Nerves and the neuronal action potential

TBIOL 140: Introductory Biology 3

Demo Lesson

Learning Outcomes

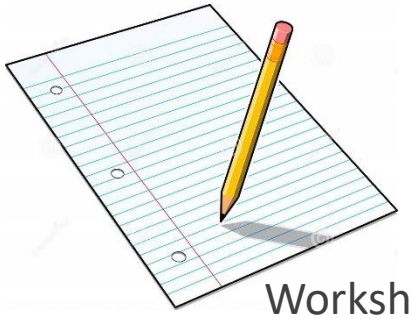
By the end of today's lesson <u>you will know</u>:

- ❑ the main anatomical structures of the neuron and its membrane
- ❑ how the membrane potential is maintained

After completing all the assignments <u>you will be able to</u>:

- ❑ explain how the neurons communicate with each other
- ❑ describe the mechanisms underlying the neuronal action potential
- ❑ evaluate how neuronal damage (such as demyelination) might affect the transmission of nerve impulses

Class Activities

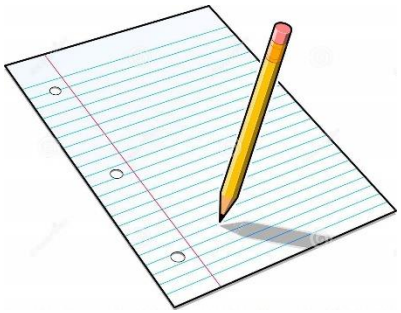


Worksheet

Small group discussion

All-class-discussion

In-class ungraded quizzes



Nervous system?

Worksheet Part 1. Please list the first words (associations) that come to your mind (30 sec)

TBIOL 140: Nerves and the neuronal action potential

Worksheet

Part I. Nervous system.

In the provided space below, please list the first words (associations) that come to your mind when you hear "nervous system" (30 sec)

- Please compare your lists in pairs and pick 5 unique associations (30 sec)

Nervous system?

Please compare your lists in pairs and pick 5 unique associations

(30 sec)

Please share your unique associations in your group and, again, pick 5 unique associations

(30 sec)

Please share your associations with the class

(2 min)

Nervous system

Neurons: individual nerve cells, responsible for the working of the brain and the rest of the nervous system

Neurons conduct information in the form of electrical signals from point to point in the body

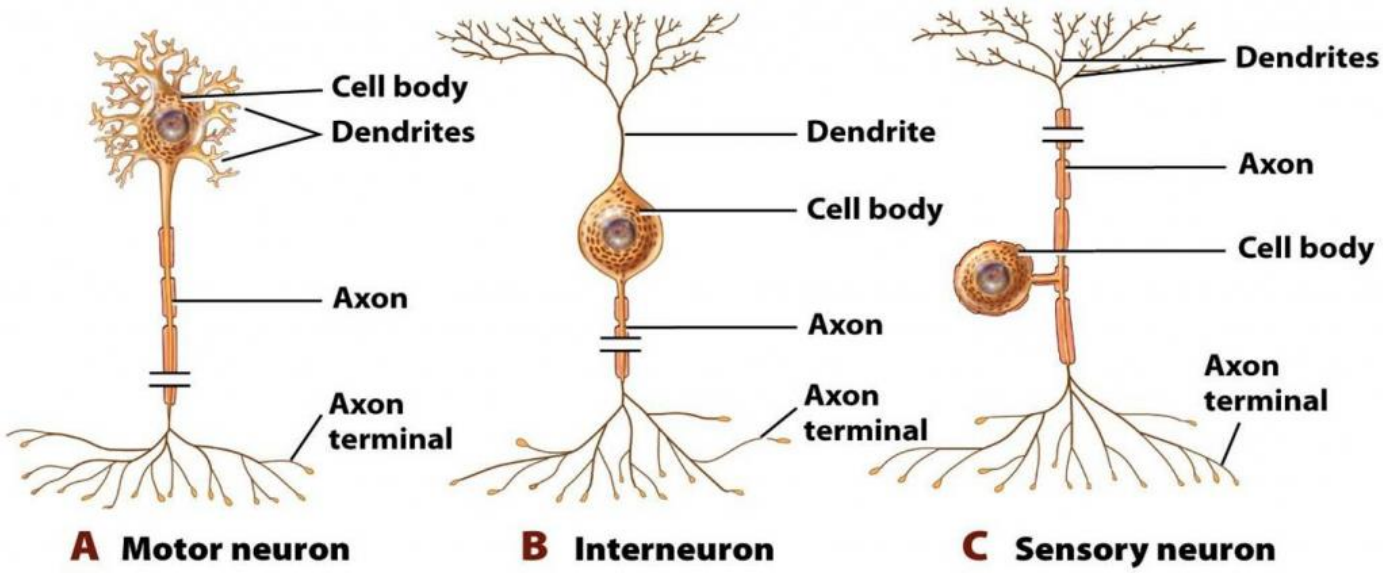
Electrical signaling is a crucial aspect of information processing

2 basic types of nervous systems:

(1) A nerve net: the diffuse arrangement of cells (e.g., jellyfish, hydra, anemones)

(2) A central nervous system (CNS): large numbers of neurons are aggregated into clusters (cephalization played an essential role in animal evolution). In vertebrates, the CNS consists of the brain and spinal cord

Types of neurons



Nerve cells that send signals to effector cells in glands or muscles

Cells in the CNS, "between-neurons", which pass signals from one neuron to another

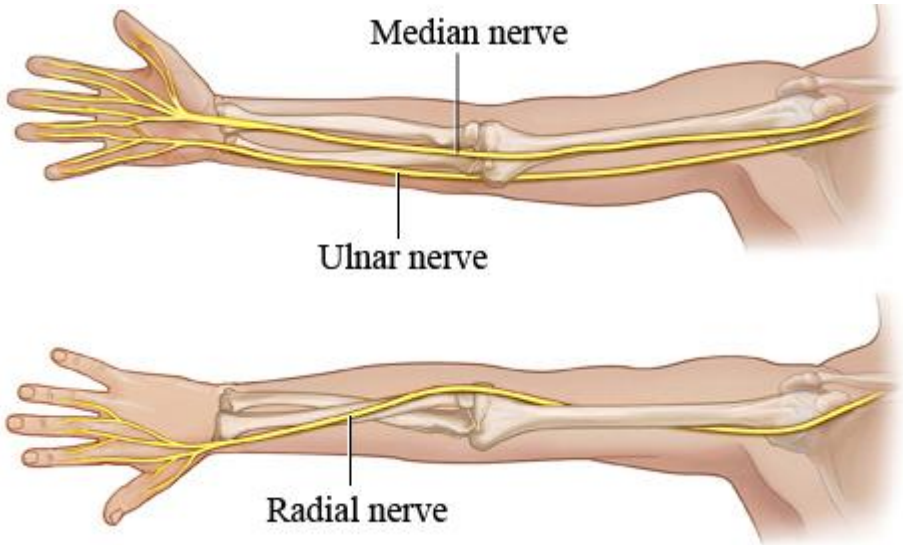
Nerve cells that carry information to the CNS

https://www.earthslab.com/physiology/sensory-motor-functions-and-neurons/

Nervous system and nerves

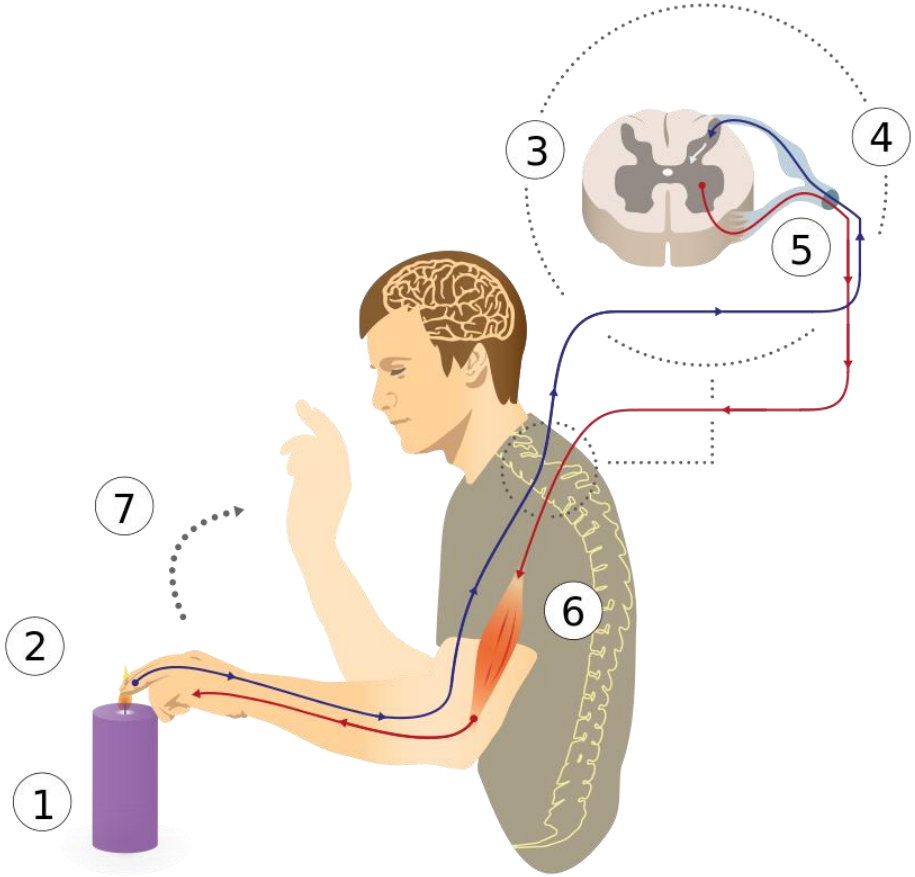
The peripheral nervous system (PNS): all neurons and other components of the nervous system that are outside the CNS

Motor neurons and sensory neurons are bundled together into long strands of nervous tissue called **nerves**



