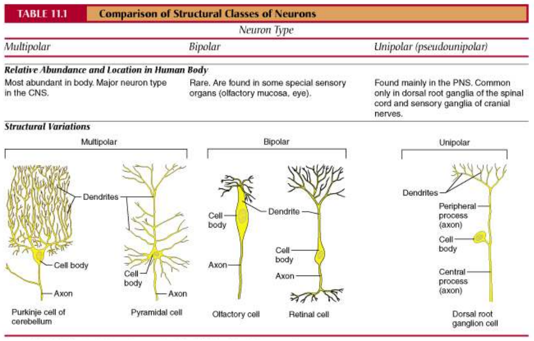


TABLE 11.1 **Comparison of Structural Classes of Neurons**

	Neuron Type	
Multipolar	*Bipolar*	*Unipolar (pseudounipolar)*
Relative Abundance and Location in Human Body		
Most abundant in body. Major neuron type in the CNS.	Rare. Are found in some special sensory organs (olfactory mucosa, eye).	Found mainly in the PNS. Common only in dorsal root ganglia of the spinal cord and sensory ganglia of cranial nerves.
Structural Variations		

Table 11.2

Comparison of Structural Classes of Neurons

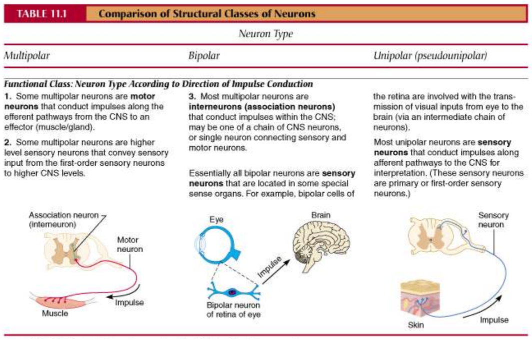


TABLE 11.1 **Comparison of Structural Classes of Neurons**

Neuron Type		
Multipolar	*Bipolar*	*Unipolar (pseudounipolar)*
Functional Class: Neuron Type According to Direction of Impulse Conduction		
1. Some multipolar neurons are **motor neurons** that conduct impulses along the efferent pathways from the CNS to an effector (muscle/gland). **2.** Some multipolar neurons are higher level sensory neurons that convey sensory input from the first-order sensory neurons to higher CNS levels.	**3.** Most multipolar neurons are **interneurons (association neurons)** that conduct impulses within the CNS; may be one of a chain of CNS neurons, or single neuron connecting sensory and motor neurons. Essentially all bipolar neurons are **sensory neurons** that are located in some special sense organs. For example, bipolar cells of the retina are involved with the transmission of visual inputs from eye to the brain (via an intermediate chain of neurons).	Most unipolar neurons are **sensory neurons** that conduct impulses along afferent pathways to the CNS for interpretation. (These sensory neurons are primary or first-order sensory neurons.)

Table 11.1.3

Neurophysiology

- Neurons are highly irritable
- Action potentials, or nerve impulses, are:
  - Electrical impulses carried along the length of axons
  - Always the same regardless of stimulus
  - The underlying functional feature of the nervous system

Electrical Definitions

- Voltage – measure (mV) of potential energy generated by separated charge
- Potential difference – voltage measured between two points
- Current (I) – the flow of electrical charge between two points
- Resistance (R) – hindrance to charge flow
- Insulator – substance with high electrical resistance
- Conductor – substance with low electrical resistance

Electrical Current and the Body

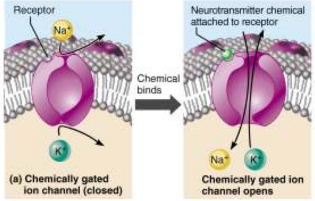
- Reflects the flow of ions rather than electrons
- There is a potential on either side of membranes when:
  - The number of ions is different across the membrane
  - The membrane provides a resistance to ion flow

