Behavioral Neuroscience Notes

PSYC 360

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CHAPTER 1

ORIGINS OF BEHAVIORAL NEUROSCIENCE

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- Complications arise because they thought the heart contained the soul–you need it to live and emotions effect it.

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- Galen is a physician to gladiators.
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- Noticed there were large spaces (called "ventricles," or "spaces") that were filled with fluid.
- From here, we get the four humors (fluids).
- Galen thought that these fluids are what control the brain, NOT the brain structure itself. Think of the purpose of canned vegetables. The tin container does not actively contribute to the liquid / vegetables; rather, it is disposable.
- These ideas were jumpstarted by the invention of aqueducts. The movement of water was so important from aqueducts, so the idea this idea was extended to the brain.

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- Again, this is adding to the idea that liquids (which can flow through things and cause movements) are responsible for the brain's functionality.

1.7 *René Descartes*–1596-1650

- Believed that non-humans–what he called animals–are controlled by fluid.
- From this, he posited that the human body is a material entity functioning as a machine (like animals)–these are known as reflexes.
- But, the mind is nonmaterial and free from the laws of the universe and was uniquely human.
- Question: How does the nonmaterial part of the body (the mind) communicate with the material part of the body? Through the pineal gland! This gland would move around like a joystick and would manipulate the fluid that came from the third ventricle.

1.8 The Mind/Body Problem

- What is the basic relationship between mental events and physical events?
- *Dualism*–The mind exists independently of the brain and exerts some control over it.

- Strengths: Commonsense view.
- Weaknesses: The universe is composed of matter or energy.
- Modern neuroscientific explanation: Everything the body does rests on the events taking place in specific, definable parts of the nervous system–the "mind" is the product of the nervous system activity.

1.9 The Scientific Method–17th and 18th Century

- A new world view at the end of the Renaissance.
  - Replace *Rationalism* with *Scientific Method*.
- Closer look at the substance of the brain:
  - Gray and white matter change the way we look at the brain. That is, why would these parts of the brain that are clearly different, be different if the brain is used just to move fluids around.
  - Also, everyone has the same brain structure, so these bumps and groves must mean something.

1.10 Electricity

- *Isaac Newton* showed it is possible to electrically stimulate nerves.
- Then, *Luigi Galvani* and *Emil du Bois-Reymond* showed that electricity can make muscles contract.
- Later on, *Hermann von Helmholtz* showed that the speed of nerve conduction is not instantaneous.
- This important distinction shows that these nerves are not like wires–such as *Luigi Galvani* and *Emil du Bois-Reymond* thought.
- *Bell* and *Magendie* showed that the dorsal nerve root and the ventral nerve root are different.
  - Specifically, Bell showed that the ventral nerve root is for motor information, and Magendie showed that the dorsal nerve root is for sensory information.
- The dorsal nerve root is for sensory information, and the ventral nerve root is for motor information.
- *Dorsal* = *Sensory*: Think of the dorsal fin of a shark sensing vibrations in the water.
- *Ventral* = *Motor*: Think of a vent (like a car exhaust) pushing out movement.

- *Johannes Müller* came up with the doctrine of *Specific Nerve Energies*.
  - This doctrine states that the nature of a sensation depends on which nerve is stimulated, not on how the nerve is stimulated.
  - For example, if you stimulate the optic nerve, you will see something. If you stimulate the auditory nerve, you will hear something.
- Spawned the *Great Debate*: Is the brain a homogenous mass or is it made up of different parts?

1.11 The Great Debate

- *Franz Joseph Gall* and *Johann Spurzheim* thought the bumps and groves on the head were due to the size of the brain parts.
- They concluded that the size of the brain parts was correlated to the use of that part.
- This is known as *phrenology*.
- *Localization of Functions*–brain function can be localized to regions, pathways, or neurons.
  - Basically, if you cut out a piece of brain, and the animal (a pigeon) is no longer able to do a specific task, then that part of the brain is responsible for that task.
  - However, it turns out that these pigeons were able to relearn the task, so the brain is not as localized as we thought (this research is from Flourens).
- *Aggregate Field Theory*–the brain is a homogenous mass.
  - Complex brain functions emerge from the collective interactions of numerous simple neuronal activities.
  - Unlike localizationist models, this theory emphasizes the distributed nature of cognitive processes across neural networks.
- *Pierre Flourens* (1794–1867)
  - Studied the effect of brain damage with pigeons and supported the Aggregate Field Theory.
- *Paul Broca* (1824–1880)
  - Found a patient who *could speak* but could *not understand language*.
  - After the patient died, Broca found a lesion in the *left frontal lobe*.
  - This area is now known as *Broca's area*.
  - This area is responsible for *speech production*.
  - These results put us back into the realm of Localization of Function.

