Online Physiology 2130 – Nerve Cells

Introduction

Dear Student,
Thank you for opening this resource for Physiology 2130, and welcome. This resource has been created by the Education Team at WebStraw. The Education Team consists of students that have previously taken and/or students that are currently taking Physiology 2130.

Purpose

This resource focuses on key concepts that are important for students to understand to succeed within this course. This resource was created by students for other students. Our goal is to help students (1) further develop their understanding of course content and (2) achieve greater academic success. (3) Our resource is also open access meaning there are no financial or legal barriers to students who wish to access and use our resource.

Instructions

These study resources consists of several parts. The first part includes a condensed review of the major takeaways from each physiology module. This is followed by a series of questions and fill in the blank worksheets that should be completed after you have gone through the module and course material, in order to verify your understanding.

Disclaimer

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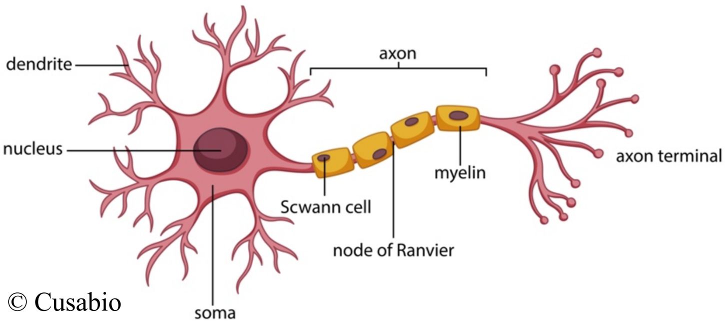
We wish you the best of luck on your exams!
The WebStraw Team

Note to Instructors: If this resource has been created for your course and you would like to collaborate with us, please email us at team@webstraw.ca

Module 4 – Nerve Cells

Typical Neuron



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"Excitable" Cells

Excitable cells include *nerve* and *muscle* cells because they can use their *resting membrane potential* (RMP) to generate an electrical impulse called an *action potential*

- Language of the nervous system
- How nerve cells communicate w/each other

Non-excitable cells cannot generate action potentials and include most of the cells in the body (e.g. RBCs)

"Voltage-Dependent" Na^+ and K^+ channels

Found on the axon of the neuron and critical for the generation of the action potential.

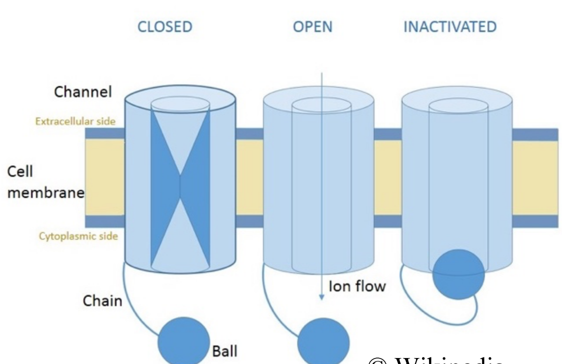
- Sensitive to changes in membrane potential
- Open when inside of cell becomes more (+)

Na^+ channels

- Open first via *activation gate*
  - Allows sodium *into the cell*
- Have *inactivation gate*: prevents further flow
  - Causes absolute refractory period when closed
- Resting configuration: activation gate (CLOSED), inactivation gate (OPEN)

K^+ channels

- Open second, allowing potassium *out of cell*
- Gate closes and channel returns to resting configuration (no inactivation period)