Role of Ion Channels

- Types of plasma membrane ion channels:
  - Passive, or leakage, channels – always open
  - Chemically gated channels – open with binding of a specific neurotransmitter
  - Voltage-gated channels – open and close in response to membrane potential

Operation of a Gated Channel

- Example: Na^+-K^+ gated channel
- Closed when a neurotransmitter is not bound to the extracellular receptor
  - Na^+ cannot enter the cell and K^+ cannot exit the cell



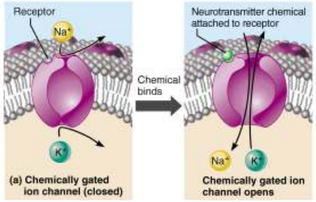
(a) Chemically gated ion channel (closed)

Chemically gated ion channel opens

Figure 11.6a

Operation of a Gated Channel

- Open when a neurotransmitter is attached to the receptor
  - Na^+ enters the cell and K^+ exits the cell



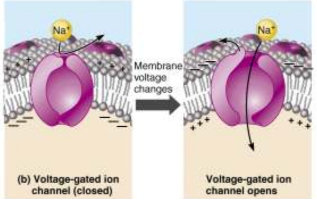
(a) Chemically gated ion channel (closed)

Chemically gated ion channel opens

Figure 11.6a

Operation of a Voltage-Gated Channel

- Example: Na^+ channel
- Closed when the intracellular environment is negative
  - Na^+ cannot enter the cell



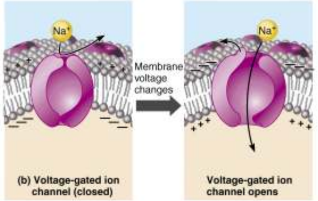
(b) Voltage-gated ion channel (closed)

Voltage-gated ion channel opens

Figure 11.6b

Operation of a Voltage-Gated Channel

- Open when the intracellular environment is positive
  - Na^+ can enter the cell



(b) Voltage-gated ion channel (closed)

Voltage-gated ion channel opens

Figure 11.6b

Gated Channels

- When gated channels are open:
  - Ions move quickly across the membrane
  - Movement is along their electrochemical gradients
  - An electrical current is created
  - Voltage changes across the membrane

Electrochemical Gradient

- Ions flow along their chemical gradient when they move from an area of high concentration to an area of low concentration
- Ions flow along their electrical gradient when they move toward an area of opposite charge
- Electrochemical gradient – the electrical and chemical gradients taken together

Resting Membrane Potential (V_r)

- The potential difference (–70 mV) across the membrane of a resting neuron
- It is generated by different concentrations of Na^+, K^+, Cl^-, and protein anions (A^-)
- Ionic differences are the consequence of:
  - Differential permeability of the neurilemma to Na^+ and K^+
  - Operation of the sodium-potassium pump

Resting Membrane Potential (V_r)

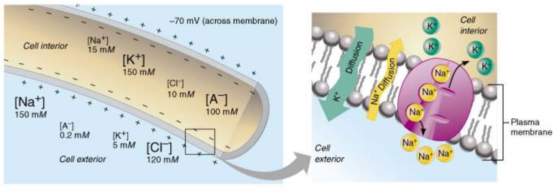


Figure .8

Membrane Potentials: Signals

- Used to integrate, send, and receive information
- Membrane potential changes are produced by:
  - Changes in membrane permeability to ions
  - Alterations of ion concentrations across the membrane
- Types of signals – graded potentials and action potentials

Changes in Membrane Potential

- Caused by three events:
  - Depolarization – the inside of the membrane becomes less negative
  - Repolarization – the membrane returns to its resting membrane potential
  - Hyperpolarization – the inside of the membrane becomes more negative than the resting potential