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  - Similarly to *Luigi Galvani* and *Emil du Bois-Reymond*, they electrically stimulated the brain.
  - They found that the *motor cortex* is responsible for *movement*.
- *Shepherd Ivory Franz* (in D.C. from 1907–1924)
  - Found that people are able to relearn tasks after brain damage.

1.12 Same Resolution?

- *Modified Aggregate Field Theory*
  - *Karl S. Lashley* (1890-1958)
    - *The Principles of Mass Action*
      - Complex behavior–such as learning–is dependent on the total mass of the brain.
    - *Equipotentiality*
      - Specialization of function is not tied to specific brain regions.
      - All parts of the cortex contribute equally to complex behavior.
    - *Vicarious functioning*
      - If one part of the brain is damaged, another part can take over.

1.13 Analysis

1. **Prehistoric**: Recognition of the brain's vital role in life through skull injuries. No scientific theories yet.
2. **7000 Years Ago**: Trephination (skull drilling) practiced to release "evil spirits," indicating early medical intervention.
3. **5000 Years Ago**: Egyptians documented brain damage but prioritized the heart as the seat of the soul.
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    Table 1.1: Key Figures in the Great Debate: Localization vs. Aggregate Theory

Localization	Aggregate Theory
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Franz Joseph Gall	Shepherd Ivory Franz
Paul Broca	
Carl Wernicke	
Gustav Fritsch	
Eduard Hitzig	

12. **Modified Aggregate Theory**: Karl Lashley emphasized mass action and equipotentiality.

Table 1.2: Key Scientists and Contributions

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Hippocrates	Brains as seat of sensation/intelligence
Aristotle	Heart as command center; brain as radiator
Galen	Cerebellum (motor), cerebrum (memory); humors
René Descartes	Mind-body dualism; pineal gland
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SKIP CHAPTER 2

Most of the content from Chapter 2 has been blended with Chapter 3.

CHAPTER 6

HOW NEURONS PROCESS INFORMATION

NEW NOTES FOR 02/26/25

6.1 The Neuron

- Definition: Basic information processing unit of the NS.
- Similarities to an animal cell:
  - *Cell membrane*: Separates the inside of the cell from the outside environment.
  - *Nucleus*: Contains the genetic material of the cell.
  - *Organells*: Carry out the basic functions of the cell.
    - *Mitochondria*: Produce energy for the cell.
    - *Endoplasmic Reticulum*: Synthesizes proteins.
    - *Golgi Apparatus*: Packages proteins for transport.
    - *Lysosomes*: Break down waste products.
  - Basic cellular processes.
- Differences:
  - Special "morphology" (shape).
  - Communicate through an electrochemical process.

6.1.1 Structure of the Neuron

(Mostly a recap of Terms)

- *Soma*
- *Dendrite*
- *Axon*
- *Terminal Arboriza* – Branches at the end of the axon.
- *Terminal Buttons* – End of the terminal arboriza.
- *Axon Hillock*
- *Myelin*

- Not all axons have it.
- Glial cells / 70% Lipid / Nodes of Ranvier.
- Mutliple Sclerosis (MS) – Demyelination.

6.1.2 Support cells in the Nervous System

- Glia/Glial Cells/ Neuroglia – Support cells.
  - Capable of cell division after birth/communication.
  - Make up half of the volume, but are 10-50 times more numerous. (The other half is made up of neurons.)
  - CNS:
    - *Macroglia* – Large glial cells.
      - *Astrocytes* – Star-shaped cells that provide physical support to neurons, clean up debris, and provide nutrients to neurons.
        - *Note* that these cells do not help neurons grow when they are damaged. In fact, they inhibit growth by proliferating and forming a scar.
      - *Oligodendrocytes* – "few branches (in contrast to Astrocytes)" – *Form* myelin sheath around multiple axons in the CNS.
    - *Microglia* – Small cells that remove debris from injured or dead cells.
    - *Ependymal Glia* – Line the ventricles of the brain and spinal cord. (Remember the CSF?)
  - PNS:
    - *Satellite Cells* – Provide nutrients and physical support to neurons.
    - *Schwann Cells* – Form myelin sheath around axons in the PNS. These cells are monogamists; they wrap their arms around one axon.
      - Neuronal Regeneration.
  - The Myelin Sheath is composed of Oligodendrocytes in the CNS and Schwann Cells in the PNS.
  - *Phagocytosis* – When an injury occurs, the glial cells divide and eat the dead cells. (Done by Microglia and Schwann Cells.)
  - Maintenance of Internal Consistency.
    - When neurons undergo rapid firing, they release potassium ions. Astrocytes absorb these ions to maintain the internal consistency of the neuron, and dump them into the blood stream.