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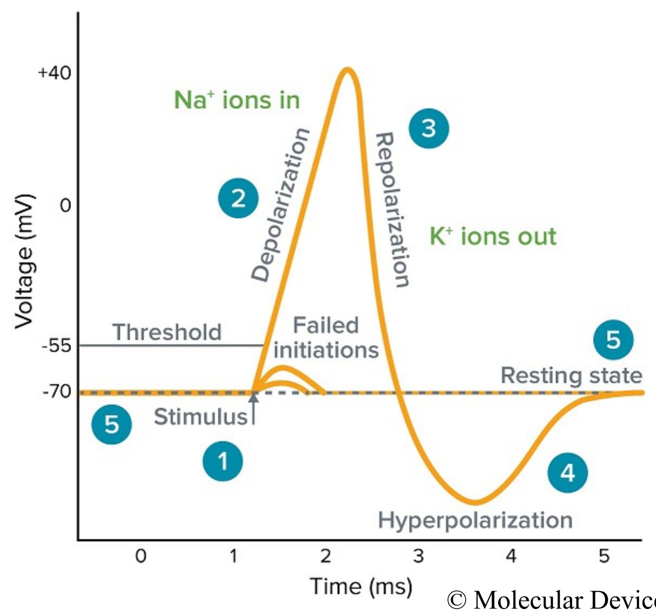
Action Potential



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Summary of Action Potential

1. Strong depolarization at *axon hillock* triggers opening of Na^+ channels
2. Na^+ rushes into neuron, causing depolarization to roughly +35 mV
3. Na^+ channels become inactivated, K^+ channels start opening
4. K^+ rushes out of cell leading to repolarization back to -70 mV
5. K^+ efflux results in hyperpolarization to -90 mV
6. K^+ channels close and membrane potential slowly returns to resting value of -70 mV

Action Potential Definitions

Depolarization: cell's membrane potential becomes more positive (due to influx of Na^+)

Repolarization: cell's membrane potential becomes more negative (due to efflux of K^+)

Threshold: membrane potential that must be reached to initiate an action potential (-55 mV)

Action Potential Definitions Continued

Overshoot: rounded top of action potential curve. Caused by Na^+ moving in while K^+ moves out

Hyperpolarization: cell's membrane potential becomes more negative than it typically is (RMP)

Action Potential (AP) Important Details

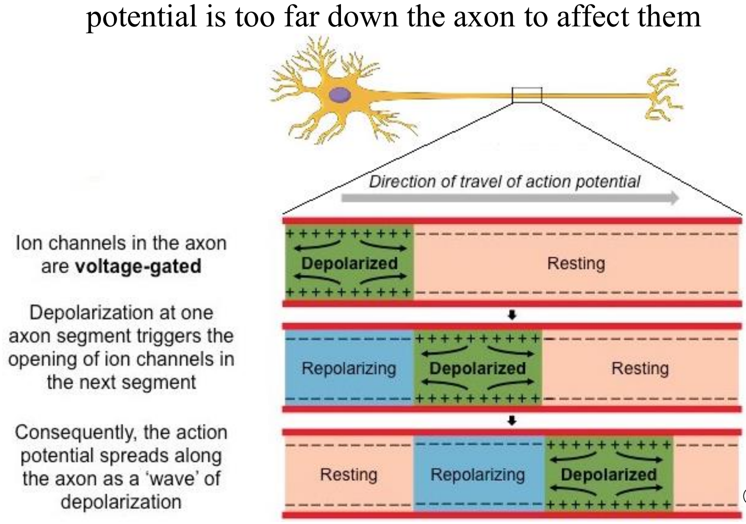
- During an AP, only about one millionth of ions available participate
- The AP does not reach sodium equilibrium potential
    - At the peak of the AP, Na^+ channels begin to close and K^+ channels begin to open, lowering membrane potential
    - Both events cause the *rounded peak* (overshoot) of the AP
- The Na^+/K^+ pump is not required for repolarization
    - Membrane potential restored by continued increased conductance of K^+ when Na^+ permeability has returned to normal

Action Potential Propagation – Unmyelinated Nerve

1. During an AP on the axon, the inside of the membrane is positive (+35mV)
2. The positive charge is attracted to an area next to it on the membrane that is at rest (negative charged) and moves toward it – creating a local current
3. Movement of the positive charge depolarizes the adjacent areas of the membrane
4. Depolarization triggers voltage-gated Na^+ channels to open
5. Na^+ rushes into the cell again and depolarizes the region to threshold, creating another AP
6. By repetition, the AP is propagated along the membrane