Changes in Membrane Potential

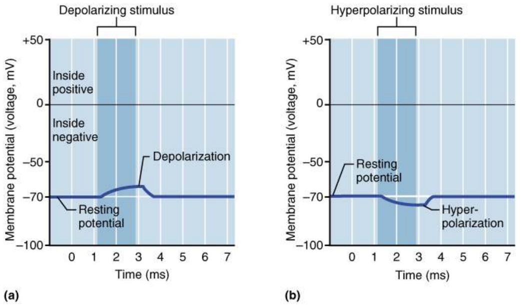


Figure .9

Graded Potentials

- Short-lived, local changes in membrane potential
- Decrease in intensity with distance
- Their magnitude varies directly with the strength of the stimulus
- Sufficiently strong graded potentials can initiate action potentials

Graded Potentials

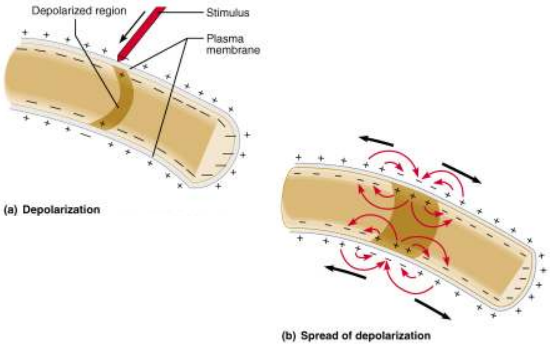


Figure 11.1 b

Graded Potentials

- Voltage changes in graded potentials are decremental
- Current is quickly dissipated due to the leaky plasma membrane
  - Can only travel over short distances

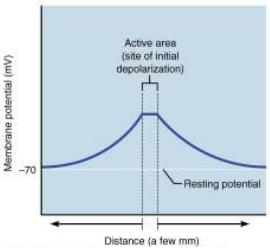


Figure 11.11

Action Potentials (APs)

- A brief reversal of membrane potential with a total amplitude of 100 mV
- Action potentials are only generated by muscle cells and neurons
- They do not decrease in strength over distance
- They are the principal means of neural communication
- An action potential in the axon of a neuron is a nerve impulse

Action Potential: Resting State

- Na^+ and K^+ channels are closed
- Leakage accounts for small movements of Na^+ and K^+
- Each Na^+ channel has two voltage-regulated gates
  - Activation gates – closed in the resting state
  - Inactivation gates – open in the resting state

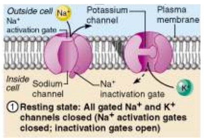


Figure 11.12, part 1

Action Potential: Depolarization Phase

- Na^+ permeability increases; membrane potential reverses
- Na^+ gates are opened; K^+ gates are closed
- Threshold – a critical level of depolarization (-55 to -50 mV)
- At threshold, depolarization becomes self generating

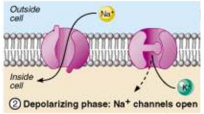


Figure 11.12, part 2

Action Potential: Repolarization Phase

- Sodium inactivation gates close
- Membrane permeability to Na^+ declines to resting levels
- As sodium gates close, voltage-sensitive K^+ gates open
- K^+ exits the cell and internal negativity of the resting neuron is restored

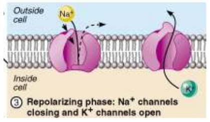


Figure 11.12, part 3

Action Potential: Undershoot

- Potassium gates remain open, causing an excessive efflux of K^+
- This efflux causes hyperpolarization of the membrane (undershoot)
- The neuron is insensitive to stimulus and depolarization during this time

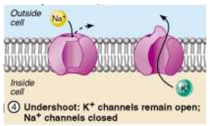
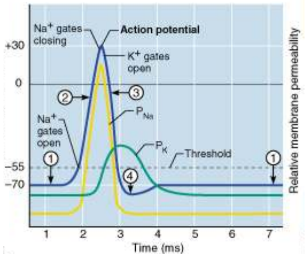


Figure 11.12, part 4

Phases of the Action Potential

- 1 – resting state
- 2 – depolarization phase
- 3 – repolarization phase
- 4 – undershoot