Discussion

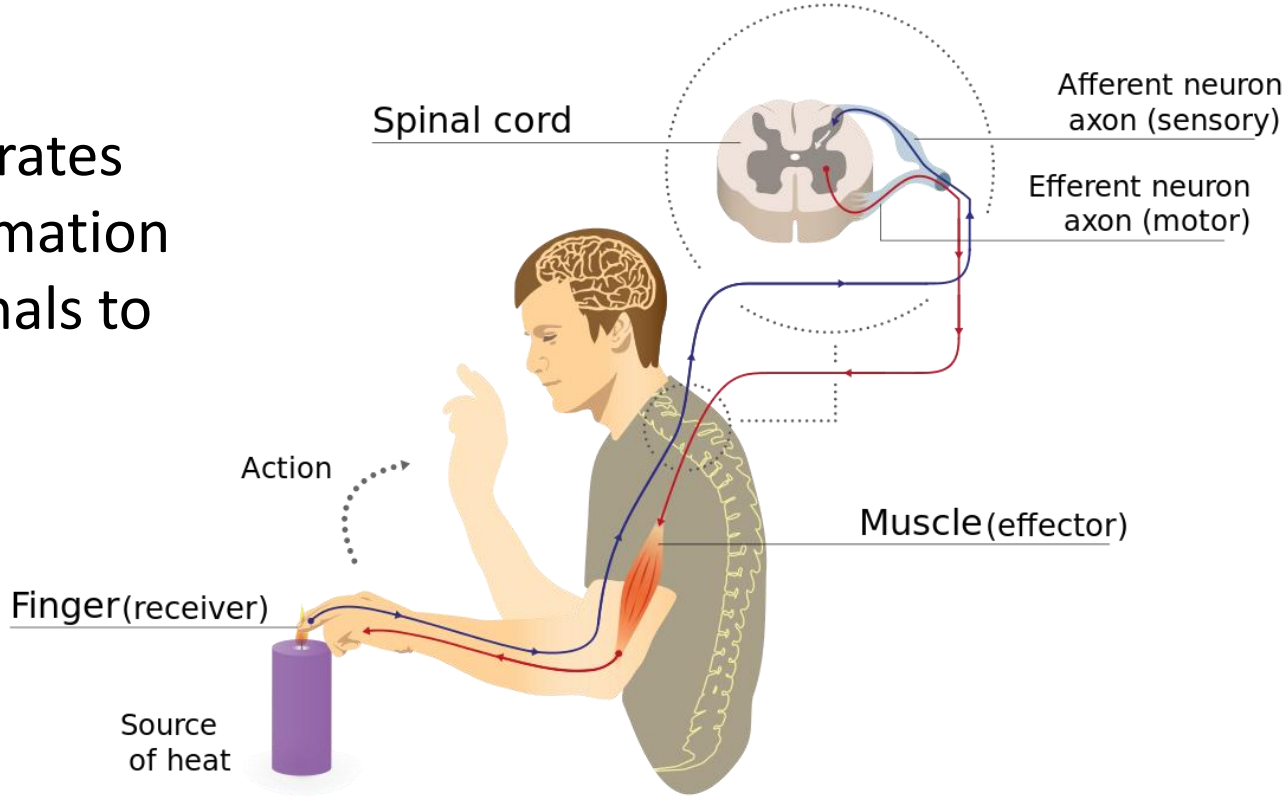
The CNS integrates sensory information and sends signals to effector cells.



Pre-class assignment

Discussion

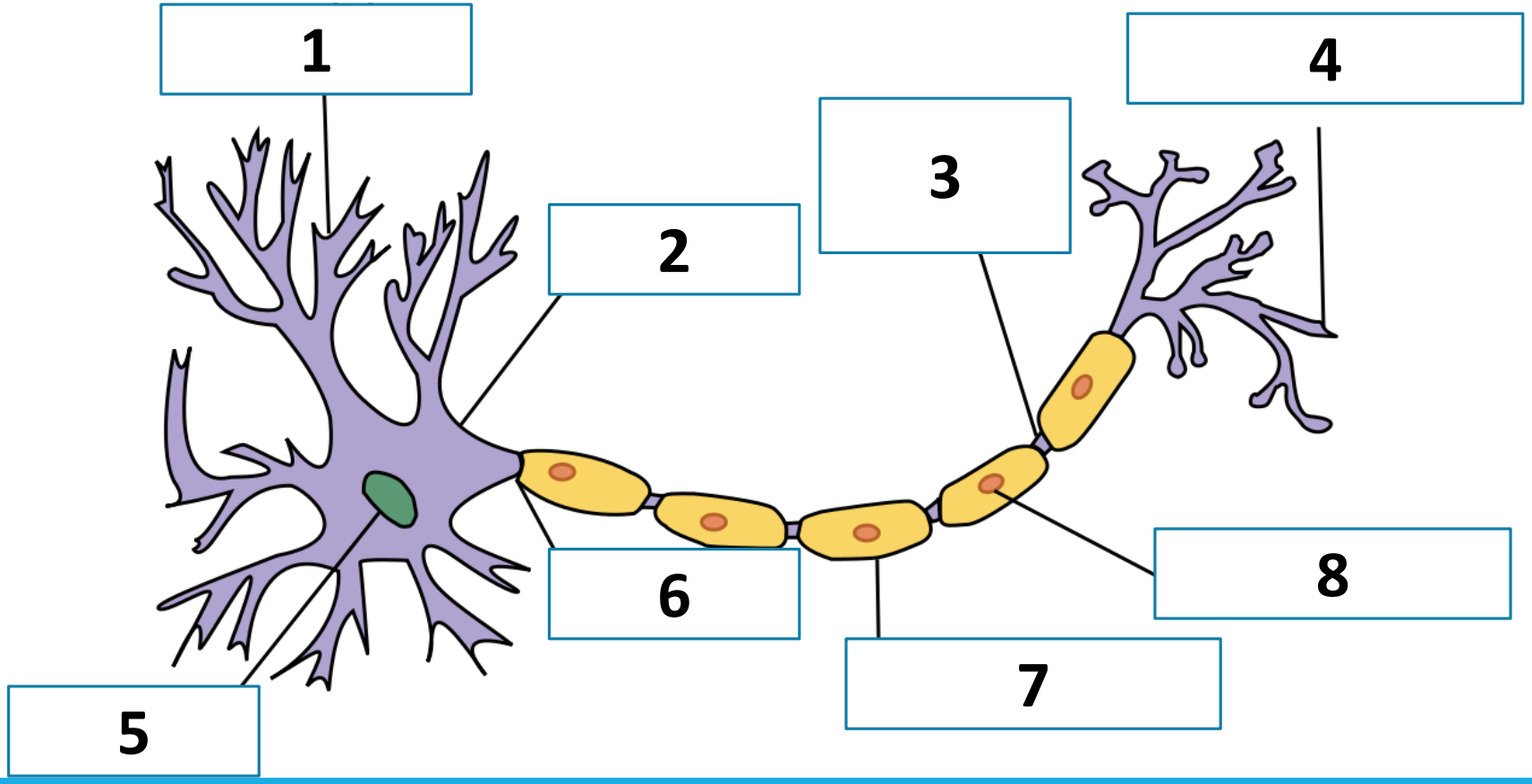
The CNS integrates sensory information and sends signals to effector cells.



Pre-class assignment

Discussion

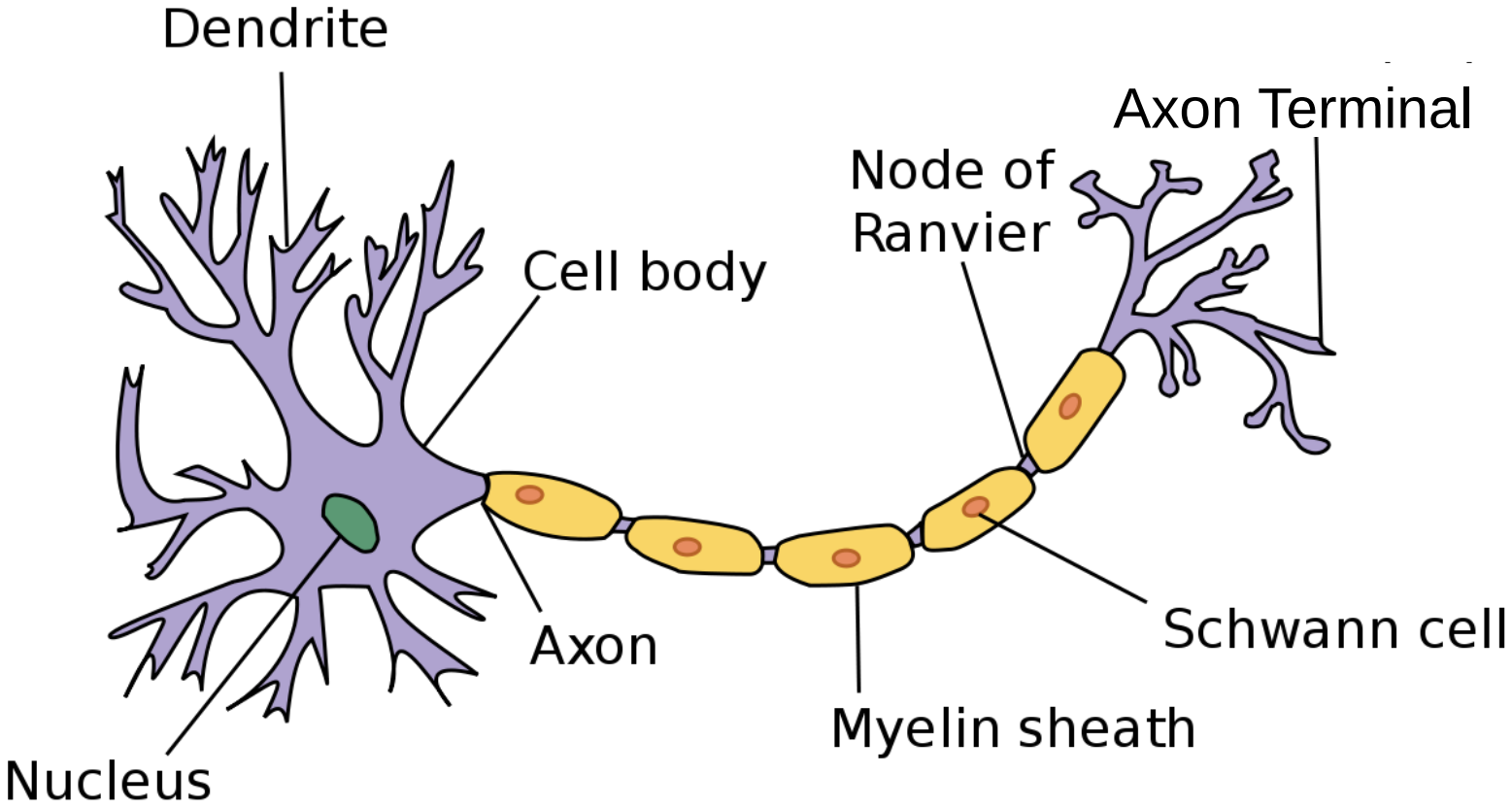
The anatomy of a neuron



https://commons.wikimedia.org/wiki/File:Neuron.svg

Discussion

The anatomy of a neuron



https://commons.wikimedia.org/wiki/File:Neuron.svg

Concept Check

1. The specialized accessory cells of the central nervous system that wrap around some axons to provide electrical insulation.