Unidirectional Nature of the Action Potential

- Na^+ voltage-gated channels go into a period of inactivation (absolute refractory period) before returning to resting membrane potential.
    - Regardless of the strength of positive currents near them, another AP cannot be re-generated.
- Once the channels are at rest again, the action potential is too far down the axon to affect them



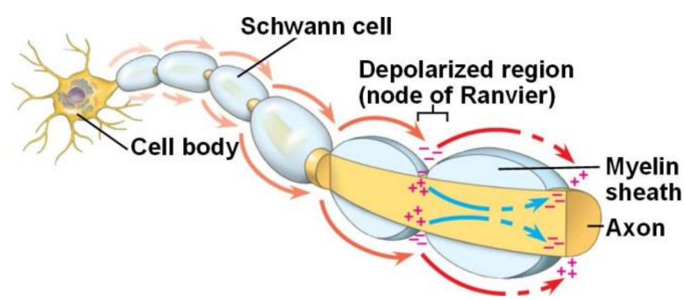
Myelinated Nerve

- Axons insulated with a fatty material called myelin
    - prevents ions from leaking through the membrane
- Na^+ and K^+ channels only exist at the gaps between the myelin - *nodes of Ranvier*

Action Potential Propagation – Myelinated Nerve

1. The positive charge from the existing AP attracted to and moves toward the adjacent *node of Ranvier* that is negative
2. This node of Ranvier depolarizes, triggering voltage-gated Na^+ channels to open.
3. Na^+ rushes into the cell and depolarizes the region to threshold, generating a new action potential.
4. By repetition, the action potential is propagated along the membrane

- Propagation is also unidirectional
- Propagation is faster with myelinated nerves due to saltatory conduction (jumps to nodes of Ranvier)



Action Potentials are All-or-Nothing

- If threshold is not reached, membrane potential will return to normal (-70 mv)
- If threshold is reached, AP is generated and will be propagated down the axon without decreasing in size

Review Questions

1. Which of the following statements about voltage-gated K+ channels is true?
    a. They contribute to the rising (depolarizing) phase of the action potential
    b. They begin opening when the membrane is in the hyperpolarized phase of the action potential
    c. They open soon after depolarization of the membrane
    d. They allow the movement of any positive ion (cation)

2. Which of the following is FALSE regarding an action potential?
    a. Action potentials are 'all-or-nothing' events
    b. Very few ions actually cross the membrane during an action potential
    c. The Na+/K+ pump is required to re-establish the resting membrane potential of -70 mV after an action potential
    d. The rounded peak at the top of the action potential occurs because both Na^+ and K^+ voltage gated channels are open at the same time

3. What is true regarding the relative refractory period?
    a. It is caused by the closing of the Na+ inactivation gate
    b. It occurs during cell hyperpolarization
    c. It is a period in time in which another action potential can fire
    d. Both B and C are correct

4. Which of the following is TRUE regarding action potential propagation?
    a. Propagation occurs slower in myelinated nerves due to the presence of myelin
    b. Propagation occurs faster in myelinated nerves due to the presence of myelin
    c. Propagation speed in myelinated and unmyelinated nerves is the same
    d. Propagation occurs slower in unmyelinated nerves due to the presence of myelin