NEW NOTES FOR 02/28/25

6.1.3 Are Glial Cells Contributing to Alzheimer's Disease?

- Normally,
  - Beta amyloid cleared away through microglia.
- IF beta amyloid builds up too much, Tau INSIDE cells builds up.
- This leads to inflammation, which maybe leads to the problems of Alzheimer's.

6.2 Different Kinds of Neurons

- Based on Structure
- Based on Function

6.2.1 Structural Classification of Neurons

- *Unipolar/Pseudounipolar*
  - *The difference:* The axon and dendrite are fused together.
- *Bipolar*
- *Multipolar*

6.2.2 Functional Classification of Neurons

- Sensory Neurons (Afferent)
  - Carry information from the sensory receptors to the CNS.
  - Unipolar.
  - "Afferent" – "bearing or conducting inward"
- Interneurons
- Motor Neurons (Efferent)
  - Carry information from the CNS to the muscles and glands.
  - Multipolar.
  - "Efferent" – "conducting outward"
- Remember: Ad = towards Ex = from Ferro = I carry.

6.3 Neural Communication

- **2 Systems of Neuronal Communication:**
  - *Binary* – All or none (literally only 2 options).
  - *Analogue* –Graded, matter or degree.

NEW NOTES FOR 03/03/25 (kinda)
We added a lot to the notes that we already had, so there is new material springled throughout this section.

6.3.1 Binary System ("Off" and "On")

- *The Resting Membrane Potential (RMP)*: "OFF"
  - Click here for a diagram.
  - *Note:* Where the arrows land on either side of the cell membrane is supposed to represent the relative permeability of the cell membrane to different ions.
  - -70 mV (relative to the outside).
  - Understand the cell membrane.
    - *Phospholipid Bilayer* – Hydrophobic tails and hydrophilic heads.
    - *Semipermeability* – Some things can cross, others cannot.
      - Lipid, lipid soluble, small, and neutral.
    - *Embedded Proteins* – Channels and pumps.
      - **4 Jobs We Care About:**
        - *Receptors*
          - High specificity and affinity.
          - "Places where things can bind to the cell and cause a change."
        - *Channels*.
          - *Gated Channels*:
            - Passive movement. The cell itself does not expel any energy to move the ions.
            - Chemical (ligand) gated channels.
            - Voltage gated channels.
        - *Pumps* – Active transport.
        - *Enzymes* – Facilitates chemical reactions.
          - Breaking neurochemicals down or putting them back together.
  - **3 Determinants of the RMP**
    - *Differential Permeability* – The cell membrane is more permeable to some ions than others.

- For sodium, the membrane only allows a trickle of Na^+ into the cell.
- Conversely, the membrane is more permeable to K^+ and CL^-. (K^+ is the most permeable.)

- **Driving Forces**:
  - *Diffusion* – Ions move from high to low concentration (Concentration Gradient).
    - *Note:* The cell membrane is more permeable to potassium ions than sodium ions.
  - *Electrostatic Pressure* – Ions move towards the opposite charge (Electrical Gradient).
  - *Equilibrium Potential* – The charge the ion "perfers" if it were the only one and could pass freely through the membrane.
    - This answers the question: "Why doesn't the cell get more and more negative?"
    - Driving force in (influx) = Driving force out (efflux).
    - $K^+ = -80$ mV and $Na^+ = +55$ mV.
  - *Sodium-Potassium Pump* (Na^+/K^+ Pump)
    - 3 Na^+ out for every 2 K^+ in.
    - Costs 1 ATP.

- *The Action Potential (AP)*: "ON"
  - Click here for a diagram.
    - *Note:* The above diagram neglects to show that there can be *failed* attempts at an action potential wherein the threshold is not reached. In these cases, the charge of the cell can increase or decrease, but if it does not reach -55 mV, it will quickly settle back to its resting potential of -70 mV.
  - +40 mV (relative to the outside).
  - Thus, during an action potential, there is a total of 110 mV difference between the inside and outside the cell.