Action Potential: Role of the Sodium-Potassium Pump

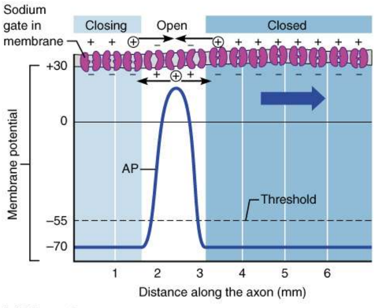
- Repolarization
  - Restores the resting electrical conditions of the neuron
  - Does not restore the resting ionic conditions
- Ionic redistribution back to resting conditions is restored by the sodium-potassium pump

---

Propagation of an Action Potential (Time = 0ms)

- Na^+ influx causes a patch of the axonal membrane to depolarize
- Positive ions in the axoplasm move toward the polarized (negative) portion of the membrane (bottom arrows in figure)
- Sodium gates are shown as closing, open, or closed

Propagation of an Action Potential (Time = 0ms)



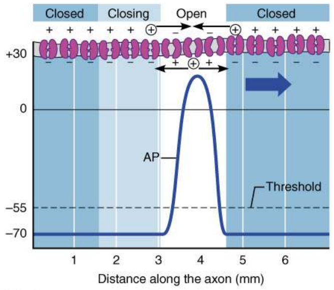
(a) Time = 0 ms

Figure 11.18a

Propagation of an Action Potential (Time = 1ms)

- Ions of the extracellular fluid move toward the area of greatest negative charge
- A current is created that depolarizes the adjacent membrane in a forward direction
- The impulse propagates away from its point of origin

Propagation of an Action Potential (Time = 1ms)



(b) Time = 1 ms

Figure 11.18b

Propagation of an Action Potential (Time = 2ms)

- The action potential moves away from the stimulus
- Where sodium gates are closing, potassium gates are open and create a current flow

Propagation of an Action Potential (Time = 2ms)

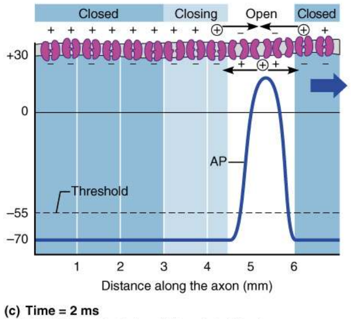


Figure 11.13c

Threshold and Action Potentials

- Threshold – membrane is depolarized by 15 to 20 mV
- Established by the total amount of current flowing through the membrane
- Weak (subthreshold) stimuli are not relayed into action potentials
- Strong (threshold) stimuli are relayed into action potentials
- All-or-none phenomenon – action potentials either happen completely, or not at all

Coding for Stimulus Intensity

- All action potentials are alike and are independent of stimulus intensity
- Strong stimuli can generate an action potential more often than weaker stimuli
- The CNS determines stimulus intensity by the frequency of impulse transmission

Coding for Stimulus Intensity

- Upward arrows – stimulus applied
- Downward arrows – stimulus stopped

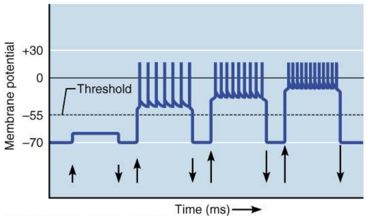


Figure 11.14

Coding for Stimulus Intensity

- Length of arrows – strength of stimulus
- Vertical lines – action potentials

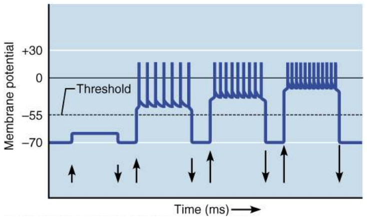


Figure 11.14

Absolute Refractory Period

- Time from the opening of the Na^+ activation gates until the closing of inactivation gates
- The absolute refractory period:
  - Prevents the neuron from generating an action potential
  - Ensures that each action potential is separate
  - Enforces one-way transmission of nerve impulses