(A) Schwann cells (B) Axon terminal

2. Neuron which carries signals to the effector (a muscle, gland, etc.).

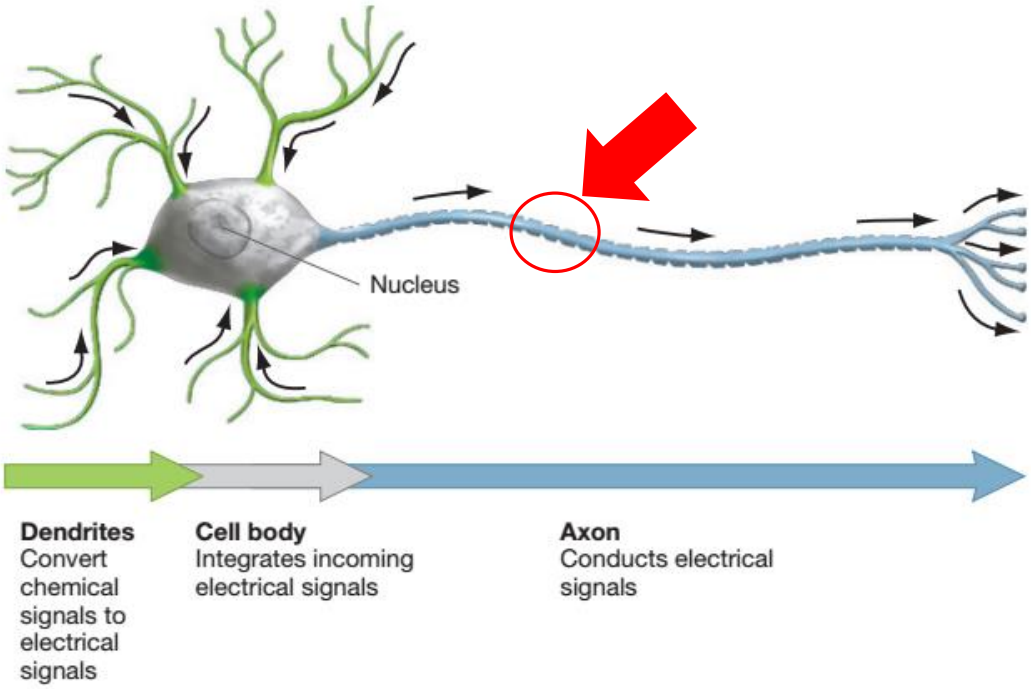
(A) Efferent motor neuron (B) Afferent sensory neuron

3. A short extension from a neuron's cell body that receives signals from other neurons.

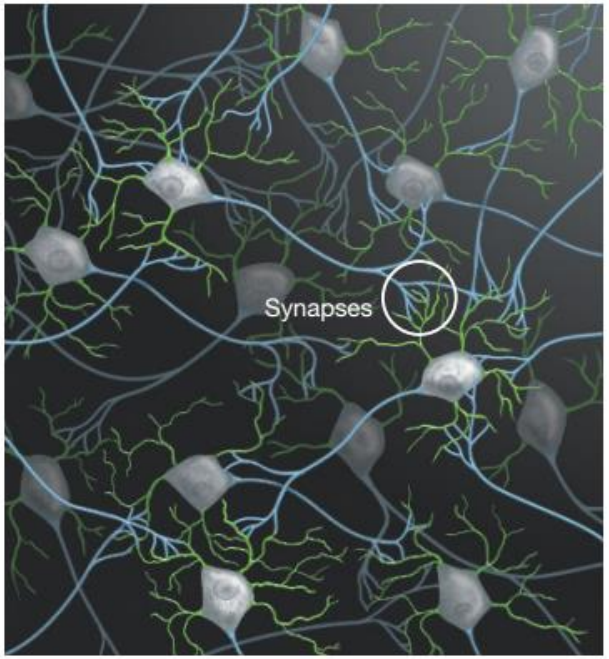
(A) Axon (B) Dendrites

How does information flow in a neuron?

(a) Information flows from dendrites to the axon.

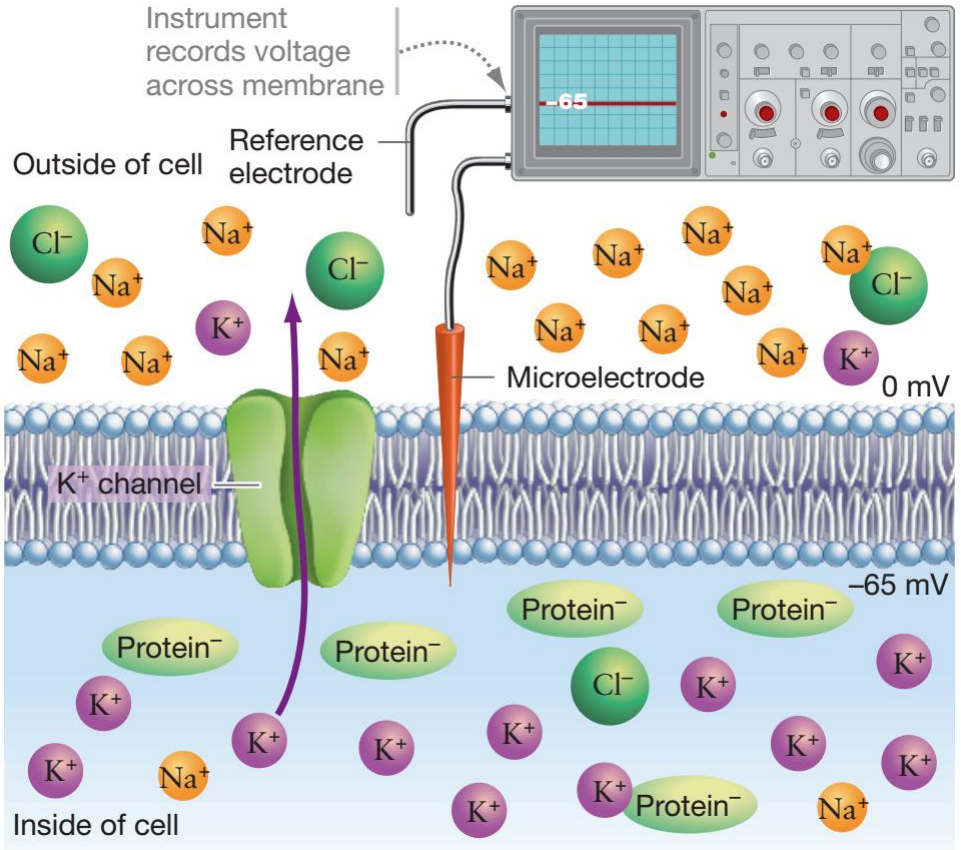


(b) Neurons form networks for information flow.



Discussion

What do you see?



What does it mean?

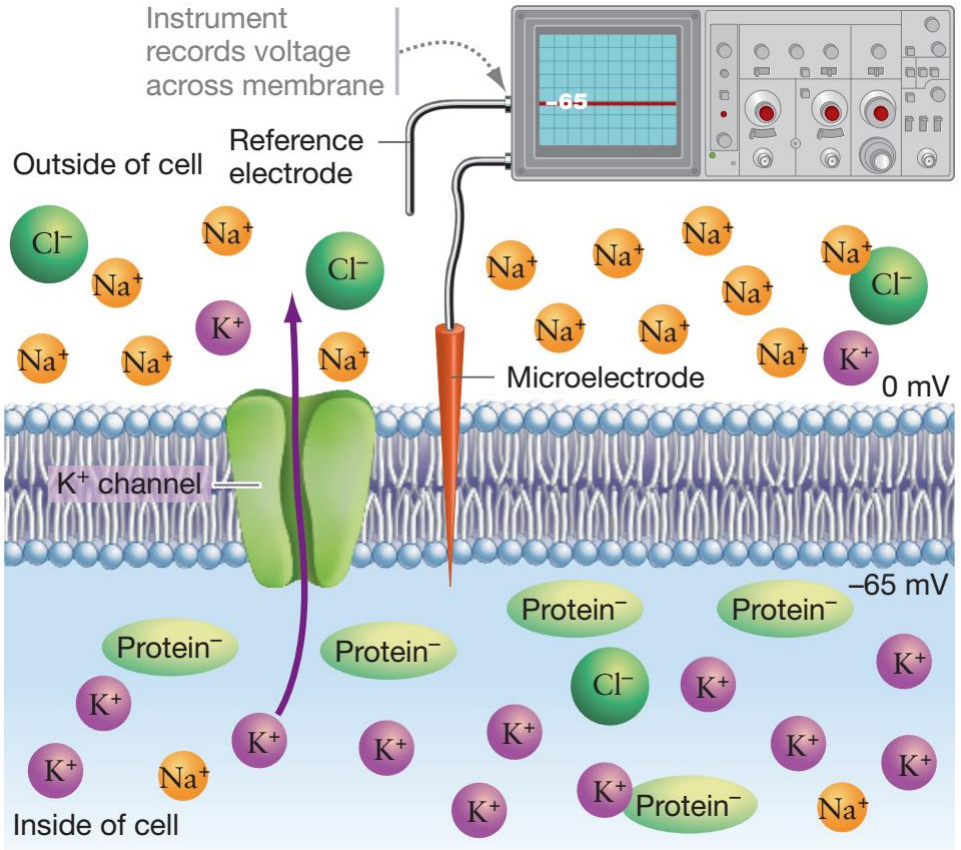
- Predominant ions?

Outside of the cell

(A) Na^+ (B) K^+

Inside of the cell

(A) Na^+ (B) K^+



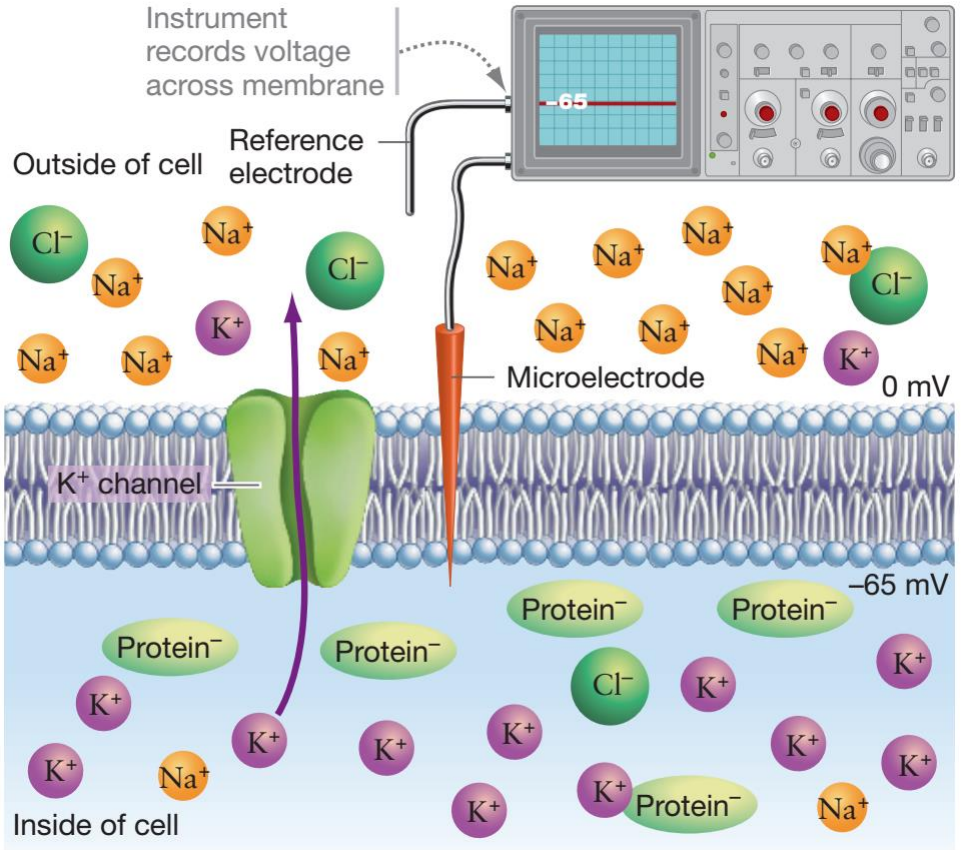
What does it mean?