NEW NOTES FOR 03/05/25

- **Electrical Current**
  - *Depolarization*
    - A little
    - A lot
      - *Threshold of Excitation* = +15 mV.
      - Action potential
    - Even more.
  - *Repolarization*

- A little
- A lot
- Even more.

- *Refractory Period*
  - Cell is resistant to reexciation for a period after the AP peak.
    - *Absolute Refractory Period* – No amount of stimulation will cause another AP.
    - *Relative Refractory Period* – A stronger than normal stimulus is required to cause another AP. (This is because of hyperpolarization.)
  - **Three Questions:**
    - Why don't the Na^+ channels reopen during repolarization?
      - *Answer:* Because of the refractory period.
    - How can an all or none signal convey analog information?
      - *Answer:* The frequency of the APs can convey the intensity of the stimulus.
      - *Rate Law* – Variations in the intensity of a stimulus are represented by variations in the rate of firing.
    - Where does that signal come from that meets the threshold of excitation?
      - Refer to Conduction of Electrical Activity.

6.4 Conduction of Electrical Activity

6.4.1 Conduction of Hyper and (subthreshold) Depolarizations

- *Decremental Conduction* – The further the signal travels, the weaker it gets. (cable properties)
  - Analogue communication.
    - Degrading because for resistance and leakage.
  - *Passive Conduction* – No energy is expended.

6.4.2 Conduction of Action Potential in Unmyelinated Axons

NEW NOTES FOR 03/07/25

- *All or Nothing Law* – AP occurs or not once triggered, always the same size.
- *Active Regeneration* – The AP is regenerated at each point along the axon.
  - Takes a lot of time (< 1 - 10 meters/second).
  - Takes a lot of energy.

6.4.3 Conduction of Action Potential in Myelinated Axons

- *Saltatory Conduction* = "To jump" – AP jumps from node to node.
  - Decremental conduction in the myelinated portions.
    - No extracellular fluid.
    - Almost absent Na^+ channels.
  - Active regeneration at Nodes of Ranvier.
    - High density of Na^+ channels.
    - AP is regenerated.
  - **Advantages:**
    - Economic
      - Much less work for the Na^+/K^+ pump.
    - Speed
      - in excess of 100 m/s (225 mph) (not as fast as electricty's 300 million m/s).
    - So why not evolve 1 long myelin sheath?
      - *Answer:* The AP would be too weak from the decremental conduction by the time it reached the end.
  - Think of how this applies to multiple sclerosis: The myelin sheath is destroyed, and the AP can no longer jump from node to node. This results in a loss of sensation and motor control.

6.5 Conversion from Electrical to Chemical Signals

- Occurs at the synapse (Greek: "syn" = together, "haptein" = to clasp).
  - Synaptic cleft (200 angstroms (Å) across). *Note:* 10^7 Å = 1 mm.
  - Pre-synaptic membrane
    - *Golgi bodies* – Synthesize neurotransmitters and package them into vesicles.
    - *Synaptic vesicles* – Contain neurotransmitters.
      - In the pre-synaptic cell, the golgi bodies
    - *Docking proteins* – Hold the vesicles in place.
      - Full synaptic vesicles migrate to membrane and attach.
    - Voltage gated *Ca^{+2} channels* open.
    - Once the AP arrives at the synapse, the docking proteins release the vesicles and the neurotransmitters are released into the synaptic cleft (this is due to the Ca^{+2} channels opening).
  - Post-synaptic membrane
    - *Receptors* – Bind to the neurotransmitters.

NEW NOTES FOR 03/10/25

6.6 Conversion from Chemical Back to Electrical Signal

6.6.1 Two Kinds of Post Synaptic Potentials

- *Excitatory Post Synaptic Potentials* (ESPSs)
  - Bring the cell closer to firing.
  - i.e., opening of Na^+ channels.
- *Inhibitory Post Synaptic Potentials* (ISPSs)
  - Take the cell further from firing.
  - i.e., opening of K^+ channels (and potassium leaves).
- Thus, post synaptic into action potential by summing up of the EPSPs and IPSPs at the axon hillock.