Absolute Refractory Period

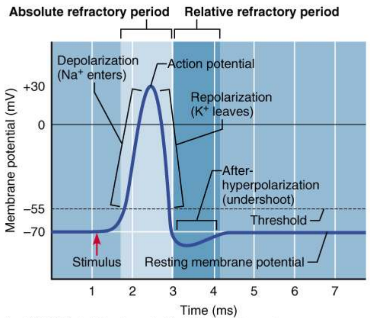


Figure 11.15

Relative Refractory Period

- The interval following the absolute refractory period when:
  - Sodium gates are closed
  - Potassium gates are open
  - Repolarization is occurring
- The threshold level is elevated, allowing strong stimuli to increase the frequency of action potential events

Conduction Velocities of Axons

- Conduction velocities vary widely among neurons
- Rate of impulse propagation is determined by:
  - Axon diameter – the larger the diameter, the faster the impulse
  - Presence of a myelin sheath – myelination dramatically increases impulse speed

Saltatory Conduction

- Current passes through a myelinated axon only at the nodes of Ranvier
- Voltage-regulated Na^+ channels are concentrated at these nodes
- Action potentials are triggered only at the nodes and jump from one node to the next
- Much faster than conduction along unmyelinated axons

Saltatory Conduction

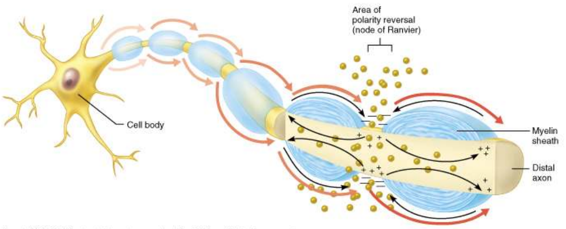


Figure 11.16

Multiple Sclerosis (MS)

- An autoimmune disease that mainly affects young adults
- Symptoms include visual disturbances, weakness, loss of muscular control, and urinary incontinence
- Nerve fibers are severed and myelin sheaths in the CNS become nonfunctional scleroses
- Shunting and short-circuiting of nerve impulses occurs
- Treatments include injections of methylprednisolone and beta interferon

---

Nerve Fiber Classification

- Nerve fibers are classified according to:
  - Diameter
  - Degree of myelination
  - Speed of conduction

Synapses

- A junction that mediates information transfer from one neuron:
  - To another neuron
  - To an effector cell
- Presynaptic neuron – conducts impulses toward the synapse
- Postsynaptic neuron – transmits impulses away from the synapse

---

Synapses

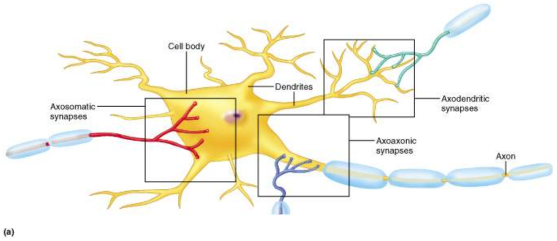


Figure 11.17

Electrical Synapses

- Electrical synapses:
  - Are less common than chemical synapses
  - Correspond to gap junctions found in other cell types
  - Contain intercellular protein channels
  - Permit ion flow from one neuron to the next
  - Are found in the brain and are abundant in embryonic tissue

---

Chemical Synapses

- Specialized for the release and reception of neurotransmitters
- Typically composed of two parts:
  - Axonal terminal of the presynaptic neuron, which contains synaptic vesicles
  - Receptor region on the dendrite(s) or soma of the postsynaptic neuron

Synaptic Cleft

- Fluid-filled space separating the presynaptic and postsynaptic neurons
- Prevents nerve impulses from *directly* passing from one neuron to the next
- Transmission across the synaptic cleft:
  - Is a chemical event (as opposed to an electrical one)
  - Ensures unidirectional communication between neurons

