The Nervous System

# Cells of the Nervous System

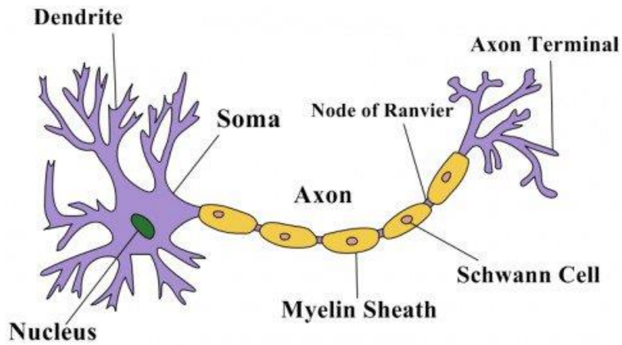
## Neurons

- Are specialized cells capable of transmitting electrical impulses and then translating them to chemical signals. All neurons have a shape that matches their function, but all share some features
- Cell Body or Soma: The location of the nucleus, ribosomes, endoplasmic reticulum.
- Dendrites: are appendages emanating from the soma. These receive signals from other cells.
    - The information is sent through the cell body to the axon hillock.
- Axon Hillock: Integrates incoming signals and transmits the incoming electrical impulses down the axon. The axon hillock sums the net electrical impulse and determines whether the signal is excitatory or inhibitory. If excitatory, an action potential will arise.
- Axon: Long appendage that terminates in close proximity to a target structure.
    - Can be insulated by **myelin** to prevent signal loss or crossing of signal.
- Myelin Sheath: maintains the electric signal within one neuron, and increases the speed of conduction.
    - Myelin is produced by **oligodendrocytes** in the CNS and **Schwann Cells** in the PNS.
    - **Nodes of Ranvier:** small breaks within sheath, make conduction faster
- Nerve Terminal or Synaptic Bouton (knob): enlarged and flattened structure at the end of the axon. Structure is shaped this way to maximize release of neurotransmitters.
    - **Neurotransmitters** are the chemicals that transmit info between neurons
- Synaptic Cleft: Space between one neuron end and the other neuron beginning. Neurotransmitters released from Nerve terminal are received by the dendrites of another neuron.
- Synapse: Nerve terminal, synaptic cleft and postsynaptic membrane are structures needed for the transmission of N.T to take place.

A **nerve** is a bundle of multiple neurons in the PNS. Nerves may be sensory, motor or mixed. Cell bodies of neurons with same functionality are clustered together into **ganglia.**

## Other Cells in The Nervous System

- Glial Cells or Neuroglia: are supporting cells in the nervous system which support and myelinate the neurons.
    - Astrocyte: nourish neurons and form the blood-brain barrier.
    - Ependymal Cells: line the ventricles of the brain and produce Cerebrospinal fluid.
    - Microglia: Phagocytic cells that ingest and break down waste products and pathogens
    - Oligodendrocytes (CNS) and Schwann Cells (PNS): produce myelin around axons.




# Transmission of Neural Impulses

## The Action Potential

Neurons use all or nothing messages to relay electrical impulses

### Resting Potential

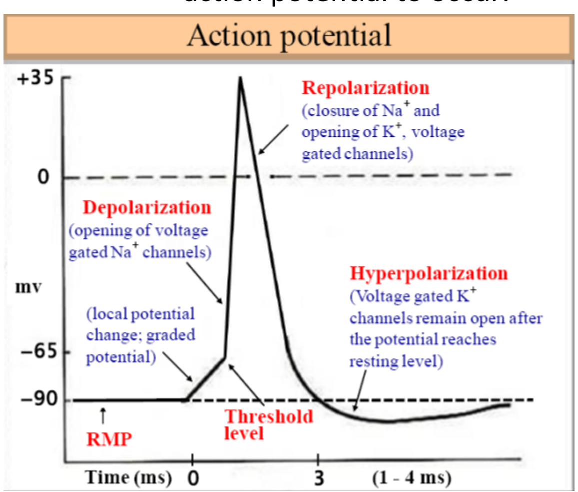
- Resting membrane potential is the net electric potential difference that exists across a cell's membrane (-70 mV). Which means that the inside of the neuron is more negative than the outside.
- **Potassium** concentration inside the cell average about 140 mM while outside the cell it averages 4 mM.
    - **Potassium Leak Channels** are used to facilitate the diffusion out of the cell. As potassium slowly leaks out, the cell loses pos charge and becomes negative.
    - **Equilibrium potential of potassium** is around -90 mV. This potential is when the net movement of ions out of the cell equals the movement in.
- **Sodium has** a concentration of 12mM inside and 145mM outside. Thus Na is pushed inside the cell through **sodium leak channels**.
    - Slow leak causes a buildup of sodium into the cell and increases the potential
    - **Equilibrium potential of sodium** is 60 mV.
- The resting membrane potential results from a balance between the sodium and potassium equilibrium potentials. Neither ion ever established equilibrium due to this
    - Cell is slightly more permeable to potassium so the resting potential is closer to the potential for potassium.
- Sodium and potassium need to be returned to their original medium, and this is done using **$Na^+/K^+$ ATPase** active transport.