- What ions go inside of the cell?

(A) Na+ (B) K+

- What ions go outside of the cell?

(A) Na+ (B) K+



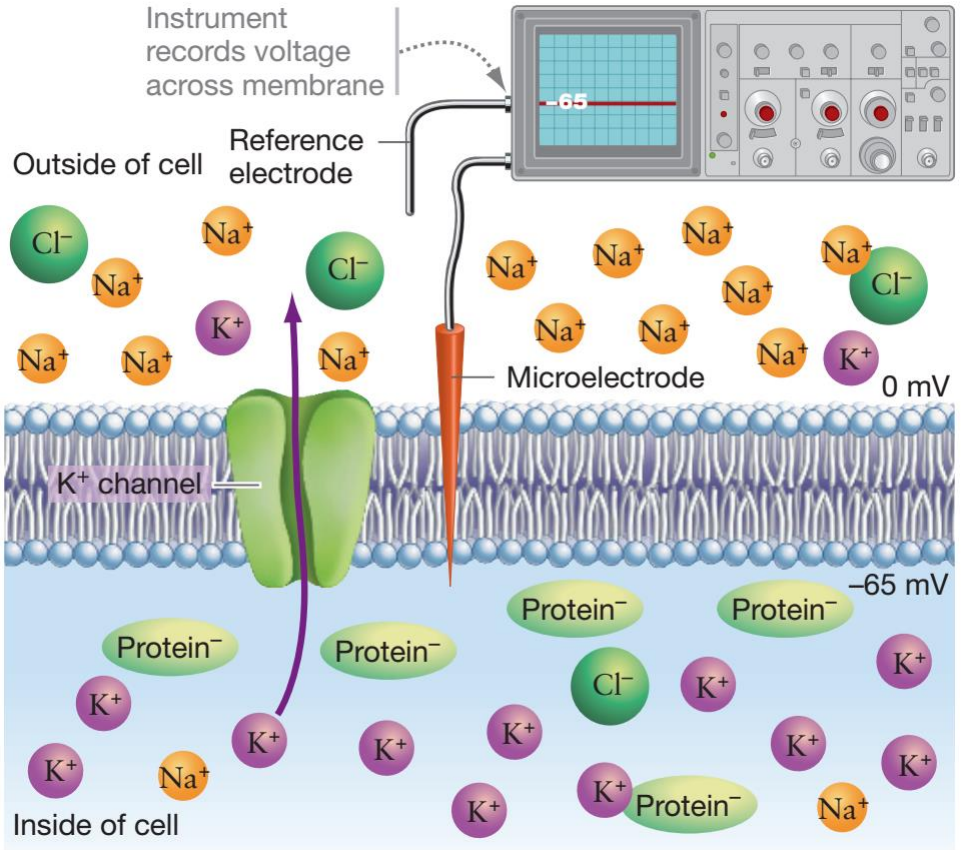
What does it mean?

- Electric charge outside of the cell? Why?

(A) + (B) −

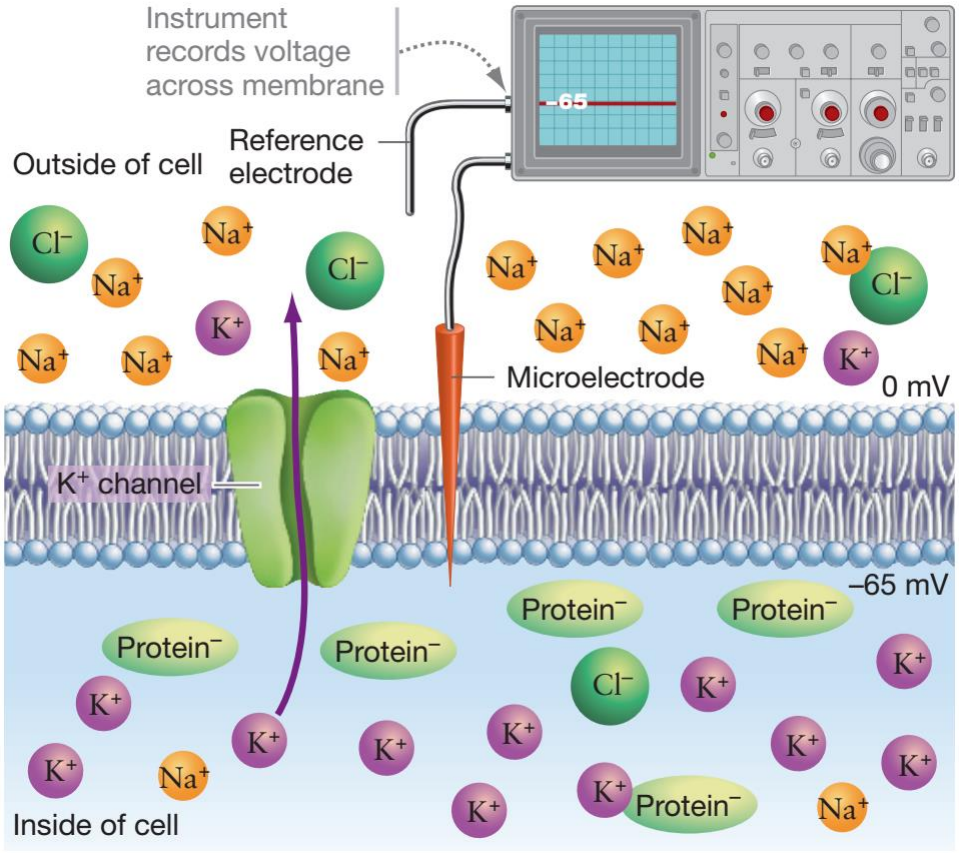
- Electric charge inside of the cell? Why?

(A) + (B) −



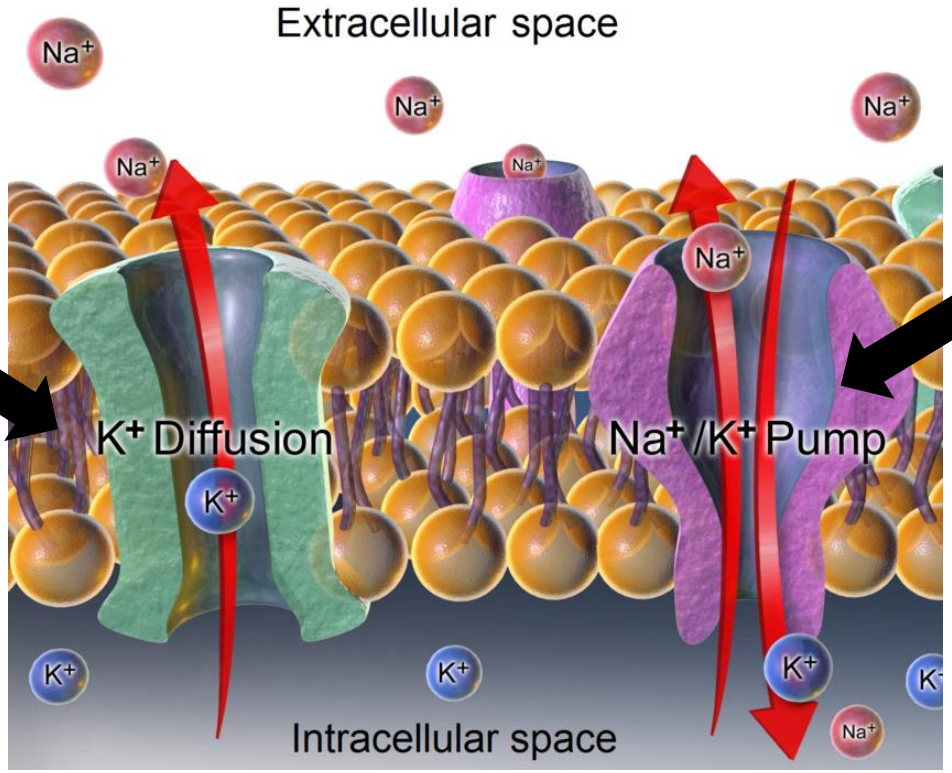
Membrane potential

The resting potential: the difference in charge across a neuron's membrane when the neuron is not communicating with other cells



How Is the Resting Potential Maintained?

K+ leak channels



The sodium–potassium pump, Na+/K+-ATPase, actively pumps Na+ out of the cell and K+ into the cell: 3 Na+ ions out of the cell and 2 K+ ions into the cell

Concept Check

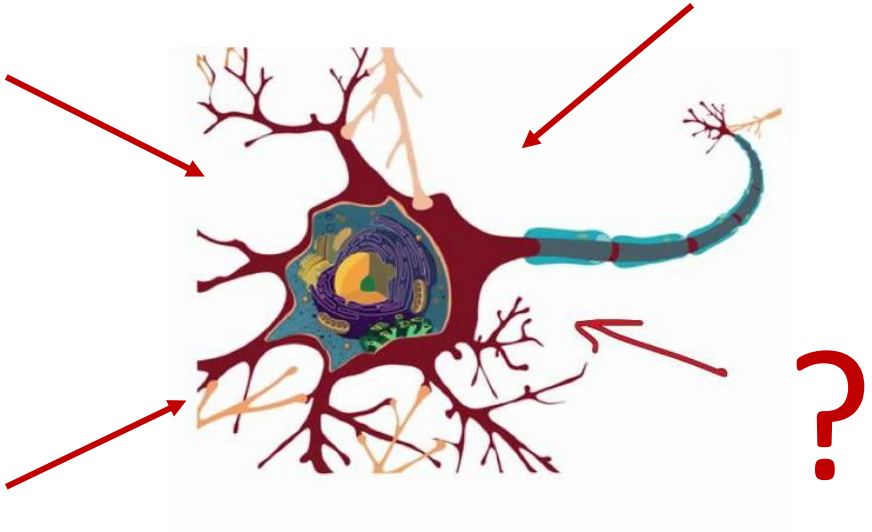
1. A typical neuron has a resting membrane potential of about:

(A) +70 mV (B) +70 V (C) -70 mV (D) -70 V

2. Potassium channel that allows potassium ions to leak out of a neuron in its resting state:

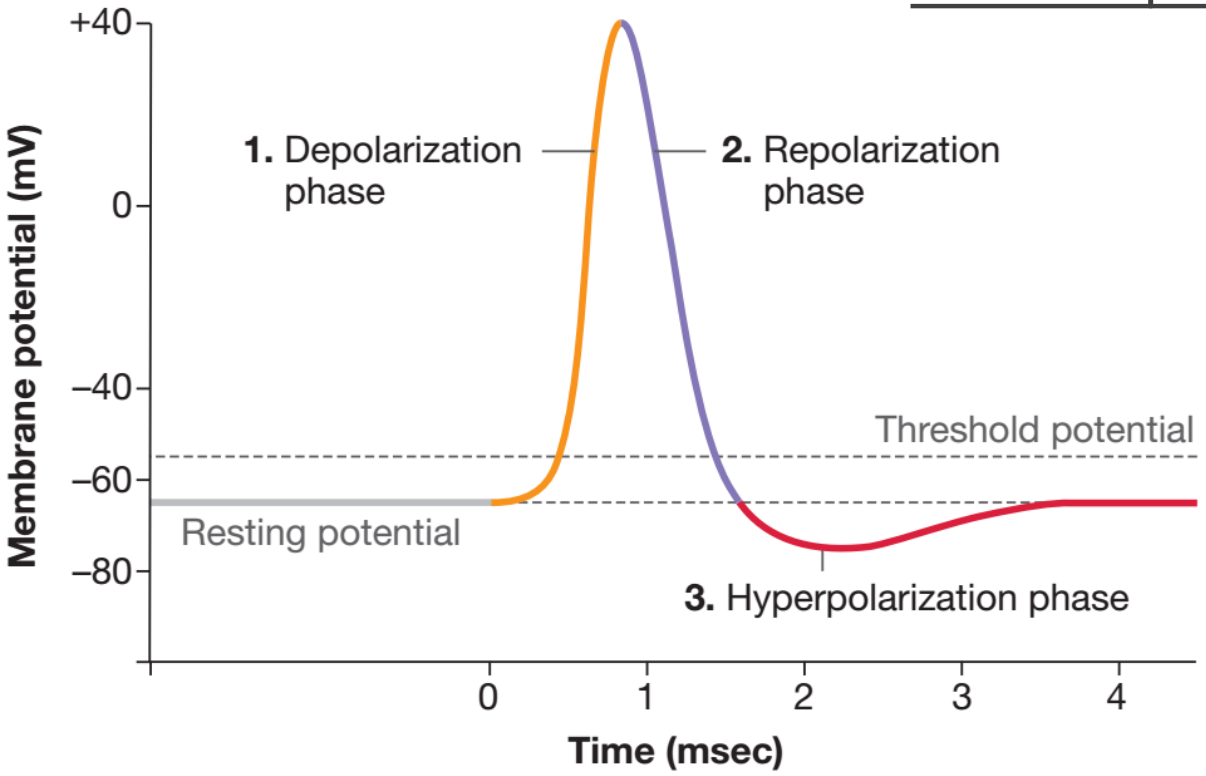
(A) Axon terminal (B) Leak channel (C) The sodium–potassium pump

What will happen if the neuron is stimulated?



Discussion

Action potential

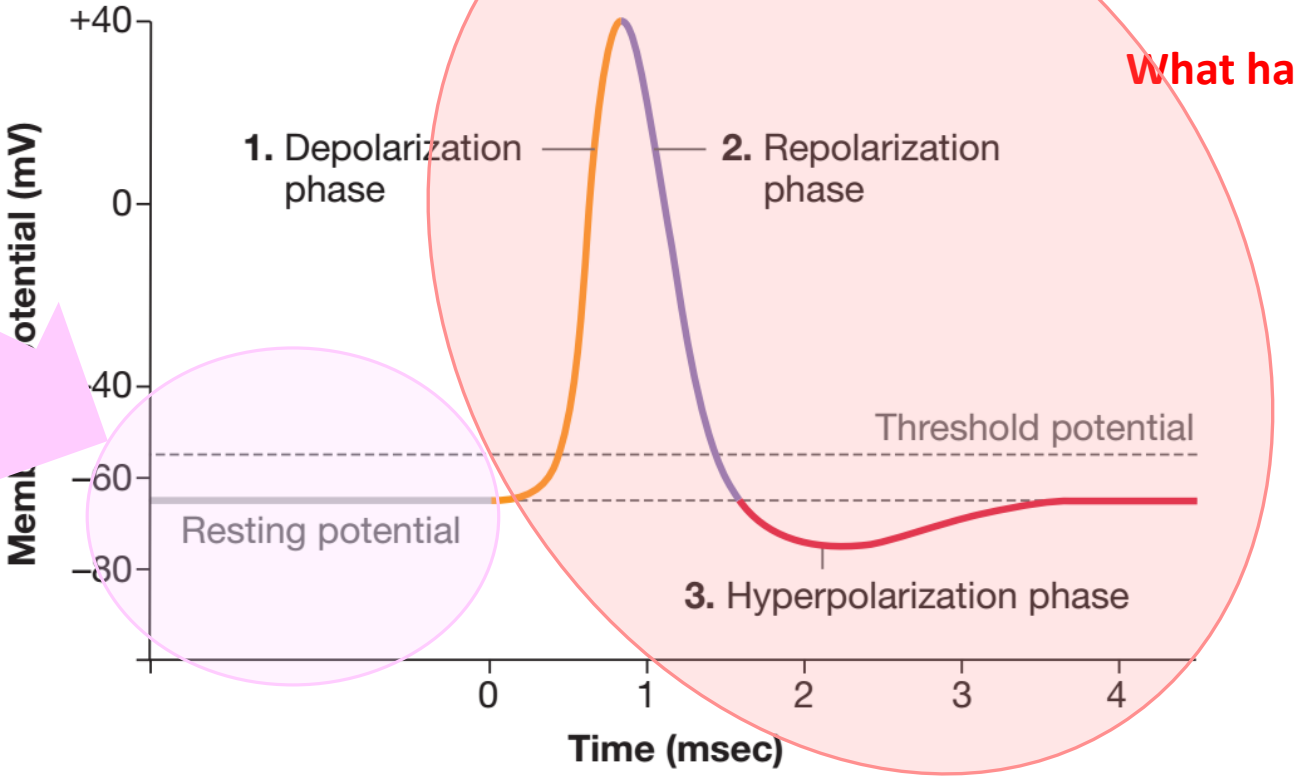


Freeman, Scott. Biological Science. 6th Ed. 2016 (p. 903). Pearson Education. Kindle Edition.

Discussion

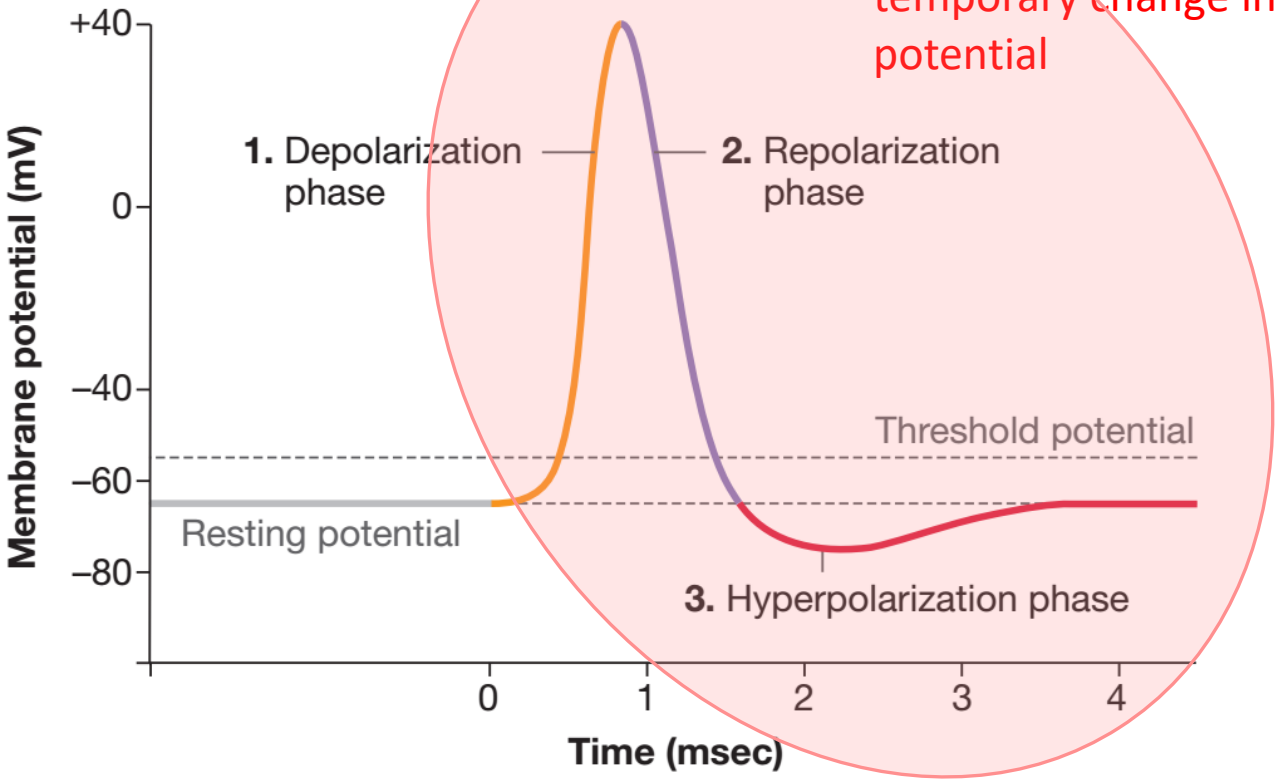
We have just described

What happens here?