Synaptic Cleft: Information Transfer

- Nerve impulse reaches axonal terminal of the presynaptic neuron
- Neurotransmitter is released into the synaptic cleft
- Neurotransmitter crosses the synaptic cleft and binds to receptors on the postsynaptic neuron
- Postsynaptic membrane permeability changes, causing an excitatory or inhibitory effect

Synaptic Cleft: Information Transfer

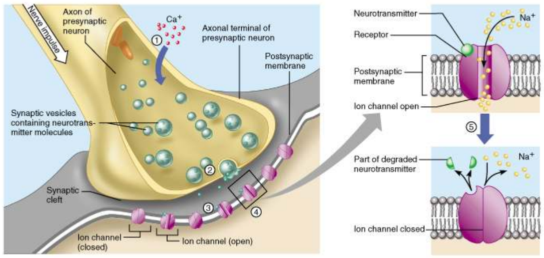


Figure 11.18

Termination of Neurotransmitter Effects

- Neurotransmitter bound to a postsynaptic neuron:
  - Produces a continuous postsynaptic effect
  - Blocks reception of additional “messages”
  - Must be removed from its receptor
- Removal of neurotransmitters occurs when they:
  - Are degraded by enzymes
  - Are reabsorbed by astrocytes or the presynaptic terminals
  - Diffuse from the synaptic cleft

Synaptic Delay

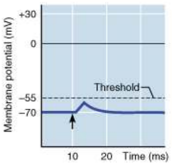
- Neurotransmitter must be released, diffuse across the synapse, and bind to receptor
- Synaptic delay – time needed to do this (0.3-5.0 ms)
- Synaptic delay is the rate-limiting step of neural transmission

Postsynaptic Potentials

- Neurotransmitter receptors mediate changes in membrane potential according to:
  - The amount of neurotransmitter released
  - The amount of time the neurotransmitter is bound to receptor
- The two types of postsynaptic potentials are:
  - EPSP – excitatory postsynaptic potentials
  - IPSP – inhibitory postsynaptic potentials

Excitatory Postsynaptic Potentials

- EPSPs are graded potentials that can initiate an action potential in an axon
  - Use only chemically gated channels
  - Na^+ and K^+ flow in opposite directions at the same time
- Postsynaptic membranes do *not* generate action potentials

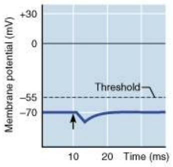


(a) Excitatory postsynaptic potential (EPSP)

Figure 11.19a

Inhibitory Synapses and IPSPs

- Neurotransmitter binding to a receptor at inhibitory synapses:
  - Causes the membrane to become more permeable to potassium and chloride ions
  - Leaves the charge on the inner surface negative
  - Reduces the postsynaptic neuron's ability to produce an action potential



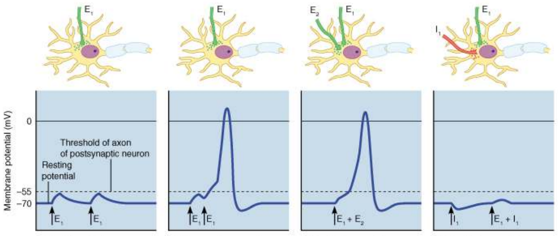
(b) Inhibitory postsynaptic potential (IPSP)

Figure 11.19b

Summation

- A single EPSP cannot induce an action potential
- EPSPs must summate temporally or spatially to induce an action potential
- Temporal summation – presynaptic neurons transmit impulses in rapid-fire order
- Spatial summation – postsynaptic neuron is stimulated by a large number of terminals at the same time
- IPSPs can also summate with EPSPs, canceling each other out

Summation



(a) Subthreshold, no summation
(b) Temporal summation
(c) Spatial summation
(d) Spatial summation of EPSP and IPSP