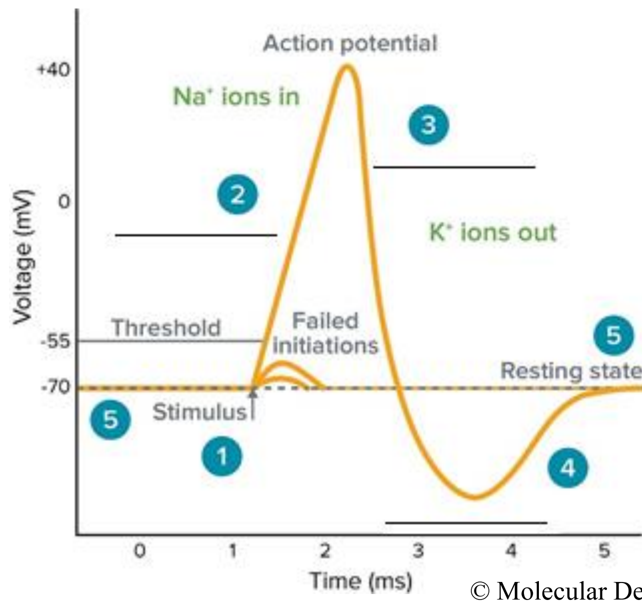
5. Which of the following is FALSE regarding the unidirectional nature of action potentials
    a. Action potentials are unidirectional due to the absolute refractory periods caused by K^+ voltage-gated channels
    b. Once an action potential has fired, regardless of the strength of positive currents near them, another AP cannot be re-generated until after the absolute refractory period
    c. Action potentials are unidirectional in both unmyelinated and myelinated nerves
    d. The action potential has travelled away from activated channels by the time they come out the absolute refractory period

Answer Key:
1. C 2. C 3. D 4. B 5. A

Fill in the blanks – Action Potential Summary

1. Strong depolarization at *axon hillock* triggers opening of ___ channels
2. ___ rushes into neuron, causing depolarization to roughly ___ mV
3. ___ channels become inactivated, ___ channels start opening
4. ___ rushes out of cell leading to repolarization back to ___ mV
5. ___ efflux results in hyperpolarization to ___ mV
6. ___ channels close and membrane potential slowly returns to resting value of ___ mV

Fill in the blank stages of the diagram below:



True or False?

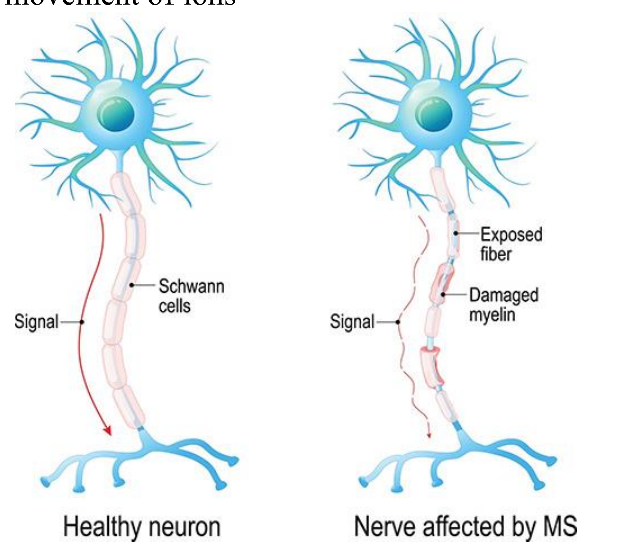
1. Depolarization of a cell is when its membrane potential becomes more negative in value.
2. Propagation of action potentials in unmyelinated and myelinated nerves is unidirectional.
3. Action potentials exhibit "all-or-nothing" behaviour.
4. Action potential propagation is faster in unmyelinated axons.
5. It is possible to fire another action potential during the relative refractory period.
6. The absolute refractory period is caused by the closing of activation gate Na^+ channels.

Things to keep in mind when considering action potentials:

- Unlike charges attract
- Direction of current flow is generally + to –
- Current is carried by positively charged ions, such as Na^+
- Currents are set up inside and outside the axon due to the movement of ions

Real Life Application – Multiple Sclerosis (MS)

- A disease of the brain and spinal cord (Central Nervous System)
- Caused by the body's immune system attacking and damaging myelin surrounding axons of nerves
- Can interrupt the natural flow of action potentials along the axon to the point where no transmission occurs
- Damaged nerves connected to muscle, will reduce muscle contraction and possibly result in paralysis



Answers:

Fill in the blanks - Action Potential Summary

1. Na^+
2. Na^+, +35
3. Na^+, K^+
4. K^+, -70
5. K^+, -90
6. K^+, -70

Action Potential Diagram

2. Depolarization
3. Repolarization
4. Hyperpolarization

True or False

1. F
2. T
3. T
4. F
5. T
6. F