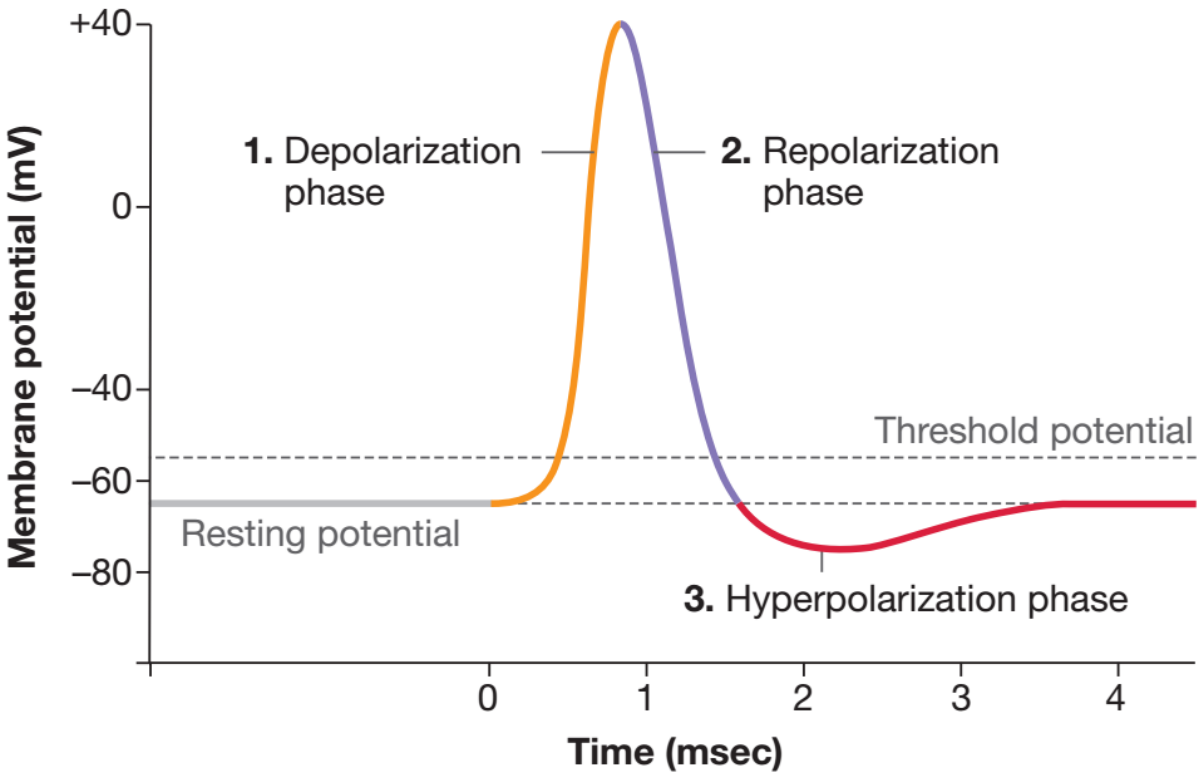
Discussion

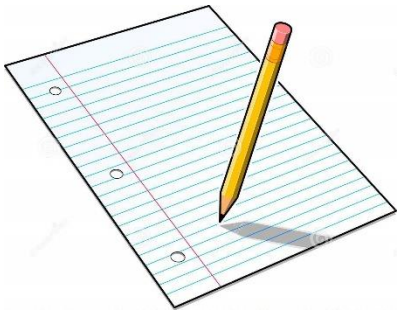
An action potential: a rapid, temporary change in a membrane potential



Action potential

1. **Depolarization phase**
2. **Repolarization phase**
3. **Hyperpolarization phase**





Action potential

1. Depolarization phase **2. Repolarization phase** **3. Hyperpolarization phase**

Worksheet Part 2. Your group will be assigned a phase. For this phase, please describe the following:

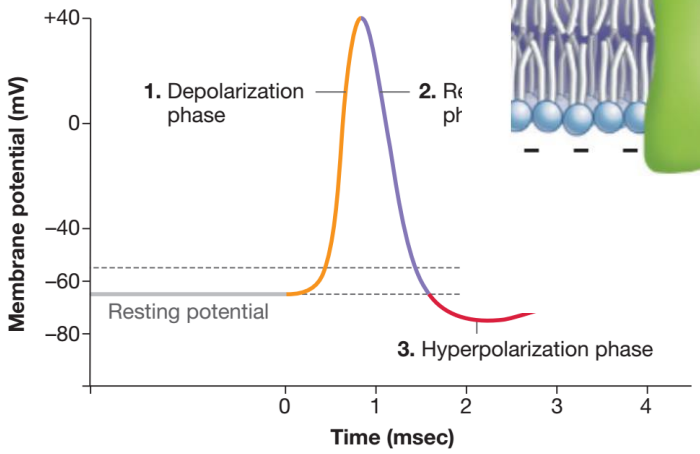
- Charges on each side of the membrane
- Changes in membrane potential (becomes more/less positive, negative, or no changes)

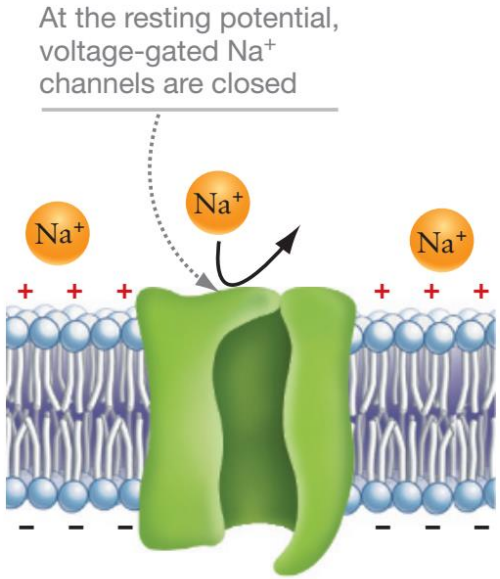
Please fill out the corresponding part of Table 1 in your worksheet.

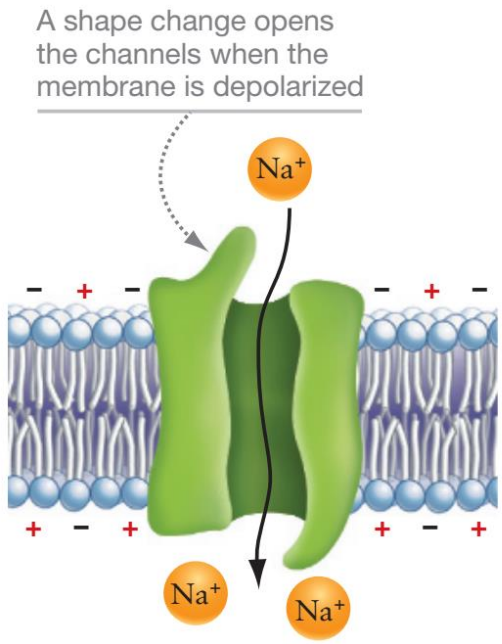
Using the answers from other groups on other phases, please fill out the other parts of Table 1 in your worksheet.

Action potential: how does it work?

The membrane contains ion channels whose behavior depends on voltage (**voltage-gated channels**)







Freeman, Scott. Biological Science. 6th Ed. 2016 (p. 904). Pearson Education. Kindle Edition.

Action potential is an “all-or-none” event

- There is no such thing as a partial action potential
- All action potentials for a given neuron are identical in magnitude and duration
- Action potentials are always propagated down the entire length of the axon

Freeman, Scott. Biological Science. 6th Ed. 2016 (p. 904). Pearson Education. Kindle Edition.

Concept Check

1. A rapid, temporary change in electrical potential across a membrane, from negative to positive and back to negative.

(A) Resting potential (B) Action potential

2. Match each ion's movement with the type of graded potential it creates.

Na^+ entry -> (A) Depolarization (B) Hyperpolarization

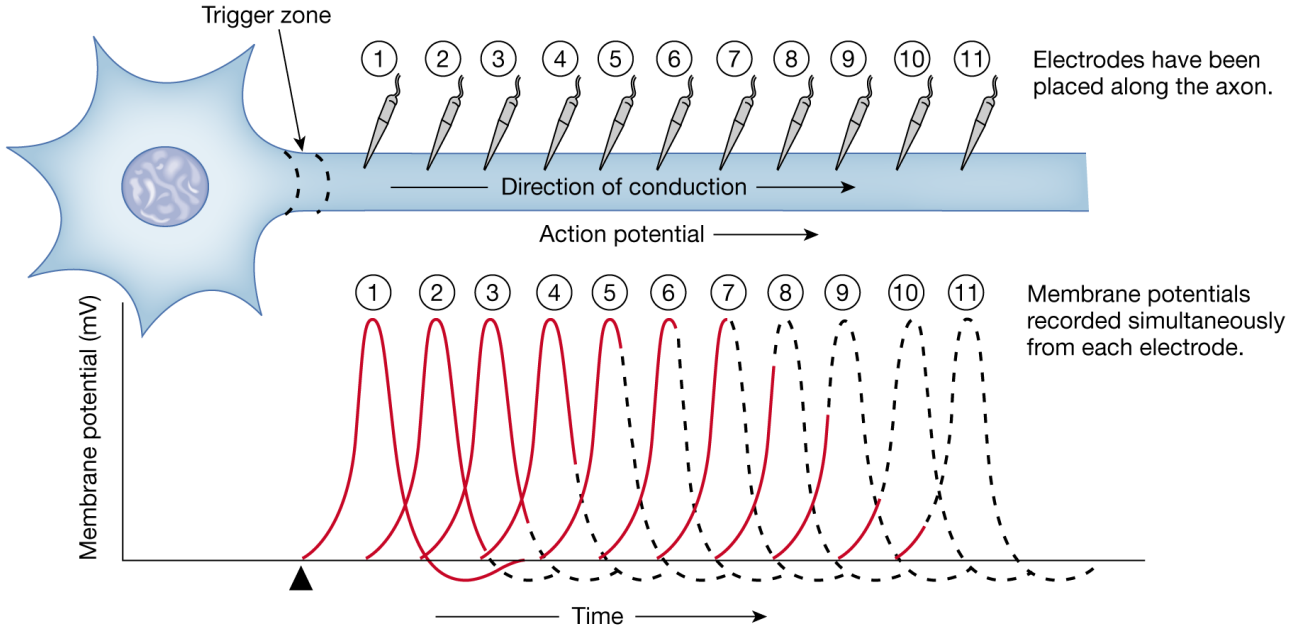
K^+ exit -> (A) Depolarization (B) Hyperpolarization