Figure 11.20

Neurotransmitters

- Chemicals used for neuronal communication with the body and the brain
- 50 different neurotransmitters have been identified
- Classified chemically and functionally

Chemical Neurotransmitters

- Acetylcholine (ACh)
- Biogenic amines
- Amino acids
- Peptides
- Novel messengers

Neurotransmitters: Acetylcholine

- First neurotransmitter identified, and best understood
- Released at the neuromuscular junction
- Synthesized and enclosed in synaptic vesicles
- Degraded by the enzyme acetylcholinesterase (AChE)
- Released by:
  - All neurons that stimulate skeletal muscle
  - Some neurons in the autonomic nervous system

Neurotransmitters: Biogenic Amines

- Include:
  - Catecholamines – dopamine, norepinephrine (NE), and epinephrine
  - Indolamines – serotonin and histamine
- Broadly distributed in the brain
- Play roles in emotional behaviors and our biological clock

Synthesis of Catecholamines

- Enzymes present in the cell determine length of biosynthetic pathway
- Norepinephrine and dopamine are synthesized in axonal terminals
- Epinephrine is released by the adrenal medulla

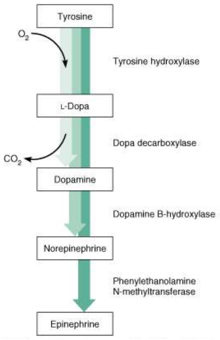


Figure 11.21

Neurotransmitters: Amino Acids

- Include:
  - GABA – Gamma (γ)-aminobutyric acid
  - Glycine
  - Aspartate
  - Glutamate
- Found only in the CNS

Neurotransmitters: Peptides

- Include:
  - Substance P – mediator of pain signals
  - Beta endorphin, dynorphin, and enkephalins
- Act as natural opiates, reducing our perception of pain
- Bind to the same receptors as opiates and morphine
- Gut-brain peptides – somatostatin, vasoactive intestinal peptide (VIP), and cholecystokinin

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Novel Messengers

- ATP
  - Found in both the CNS and PNS
  - Produces fast excitatory responses
- Nitric oxide (NO)
  - Activates the intracellular receptor guanylyl cyclase
  - Is involved in learning and memory
- Carbon monoxide (CO) is a main regulator of cyclic GMP in the brain

Functional Classification of Neurotransmitters

- Two classifications: excitatory and inhibitory
  - Excitatory neurotransmitters cause depolarizations (e.g., glutamate)
  - Inhibitory neurotransmitters cause hyperpolarizations (e.g., GABA and glycine)
- Some neurotransmitters have both excitatory and inhibitory effects
  - Determined by the receptor type of the postsynaptic neuron
  - Example: aceytylcholine
    - Excitatory at neuromuscular junctions
    - Inhibitory with cardiac muscle

Neurotransmitter Receptor Mechanisms

- Direct: neurotransmitters that open ion channels
  - Promote rapid responses
  - Examples: ACh and amino acids
- Indirect: neurotransmitters that act through second messengers
  - Promote long-lasting effects
  - Examples: biogenic amines and peptides

Channel-Linked Receptors

- Composed of integral membrane protein
- Mediate direct neurotransmitter action
- Action is immediate, brief, simple, and highly localized
- Ligand binds the receptor, and ions enter the cells
- Excitatory receptors depolarize membranes
- Inhibitory receptors hyperpolarize membranes

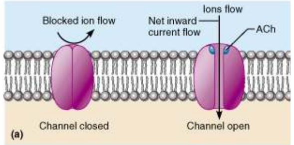

Figure 11.22a

G Protein-Linked Receptors

- Responses are indirect, slow, complex, prolonged, and often diffuse
- These receptors are transmembrane protein complexes
- Examples: muscarinic ACh receptors, neuropeptides, and those that bind biogenic amines

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G Protein-Linked Receptors: Mechanism