6.6.2 What Happens to Excess or Used Neurotransmitters?

- **Three things can occur:**
  - *Active Reuptake* – The neurotransmitter is taken back up into the pre-synaptic cell.
  - *Metabolism* – The neurotransmitter is broken down by enzymes.
  - *Bound to Autoreceptors* – The neurotransmitter binds to autoreceptors on the pre-synaptic cell.
    - This inhibits the release of more neurotransmitters.

6.6.3 Two Types of Chemically Gated Channels

2 Kinds of Synapse: *ionotropic* and *metabotropic*.

6.6.4 *Ionotropic Synapse*

- No change in metabolism. (No ATP expended.)
- Direct change of ions.
- Fixed duration (rapid and short).
- 1 neurotransmitter binds to 1 receptor.
- **Example:** Acetylcholine (ACh) binds to a receptor and opens a Na^+ channel.

6.6.5 *Metabotropic Synapse*

- Actual change in cellular metabolism.
- Indirect exchange of ions.
- Variable duration (can be very long).
- At least 2 neuromodulator molecules bind to a receptor.
- **Example:** Dopamine binds to a receptor, which activates a G-protein, which activates an enzyme, which produces a second messenger, which opens a K^+ channel.
- **At the Metabotropic Synapse:**
  - Neuromodulator binds and initiates process.
  - Alpha subunit of *G-Protien* binds to *Adenylate Cyclase*.
    - Activating adenylate cyclase to convert ATP to *cAMP* (cyclic adenosine monophosphate).
  - cAMP activates *Protein Kinase A*.
    - Causing 2 subunits to dissociate.
    - Catalytic portion is no longer inhibited.
    - Allowing it to convert ATP to ADP.
      - This produces a phosphate group.
    - To end this process:
      - Neuromodulator dissociates to end cAMP production.
      - Enzymes
        - *Phosphodieterase* – Metabolizes residual cAMP
        - *Phosphoprotein phosphatase* – Removes the phosphate and resets the channel.