3. Return to a normal membrane potential after it has changed; a normal phase in an action potential.

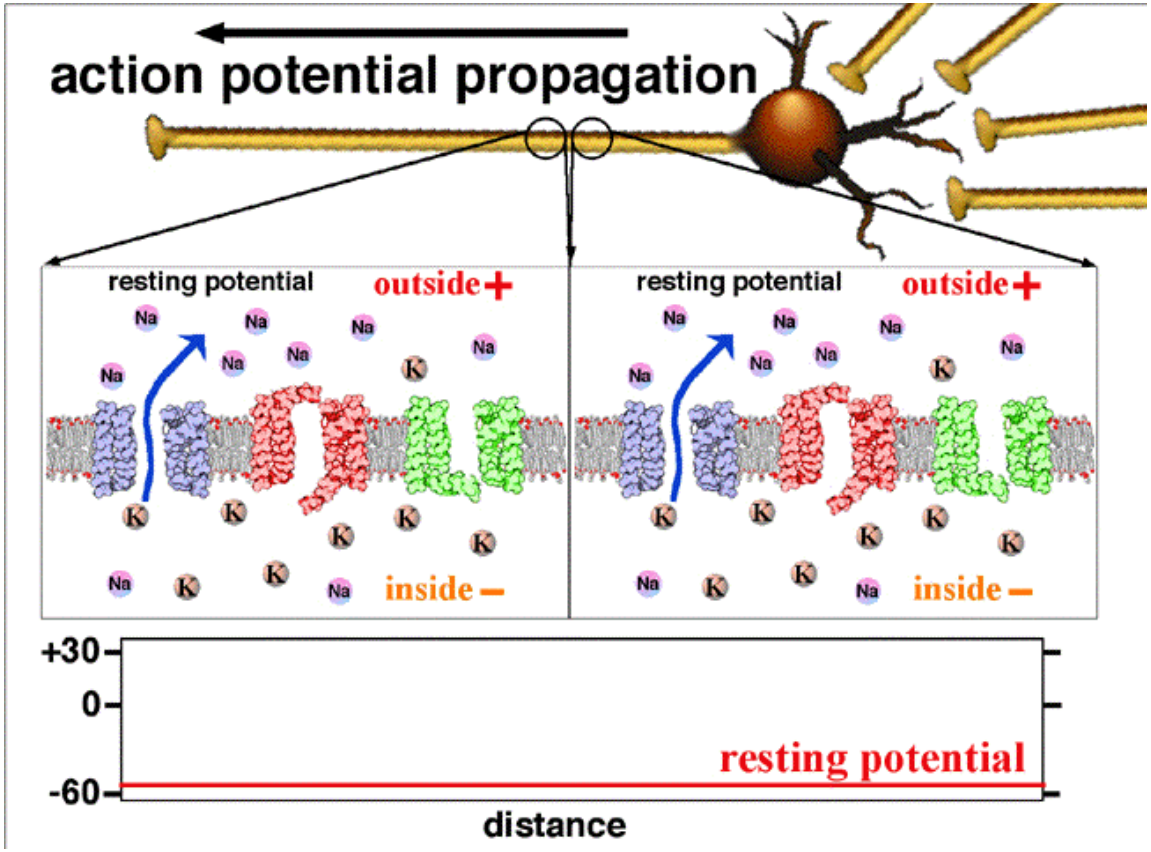
(A) Depolarization (B) Repolarization (C) Hyperpolarization

How do action potentials propagate?

Falling dominos



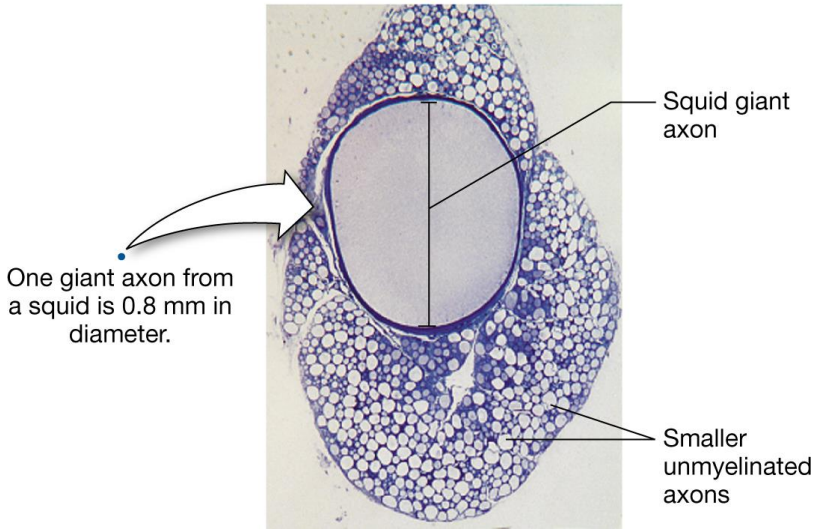
Propagation of action potential



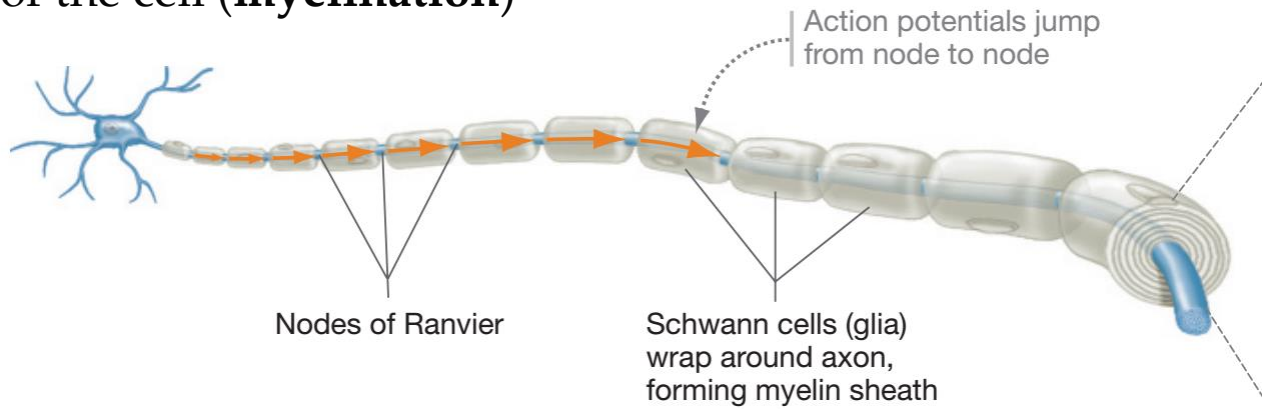
Animation: https://teachmephysiology.com/nervous-system/synapses/action-potential/

Key factors affecting the speed of action potential conduction

(1) the **diameter** of the axon

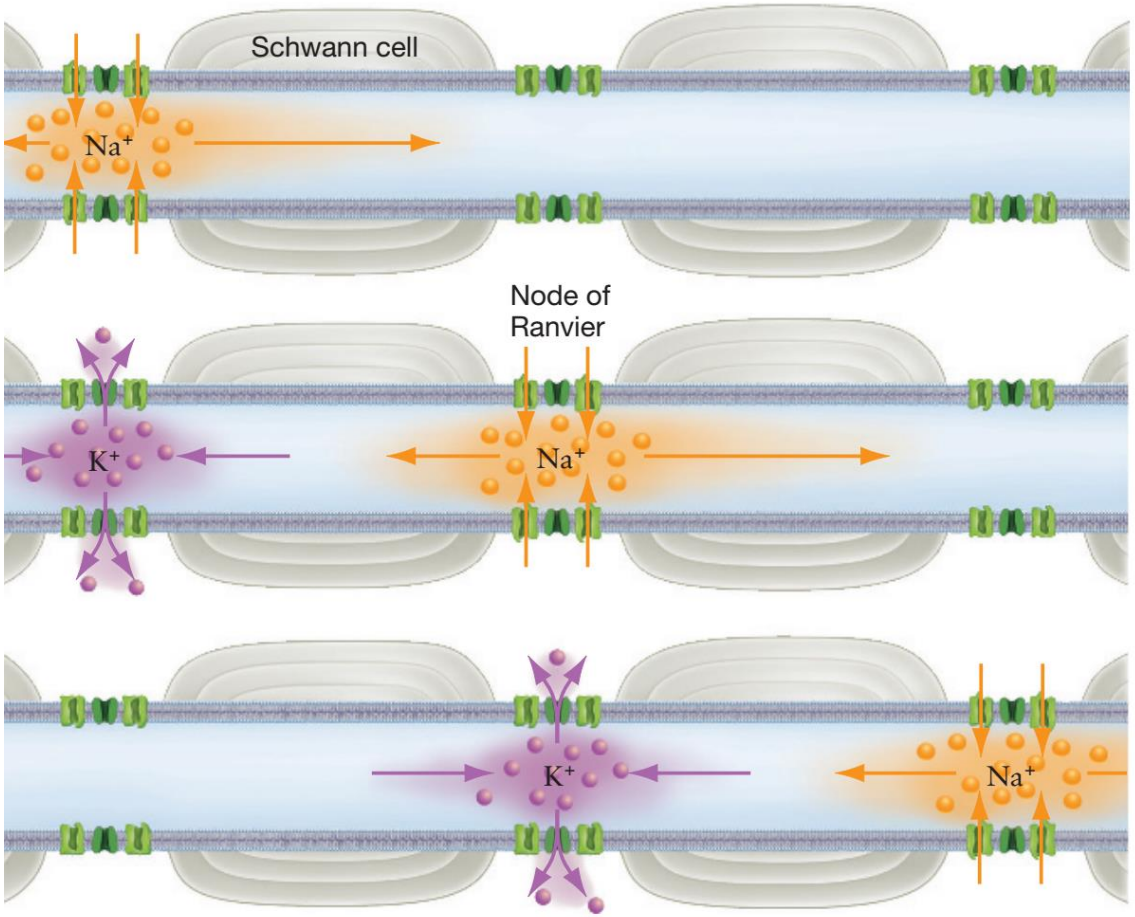


(2) the resistance of the axon membrane to ion leakage out of the cell (**myelination**)



Freeman, Scott. Biological Science. 6th Ed. 2016 (p. 906). Pearson Education. Kindle Edition.

Action Potentials in Myelinated Axons



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Concept Check

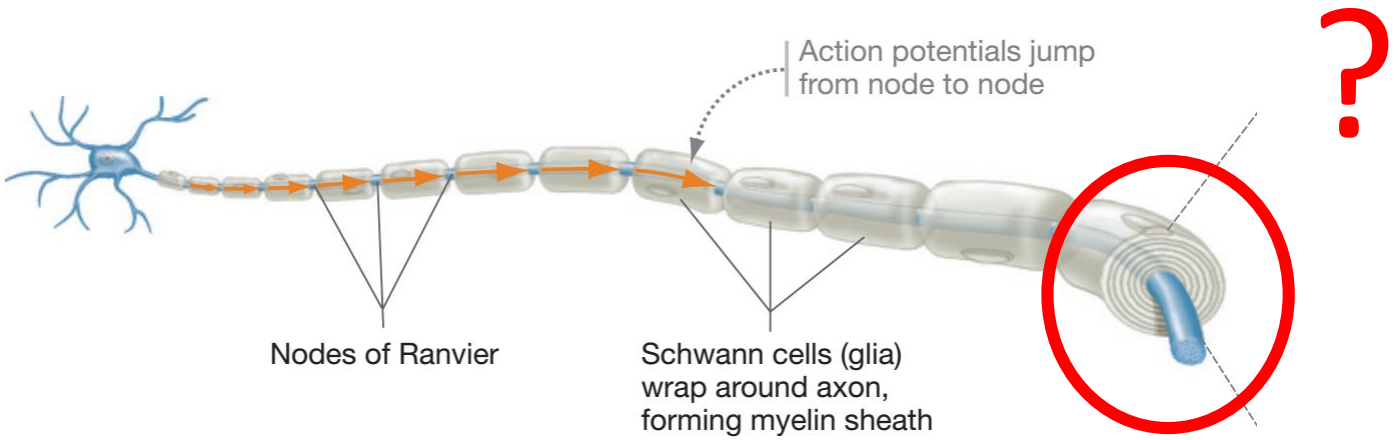
1. One of the periodic unmyelinated sections of a neuron's axon at which an action potential can be regenerated:
(A) Nodes of Ranvier (B) Axon terminal

2. A stimulating electrode placed halfway down an axon artificially depolarizes the cell above threshold. In which direction will an action potential travel:

(A) to the axon terminal (B) to the cell body (C) to both

3. Place the following neurons in order of their speed of conduction, from fastest to slowest:
(A) myelinated axon, diameter 20 µm
(B) unmyelinated axon, diameter 20 µm
(C) unmyelinated axon, diameter 200 µm

What happens when action potentials reach the end of the axon?