- Neurotransmitter binds to G protein-linked receptor
- G protein is activated and GTP is hydrolyzed to GDP
- The activated G protein complex activates adenylate cyclase
- Adenylate cyclase catalyzes the formation of cyclic AMP from ATP
- Cyclic AMP, a second messenger, brings about various cellular responses

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G Protein-Linked Receptors: Mechanism

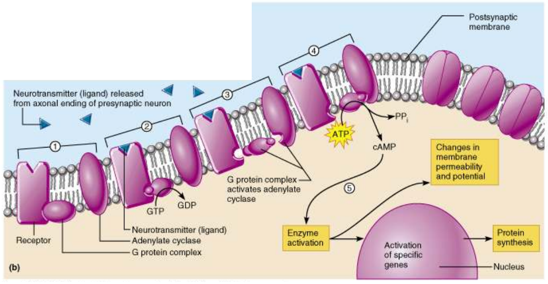

Figure 11

G Protein-Linked Receptors: Effects

- G protein-linked receptors activate intracellular second messengers including Ca^{2+}, cyclic GMP, diacylglycerol, as well as cyclic AMP
- Second messengers:
  - Open or close ion channels
  - Activate kinase enzymes
  - Phosphorylate channel proteins
  - Activate genes and induce protein synthesis

Neural Integration: Neuronal Pools

- Functional groups of neurons that:
  - Integrate incoming information
  - Forward the processed information to its appropriate destination

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Neural Integration: Neuronal Pools

- Simple neuronal pool
  - Input fiber – presynaptic fiber
  - Discharge zone – neurons most closely associated with the incoming fiber
  - Facilitated zone – neurons farther away from incoming fiber

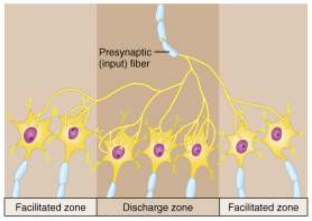
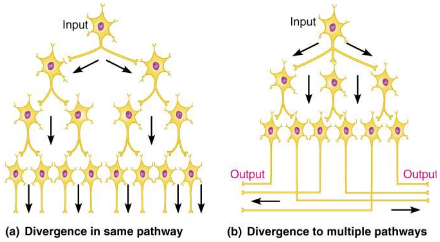


Figure 11.23

Types of Circuits in Neuronal Pools

- Divergent – one incoming fiber stimulates ever-increasing number of fibers, often amplifying circuits

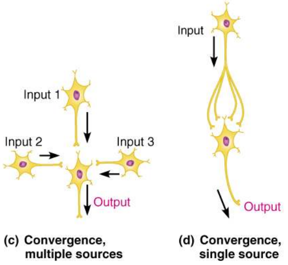


(a) Divergence in same pathway **(b) Divergence to multiple pathways**

Figure 11.24a, b

Types of Circuits in Neuronal Pools

- Convergent – opposite of divergent circuits, resulting in either strong stimulation or inhibition

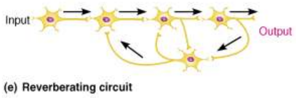


(c) Convergence, multiple sources **(d) Convergence, single source**

Figure 11.24c, d

Types of Circuits in Neuronal Pools

- Reverberating – chain of neurons containing collateral synapses with previous neurons in the chain

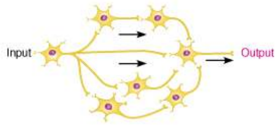


(e) Reverberating circuit

Figure 11.24e

Types of Circuits in Neuronal Pools

- Parallel after-discharge – incoming neurons stimulate several neurons in parallel arrays



(f) Parallel after-discharge circuit

Figure 1

Patterns of Neural Processing

- Serial Processing
  - Input travels along one pathway to a specific destination
  - Works in an all-or-none manner
  - Example: spinal reflexes

Patterns of Neural Processing

- Parallel Processing
  - Input travels along several pathways
  - Pathways are integrated in different CNS systems
  - One stimulus promotes numerous responses
- Example: a smell may remind one of the odor *and* associated experiences