The Nervous System

Nervous System Organization

- Animals must be able to respond to environmental stimuli.
- Three functions of the nervous system:
  - **Sensory input** — conduction of signals from sensory receptors.
  - **Integration** — analysis and interpretation of those signals and formulation of a response.
  - **Motor output** — conduction of response signal to effector cells. Response.

Two parts to the nervous system

- **Central Nervous System (CNS)**
  - Brain and spinal cord.
  - Integration and interpretation of input.
- **Peripheral Nervous System (PNS)**
  - Nerves and ganglia.
  - Communication of signals into and out of the CNS to the rest of the body.

- **Neuron**: specialized cell that produces and conducts electrochemical impulses. It is the functional unit of the nervous system.
- **Nerve**: a communication line consisting of a bundle of neurons tightly wrapped in connective tissue.
- **Ganglia**: clusters of neuron cell bodies.

Nerve Tissue

- Most neurons consist of three parts:
  - **Cell body** — contains the nucleus
  - **Dendrites** — highly branched extensions
    - Conduct electrical impulses toward the cell body
  - **Axon** — single cytoplasmic extension
    - Conducts impulses away from cell body
  - **Supporting cells**: **Neuroglia** (or just glia)
    - Do not conduct electrical impulses.
    - Support and insulate neurons and eliminate foreign materials in and around neurons.
    - Associate with axon to form an insulating cover called the myelin sheath.
Myelin Sheath

Vertebrates have three kinds of neurons:
1. Sensory neurons (afferent neurons) carry impulses (signals) to central nervous system (CNS).
2. Motor neurons (efferent neurons) carry impulses (signals) from CNS to effectors (muscles and glands).
3. Interneurons (association neurons) integrate data and then relay appropriate signals to other interneurons in the CNS (relay to brain) or to motor neurons.

Nervous System Organization
How nerve impulses are generated:

**Resting Neuron**

- **Polarized** – charge difference between inside and outside of neuron.
- More sodium (Na+) ions on the outside and more potassium (K+) on the inside.
- **Sodium-Potassium pump** (active transport) maintain this gradient.
- Cell contains other ions that contribute to the interior negative charge. Example: large negatively charged proteins and nucleic acids.
- **Resting potential**: voltage across membrane of resting neuron. At rest, this is -40 to -90 millivolts (mV). Average: -70 mV. This is about 5% of a flashlight battery.
How nerve impulses are generated:  
Active Neuron

- Other gated sodium and potassium channels exist along the membrane.
- These are activated (opened) by a ligand (hormone, neurotransmitters, or other stimuli).
- Thus, ions rush in. This depolarizes the neuron and triggers an impulse.
- Change must be large enough to move past an electrical threshold, otherwise nothing happens (no signal sent). Threshold is about -50mV.
- Then depolarization activates voltage-gated channels allowing more Na+ to come into the neuron.
- **Action potential**: voltage required for a signal to be transmitted along the axon.

Nerve Impulse Transmission

- Chemically-gated or ligand-gated channels
- Ligands are hormones or neurotransmitters
- Induce opening and cause changes in cell membrane permeability

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**ACTION POTENTIAL**

Step 1: Resting membrane potential.
Step 2: Some of the voltage-gated Na-channels open and Na enters the cell (threshold potential).
Step 3: Opening of more voltage-gated Na-channels and further depolarization (rapid upstroke).
Step 4: Reaches to peak level.
Step 5: Direction of electrical gradient for Na is reversed = Na-channels rapidly enter a closed state *(inactivated state)*  → voltage-gated K-channels open *(start of repolarization)*.
Step 6: Slow return of K-channels to the closed state *(after-hyperpolarization)*.
Step 7: Return to the resting membrane potential.
Nerve Impulse Transmission

- Propagation of action potentials:
  - Each action potential, in its rising phase, reflects a reversal in membrane polarity.
  - Positive charges due to influx of Na⁺ can depolarize the adjacent region to threshold.
  - And so the next region produces its own action potential.
  - Meanwhile, the previous region repolarizes back to the resting membrane potential.
    - Signal does not go back toward cell body: **one way signal down the axon**.
    - Depending on size and type of axon, the signal can go anywhere from 4 to 120 meters per second (9 mph to 268 mph)!

Nerve Impulse Transmission

- Two ways to increase velocity of conduction:
  - Axon has a large diameter.
    - Less resistance to current flow.
    - Found primarily in invertebrates.
  - Axon is myelinated.
    - Action potential is only produced at the myelin nodes (nodes of Ranvier).
    - Impulse jumps from node to node: **Saltatory conduction**.

**Why Action Potentials Jump Down Axon**

1. As charge spreads down an axon, myelination (via Schwann cells) prevents ions from leaking out across the plasma membrane.
2. Charge spreads unimpeded until it reaches an unmyelinated section of the axon, called the node of Ranvier, which is packed with Na⁺ channels.
3. In this way, electrical signals continue to jump down the axon much faster than they can move down an unmyelinated cell.
**Synapses**

- Intercellular junctions with the dendrites of other neurons, with muscle cells, or with gland cells.
- **Presynaptic** cell transmits action potential.
- **Postsynaptic** cell receives it.
- Two basic types: electrical and chemical.

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**Two Types of Synapses**

1. **Electrical Synapse**
   - In cardiac muscle + smooth muscle

2. **Chemical Synapse**
   - In nervous system

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**Electrical Synapse**

- Axon of presynaptic cell
- Axon terminus
- Plasma membrane
- Direction of signaling
- Post synaptic cell

**Chemical Synapse**

- Synaptic vesicle
- Flow of ions
- Gap junction
- Neuron terminal
- Neurotransmitters
- Flow of ions
- Ion channel

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**Neurotransmitters**

1. **Acetylcholine (ACh)** is involved in both learning and memory and muscle movement.
2. **Dopamine** impacts our arousal and mood states, thought processes, and physical movement.
3. **Serotonin** and **norepinephrine** are neurotransmitters involved in levels of arousal and mood, and play a major role in mood disorders such as depression.
4. **GABA** is the main inhibitory neurotransmitter in the nervous system. **Glutamate** is the main excitatory neurotransmitter.
5. **Endorphins** are a group of neurotransmitters that are involved in pain perception and relief.

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**Caffeine**

- Blocks the activity of adenosine, a neurotransmitter that makes us tired or sleepy.
- Because it blocks adenosine, it also causes changes in the balance of other neurotransmitters, increasing levels of dopamine, acetylcholine, and serotonin.
- Increases muscle activity, relieves depression, and makes you feel relaxed, alert, energetic, and relieves migraine headaches.
- Can also make you jittery, increase anxiety levels, and cause insomnia.
“The human brain has 100 billion neurons, each neuron connected to 10 thousand other neurons. Sitting on your shoulders is the most complicated object in the known universe.”

-Michio Kaku