The Nervous System
-The master controlling and communicating system of the body

Functions:
- -Sensory input
- -Integration
- -Motor output

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 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 (SNS)
- -Conscious control of skeletal muscles

Autonomic nervous system (ANS)
- -Regulates smooth muscle, cardiac muscle, and glands
- -Divisions – sympathetic and parasympathetic

Histology of Nerve Tissue

There are two types of nerve cells:
- -Neurons – excitable cells that transmit electrical signals
- -Supporting cells – cells that surround and wrap neurons

<u>Neuroglia/Glial Cells</u>: Supporting Cells

-Segregate and insulate neurons
-Guide young neurons to the proper connections
-Promote health and growth

<u>Astrocytes</u>: Most abundant, versatile, and highly branched glial cells

-cling to neurons and their synaptic endings
-cover capillaries
-Functions:
-Support and brace neurons
-Anchor neurons to their nutrient supplies
-Guide migration of young neurons
-Control the chemical environment

<u>Microglia</u>: small, ovoid cells with spiny processes

-phagocytic
-monitor the health of neurons

<u>Ependymal cells</u>: range in shape from squamous to columnar

-line the central cavities of the brain and spinal column

<u>Oligodendrocytes</u>: branched cells that wrap CNS nerve fibers

<u>Schwann cells</u>(neurolemmocytes): surround fibers of the PNS

<u>Satellite cells:</u> surround neuron cell bodies with ganglia

^All of the above cell types are SUPPORTING CELLS

<u>Neurons</u>: (Nerve Cells)

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

Nerve Cell Body **(the Soma)**
-Contains nucleus and nucleolus
-Is the major biosynthetic center
-Is the focal point for the outgrowth of neuronal processes
-Has no centrioles (That's why it's amitotic!)
-Has well-developed rough ER
-Contains an axon hillock – cone-shaped area from which axons arise

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

Dendrites
-Short, tapering, and diffusely branched
-receptive/ input regions
-convey electrical signals as graded potentials (not action potentials)

Structure of Axons
-Slender processes of uniform diameter
-arise from the hillock
-Long axons are called nerve fibers
-Usu. only one unbranched axon per neuron
-Rare branches called *axon collaterals*
-*Axonal terminal* – branched terminus of an axon

Functions of Axons
-Generate and transmit action potentials
-Secrete neurotransmitters from terminals
-Impulse travel can be:
    -Anterograde — toward axonal terminal
    -Retrograde — away from axonal terminal

Myelin Sheath
-Whitish, fatty (protein-lipoid), segmented sheath around most long axons
-Functions:
    -Protects the axon
    -Electrically insulate fibers from one another
    -Increase the speed of nerve impulse transmission

Nodes of Ranvier **(Neurofibral Nodes)**
-gaps in the myelin sheath between adjacent Schwann cells
-sites where axon collaterals can emerge

Axons of the CNS
-Both myelinated and unmyelinated fibers
-Myelin sheaths are formed by oligodendrocytes
-Nodes of Ranvier are widely spaced

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 — three or more processes
- -Bipolar — two processes (axon and dendrite)
- -Unipolar — single, short process

-Functional:
- -Sensory (afferent) — transmit impulses toward the CNS
- -Motor (efferent) — carry impulses away from the CNS
- -Interneurons (association neurons) — shuttle signals through CNS pathways

Neurophysiology
-Neurons are highly excitable
-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 Current in the Body
-Reflects the flow of <u>ions</u> (not 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

The Role of Ion Channels

Types of plasma membrane ion channels:

-Passive, or leakage, channels – always open
-Chemically gated channels – opened by a specific neurotransmitter
-Voltage-gated channels – opened and closed by membrane potential
-Mechanically-gated channels – opened and closed by physical deformation of receptors

Operation of a Chemically-Gated Channel Protein

-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

Open when a neurotransmitter is attached to the receptor

-Na^+ enters the cell and K^+ exits the cell

Operation of a Voltage-Gated Channel Protein

-Example: Na^+ channel
Closed when the intracellular environment is negative

-Na^+ cannot enter the cell

Open when the intracellular environment is positive

-Na^+ can enter the cell

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 (usually depolarization)

Electrochemical Gradient

-chemical gradient: Ions move from an area of high chemical concentration to an area of low chemical concentration
-electrical gradient: Ions 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

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

-Changes are 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

Graded Potentials

-Short-lived, local changes in membrane potential

-Decrease in intensity with distance

-magnitude varies directly with the strength of the stimulus

- strong graded potentials can initiate action potentials

-Voltage changes are decremental

-Current is quickly dissipated (leaky plasma membrane)

-Can only travel over short distances

Action Potentials (APs) (aka nerve impulses)

-A brief reversal of membrane potential

-total amplitude of 100 mV

-generated by muscle cells and neurons

-do not decrease in strength over distance

-principal means of neural communication

Phases of the Action Potential
1 – resting state
2 – depolarization phase
3 – repolarization phase
4 – hyperpolarization

Threshold and Action Potentials
-Weak (subthreshold) stimuli <u>are not</u> relayed into action potentials
-Strong (threshold) stimuli <u>are</u> relayed into action potentials
-All-or-none phenomenon

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

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

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

Action Potential: Hyperpolarization
-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

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
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
Absolute Refractory Period

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

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-gated 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

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

Electrical Synapses
-Electrical synapses:
- -Are less common than chemical synapses
- -Are important in the CNS in:
  - -Arousal from sleep
  - -Mental attention
  - -Emotions and memory
  - -Ion and water homeostasis

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 impulses reach the axonal terminal of the presynaptic neuron and open Ca^{2+} channels
-Neurotransmitter is released into the synaptic cleft via exocytosis in response to synaptotagmin
-Neurotransmitter crosses the synaptic cleft and binds to receptors on the postsynaptic neuron
-Postsynaptic membrane permeability changes, causing an excitatory or inhibitory effect

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

Neurotransmitters-Chemicals used for neuronal communication
-50 different neurotransmitters have been identified
-Classified chemically and functionally
Chemical Neurotransmitters-Acetylcholine (ACh)
-Biogenic amines
-Amino acids
-Peptides
-Novel messengers: ATP and dissolved gases NO and CO
Acetylcholine-First neurotransmitter identified, released at the neuromuscular junction
Biogenic Amines-Examples:
    -Catecholamines – dopamine, norepinephrine (NE), and epinephrine
    -Indolamines – serotonin and histamine
-Play roles in emotional behaviors and our biological clock**Amino Acids**
-Include:
    -GABA – Gamma (g)-aminobutyric acid
    -Glycine
    -Aspartate
    -Glutamate

-Found only in the CNS

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

Functional Classification of Neurotransmitters-Two classifications: excitatory and inhibitory
    -Excitatory neurotransmitters cause depolarizations (ex: glutamate)
    -Inhibitory neurotransmitters cause hyperpolarizations (ex: GABA and glycine)

-Some neurotransmitters have both excitatory and inhibitory effects
    -Determined by the receptor type of the postsynaptic neuron
    -Example: acetylcholine
        -Excitatory at neuromuscular junctions with skeletal muscle
        -Inhibitory in cardiac muscle