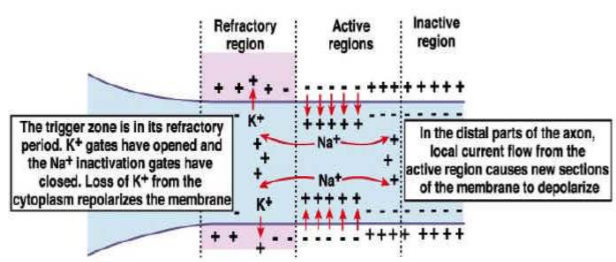
### Axon Hillock

- Excitatory input causes **depolarization** (raises membrane potential), while inhibitory input causes **hyperpolarization.**
    - If action potential receives enough excitatory input to depolarize to the **threshold** value (-55 - -40 mV), an action potential will then be triggered.
- **Summation** is the additive effect of all excitatory and inhibitory signals at a postsynaptic neuron
    - **Temporal Summation:** multiple signals integrated over a short period of time
    - **Spatial Summation:** based on number and location of the incoming signals.

## Ion channels and Membrane Potential

- Once threshold values are reached, voltage-gated sodium channels open in the membrane and there is an influx of sodium.
- Work on the basis of a strong **electrochemical gradient** since the positive ions want to go into the negatively charged cell and there is a greater concentration of sodium ions outside the cell than in, so this causes them to move into the cell when the gates are opened.
- Once a voltage of about +35 mV is reached, Na channels become inactived. The potential needs to be brought down to resting membrane potential to become functional again.
    - Have three states that the sodium channels can exist in: **Open** (from threshold to +35 mV), **Closed** (Before cell reaches threshold, but has already been deinactivated), and **Inactivated** (+35 mV to resting potential).
- Positive potential also causes potassium channels to open. **Repolarization** occurs as there an efflux of the positively charged potassium ions out of the cell.
    - Rapid efflux of K+ causes an overshoot and the hyperpolarization of the membrane. This makes the neuron refractory to further action potentials.
    - **Absolute Refractory Period:** no amount of stimulation can cause another action potential to occur.
    - **Relative Refractory Period:** must be greater than normal stimulus in order for an action potential to occur.




## Impulse propagation

Movement of signal down the axon and how it initiates neurotransmitter release.

- Sodium rushes into the axon from the soma causing depolarization in the surround region. Depolarization continues in a wave like projection until the nerve terminal is reached.
    - Each segment in which the action potential has fired in, goes into a refractory period which ensures the information is only passed in one direction.
- Speed is determined by length (greater length provides more resistance), and surface area (greater surface area provides less resistance). The effect of Surface area is greater than that of length.

- **Saltatory Conduction** occurs when myelin covers the axon. The myelin acts an insulator and ion movement is only conducted at the nodes of Ranvier. Thus the signal seems to hop from node to node.
- All action potentials within the same type of neuron have the same potential difference during depolarization. As such an increased stimulus will only result in an increased frequency of firing.

### Synapse

**Presynaptic neuron** is the neuron preceding the synaptic cleft, **postsynaptic** is the one after the synaptic cleft. If neuron is going to another cell (muscle, gland, etc.), this is termed an **effector**.

### Neurotransmitters

- Are stored in membrane-bound vesicles in the nerve terminal. When A.P reaches the terminal, voltage gated calcium channels open.
- Influx of calcium triggers the fusion of the membrane-bound vesicles and the cell membrane at the synapse. This subsequently causes the exocytosis of N.T.
- N.T's diffuse across the cleft and bind to receptors on the postsynaptic membrane.
- Distinction between inhibitory or excitatory comes down to what type of N.T receptor is activated
    - **Ligand-gated ion channel**: Postsynaptic cell will be depolarized or hyperpolarized
    - **G Protein-Couple Receptor:** Will cause either an influx of calcium or changes in the level of cyclic AMP (cAMP).
- N.T should not be continuously signaling a neuron. As such, N.T needs to be removed from synaptic cleft.
    - Can be broken down by enzymatic reactions (e.g. – Breakdown of Ach with Ache)
    - Can be brought back into the presynaptic neuron using a **reuptake carrier**. (e.g. – serotonin, Dopamine, norepinephrine)
    - May also simply diffuse out of the cleft (e.g. – Nitric Oxide)