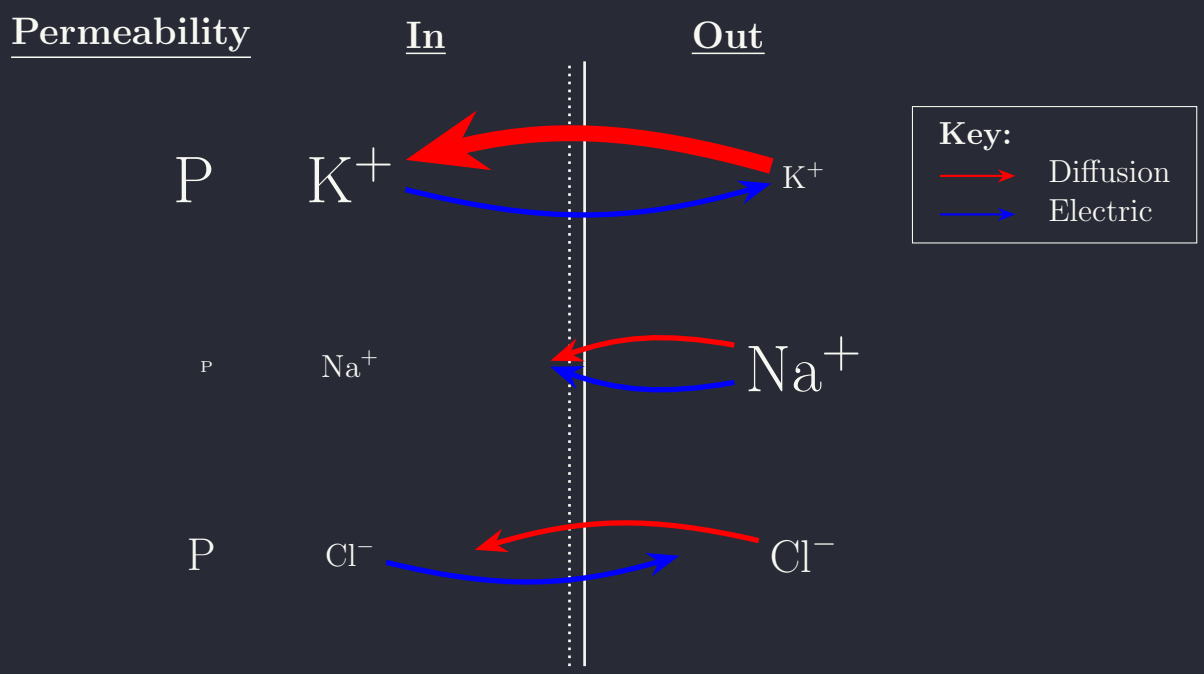


Figure 6.1: The Resting Membrane Potential (RMP) of a Neuron

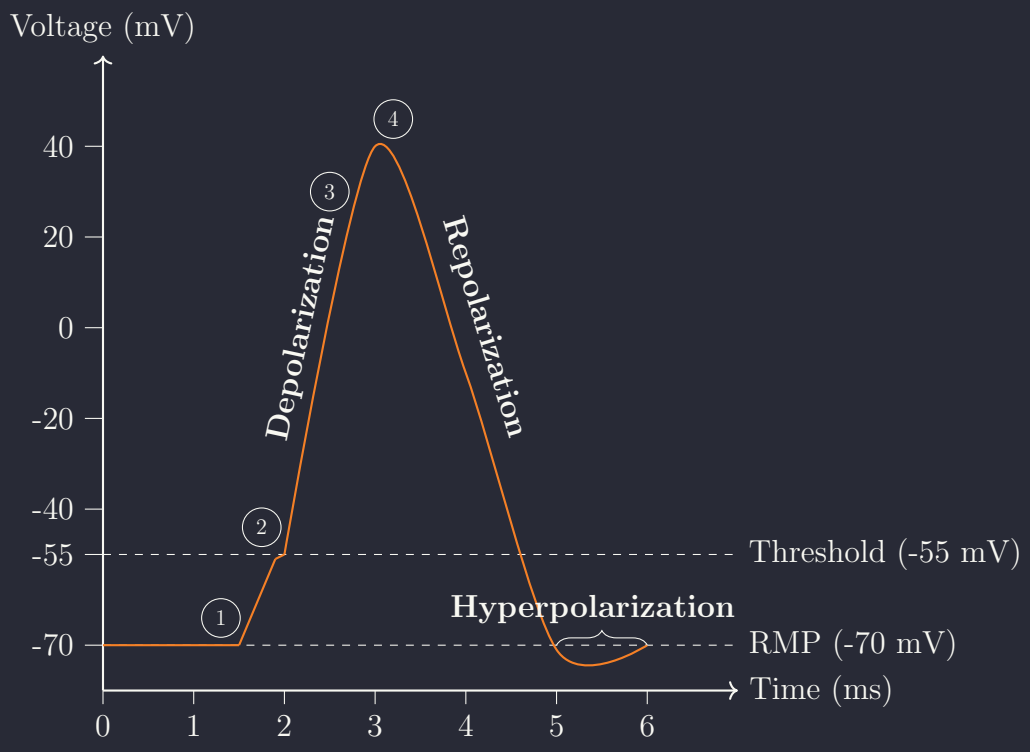


Figure 6.2: Action Potential Waveform

2.1 Neurons and Glial Cells

Q2.1.1 Short Answer: Define a neuron.

Q2.1.2 Multiple Choice: Which cell type forms the myelin sheath in the PNS?

(A) Oligodendrocytes (B) Schwann Cells

(C) Astrocytes (D) Satellite Cells

Q2.1.3 Fill in the Blank: The process by which microglia remove debris is called _____.

Q2.1.4 Short Answer: Name two functions of astrocytes.

Q2.1.5 True or False: Oligodendrocytes are responsible for myelination in the PNS.

Q2.1.6 Multiple Choice: What is one function of myelin?

(A) Insulate axons (B) Synthesize proteins

(C) Produce neurotransmitters (D) Break down debris

Q2.1.7 Fill in the Blank: Glial cells compose about half of nervous tissue volume, but are approximately _____ times more numerous than neurons.

Q2.1.8 Short Answer: What are two similarities between neurons and other animal cells?

Q2.1.9 Short Answer: In neurons, what is the primary role of mitochondria?

Q2.1.10 Fill in the Blank: The organelle responsible for protein synthesis in neurons is the _____.

Q2.1.11 Fill in the Blank: The _____ packages proteins for transport.

Q2.1.12 Fill in the Blank: Organelles that break down waste products in neurons are called _____.

Q2.1.13 Short Answer: What distinguishes the morphology of neurons from typical animal cells?

Q2.1.14 Fill in the Blank: Neurons communicate via an _____ process.

Q2.1.15 Multiple Choice: Which cell type is primarily responsible for debris removal in the CNS?