# Organization of the Human Nervous System

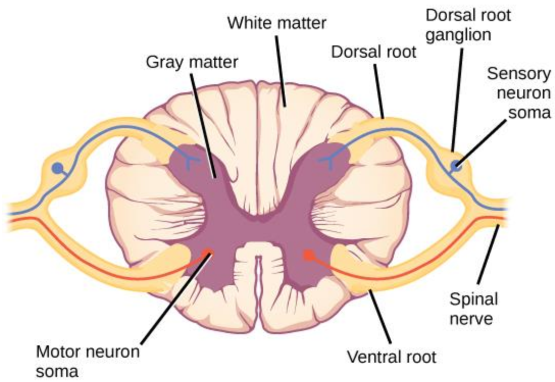
## Central & Peripheral Nervous Systems

- **Sensory Neurons** (afferent neurons) transmit sensory information from receptors to the spinal cord and brain.
- **Motor Neurons** (efferent neurons) transmit motor information from the brain and spinal to muscles and glands.
- **Interneurons** are found between other neurons and are the most numerous. Mainly located in the brain and spinal cord and are often associated with reflexes.

### Central Nervous System

- Composed of the brain and spinal cord.
- Brain consists of white matter and grey matter. The white matter is axons with Myelin sheaths, and grey matter is axons without myelinated cell bodies. White matter lies deeper than the grey matter. More primitive functions need quicker responses.
- Spinal cord extends down from brainstem and is divided into four sections: **cervical, thoracic, lumbar** and **sacral.**

- Is protected by the **vertebral column**. This also transmits nerves at the space between adjacent vertebrae.
- White matter is on the outside while grey matter is on the inside (opposite of the brain)
- Axons of motor and sensory neurons are in the spinal cord.
  - Sensory enter through the dorsal (back) side of the spinal cord. While the cell bodies are found in the **dorsal root ganglia**.
  - Motor neurons exit the spin ventrally (front).



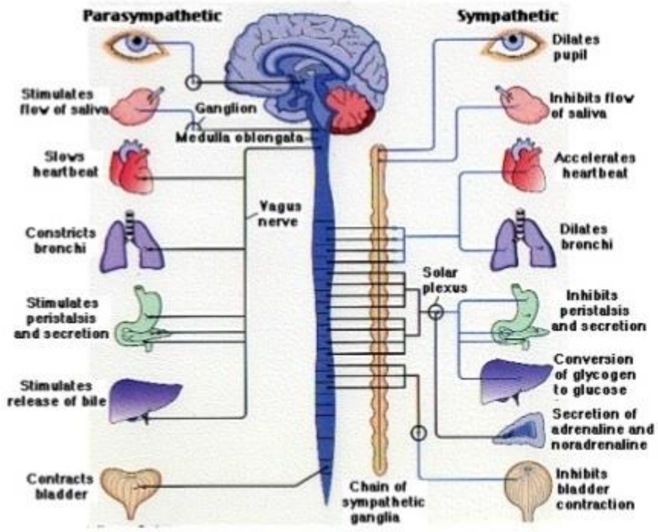

Cross Section of Spinal Cord

## Peripheral Nervous System

- Connects the CNS to the rest of the body through all 31 spinal nerves and 10 of the 12 cranial nerves.
  - Somatic Nervous System: sensory and motor neurons distributed throughout the skin, joints, and muscles. Transmit information through afferent fibers. While motor neurons travel along efferent fibers.
  - Autonomic Nervous System: regulates heartbeat, respiration, digestion and glandular secretion, temperature control. Manages involuntary muscles.
- Peripheral component of the autonomic nervous system contains two neurons rather than the one neuron seen in the somatic nervous system.
  - **Preganglionic Neuron:** first neuron. Soma is in the CNS and axon travels ganglion in PNS. Then synapses onto postganglionic neuron
  - **Postganglionic Neuron**: second neuron. Affects target tissue.

## Autonomic Nervous System

- **Parasympathetic** conserves energy and is associated with resting and sleeping states.
  - Acts to reduce heart rate and constrict the bronchi.
  - Manages digestion by increasing peristalsis and exocrine secretion.
  - Acetylcholine is main N.T involved with these responses
  - Valgus Nerve is responsible for much of P.S innervation.
- **Sympathetic** is activated by stress. Associated with "fight or flight response"
  - Increases heart rate, redistributes blood to muscles, increases glucose levels, decreases digestion, relaxes the bronchi, dilates the eye, releases **epinephrine**
  - Preganglionic neurons release Ach and postganglionic neurons release norepinephrine.




## Reflexes

- Reflex Arcs: neural circuits which control reflex behavior.
  - Monosynaptic: Single synapse between the sensory neuron that receives the stimulus and the motor neuron that responds to it.
    - Knee-Jerk reflex. Sensory neuron travels afferently to the spinal cord, where it interfaces with the efferent motor postganglionic neuron.
  - Polysynaptic: At least one interneuron between the sensory and motor neurons.
    - E.g. – Stepping on a nail. Initial reflex is a withdrawal reflex which is monosynaptic, but other leg must activate to maintain balance, so interneuron connects sensory afferent to that motor efferent.