(A) Astrocytes

(B) Microglia

(C) Oligodendrocytes

(D) Satellite Cells

Q2.1.16 Multiple Choice: Which cells line the ventricles and help form CSF?

(A) Astrocytes

(B) Ependymal Glia

(C) Schwann Cells

(D) Microglia

Q2.1.17 Short Answer: What is the function of satellite cells in the PNS?

Q2.1.18 Multiple Choice: Which glial cell in the PNS is notably associated with neuronal regeneration?

(A) Oligodendrocytes

(B) Schwann Cells

(C) Microglia

(D) Satellite Cells

Q2.1.19 Short Answer: What is the purpose of *phagocytosis* in the nervous system?

Q2.1.20 Multiple Choice: What happens during maintenance of internal consistency?

(A) Microglia remove cellular debris.

(B) Oligodendrocytes myelinate axons.

(C) Astrocytes absorb excess potassium ions.

(D) Schwann cells provide nutrients to neurons.

Q2.1.21 **Long Answer:** What evidence supports the notion that glial cells' malfunctioning may be contributing to Alzheimer's Disease? (Your answer needs to include beta amyloid, Tau, and the possible cause of Alzheimer's Disease.)

Q2.1.22 **Fill in the Blank:** The three structural classifications of neurons are _____, _____, and _____.

2.2 Neural Communication

Q2.2.1 **Fill in the Blank:** Sensory neurons carry information from the _____ to the _____.

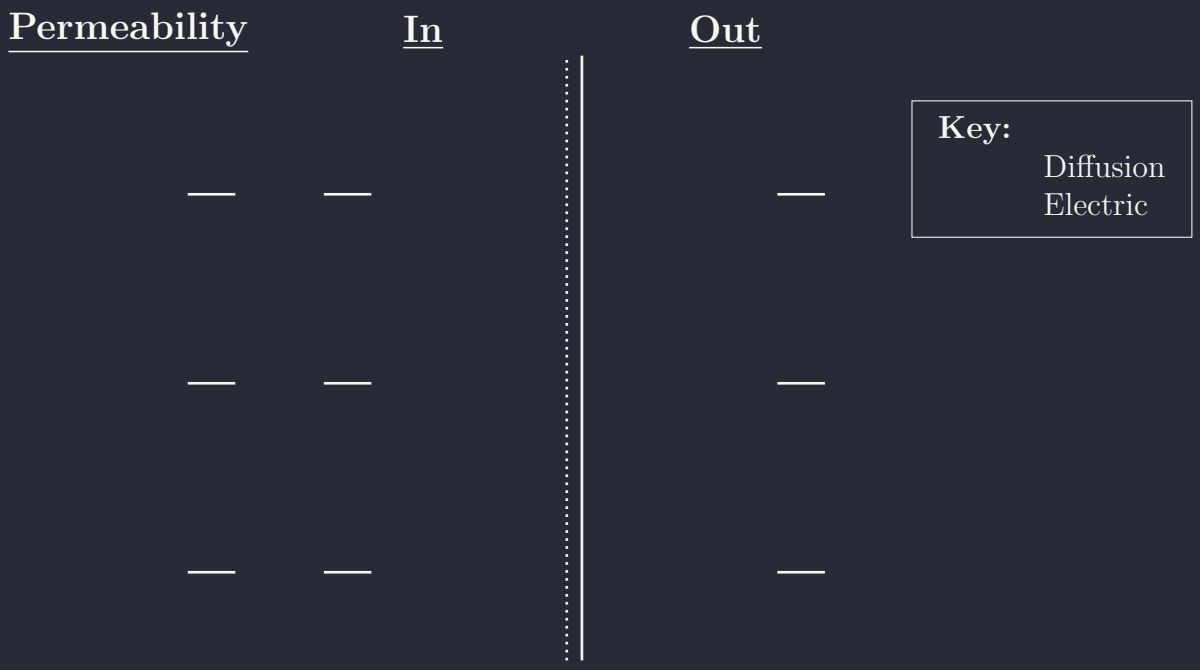
Q2.2.2 **Short Answer:** What is the primary function of motor neurons?

Q2.2.3 **Short Answer:** What are the 2 systems of neuronal communication?

Q2.2.4 **Fill in the Blank:** The *phospholipid bilayer* is made up of _____ and _____.

Q2.2.5 **Short Answer:** What are the four jobs that we care about for embedded proteins?

Q2.2.6 Fill in the Blank: Fill out the following diagram of the resting membrane potential of a neuron. Draw the size of each and permeability ion to "scale" and draw the diffusion and electric arrows with the appropriate directions.



Q2.2.7 Short Answer: What is the threshold of excitation, and what happens when it is reached?

Q2.2.8 Short Answer: Why don't the Na^+ channels reopen during repolarization?

Q2.2.9 Multiple Choice: During which phase of the action potential is a neuron unable to fire another action potential, no matter how strong the stimulus?

a) Depolarization
b) Repolarization
c) Absolute refractory period
d) Relative refractory period

Q2.2.10 Multiple Choice: How can an all-or-none action potential signal convey information about stimulus intensity?

a) By increasing the amplitude of the action potentials
b) By decreasing the duration of action potentials
c) By changing the direction of action potentials
d) By increasing the frequency of action potentials

Q2.2.11 Fill in the Blank: The period during which no amount of stimulation can cause another action potential is called the _____.

Q2.2.12 Fill in the Blank: A stronger-than-normal stimulus is required to cause another action potential during the _____ because of hyperpolarization.

2.3 Additional Questions: Membrane and Action Potentials

Q2.3.1 What is the resting membrane potential (RMP) of a neuron and what does it represent?

Q2.3.2 What does the provided diagram (via a hyperlink) illustrate regarding the RMP?

Q2.3.3 Name two key components of the cell membrane that help maintain the RMP.

Q2.3.4 Describe the phospholipid bilayer.

Q2.3.5 What is meant by semipermeability in the context of the cell membrane?

Q2.3.6 List the four main functions of embedded proteins in the cell membrane.

Q2.3.7 What does "differential permeability" mean and how does it affect ion movement?

Q2.3.8 How does diffusion contribute to the RMP?

Q2.3.9 What role does electrostatic pressure play in neuronal membrane potential?

Q2.3.10 Define equilibrium potential and state the equilibrium values for K^+ and Na^+.

Q2.3.11 What is the function of the sodium-potassium pump in neurons?

Q2.3.12 What is an action potential (AP) and what is its peak voltage?

Q2.3.13 What is the total voltage difference during an action potential and what does it mean?

Q2.3.14 What happens in a failed attempt at an action potential?

Q2.3.15 **Short Answer:** What is decremental conduction, and why does it occur?

Q2.3.16 **Short Answer:** Why does the action potential require active regeneration in unmyelinated axons?

Q2.3.17 **Multiple Choice:** What is the main advantage of saltatory conduction in myelinated axons?

a) It eliminates the need for Na^+ channels.

b) It increases conduction speed and reduces energy expenditure.

c) It allows action potentials to travel in both directions.

d) It prevents action potentials from occurring at all.

Q2.3.18 **Fill in the Blank:** In saltatory conduction, the action potential is actively regenerated at _____.

Q2.3.19 **Short Answer:** Why can't myelin sheaths extend indefinitely without nodes?

Q2.3.20 **Multiple Choice:** What happens when an action potential reaches the presynaptic terminal?

a) Voltage-gated Ca^{+2} channels open.

b) The Na^+/K^+ pump is activated.

c) The postsynaptic neuron immediately fires an action potential.

d) The synaptic vesicles dissolve.

Q2.3.21 **Fill in the Blank:** Neurotransmitters are released into the _____ when synaptic vesicles fuse with the presynaptic membrane.

Q2.3.22 **Short Answer:** What is the function of docking proteins at the presynaptic membrane?

Q2.3.23 **Multiple Choice:** Which of the following is an excitatory postsynaptic potential (EPSP)?

a) Opening of Na^+ channels

b) Opening of K^+ channels

c) Binding of neurotransmitters to autoreceptors

d) Metabolism of neurotransmitters

Q2.3.24 **Fill in the Blank:** The three possible fates of neurotransmitters after release are _____, _____, and _____.

Q2.3.25 **Short Answer:** How do ionotropic and metabotropic synapses differ in terms of speed and duration?

Q2.3.26 **Multiple Choice:** What role does cAMP play in metabotropic synapses?

a) It binds directly to ion channels to open them.

b) It activates Protein Kinase A, which leads to phosphorylation.

c) It metabolizes excess neurotransmitters.

d) It breaks down ATP into ADP.

Q2.3.27 **Fill in the Blank:** The enzyme _____ converts ATP into cAMP in metabotropic signaling.