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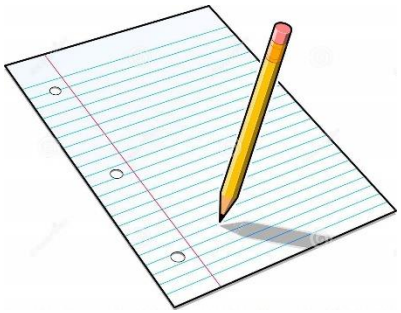


Synapse

Worksheet Part 3. Please watch this 1-min video and answer the corresponding questions in your worksheet:

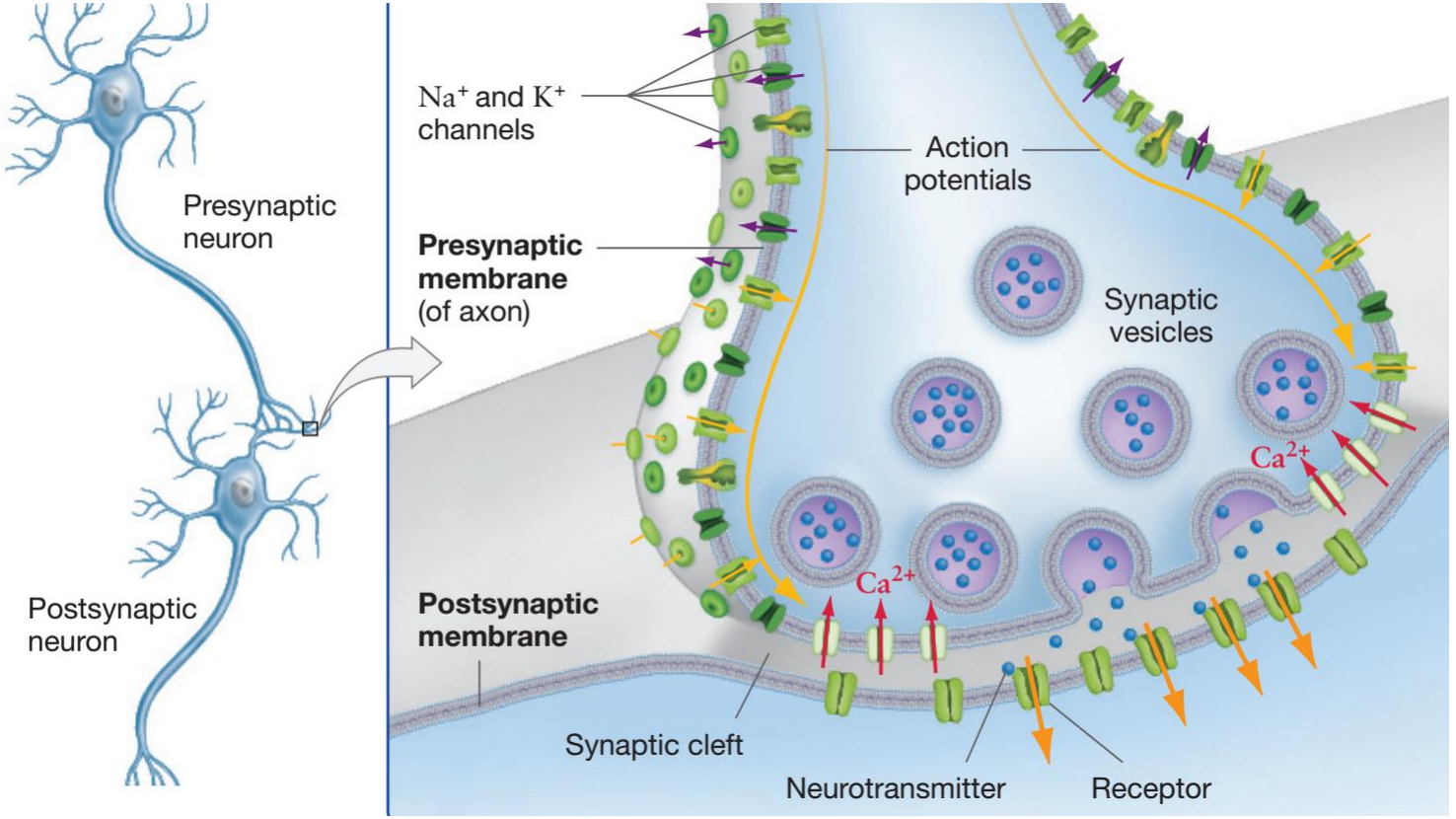
https://www.biointeractive.org/classroom-resources/molecular-mechanism-synaptic-function

Questions:

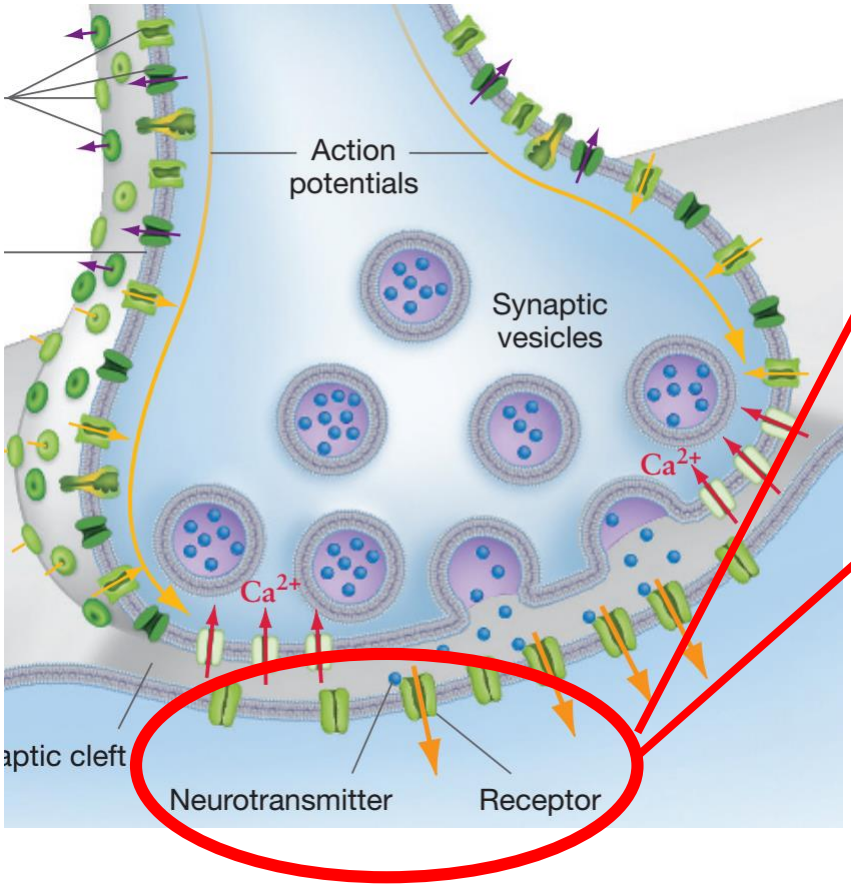
1. What ions are released at the axon terminal?
2. What activates receptors on a second neuron?

Please share your answers with the class

Neurons meet and transfer information at synapses



Postsynaptic potentials



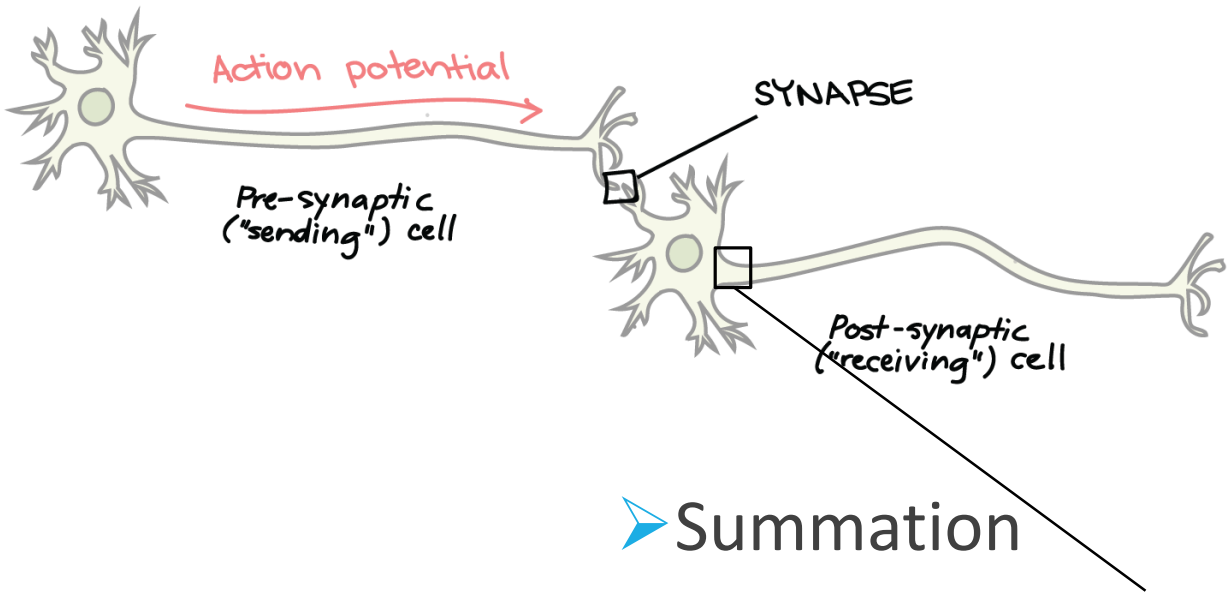
Excitatory postsynaptic potentials (EPSPs)

Inhibitory postsynaptic potentials (IPSPs)

- ✓ not all-or-none events
- ✓ their magnitude depends on the amount of neurotransmitter

How do EPSPs and IPSPs affect the postsynaptic cell?

Action potential in the postsynaptic cell?



- Summation
- Need to get axon hillock

Concept Check

1. What channels open at presynaptic membrane when the action potential arrived to the axon terminal?

(A) Voltage-gated Na+ channels (B) Voltage-gated Ca 2+ channels

2. Changes in the membrane potential of a postsynaptic cell that make the cell more likely to produce an action potential:

(A) excitatory postsynaptic potentials (B) inhibitory postsynaptic potentials

Quick Review

1. Neurons that conduct signals away from the central nervous system are classified as:

(A) afferent (B) associative (C) sensory (D) motor

2. When a neuron is not stimulated:

(A) the outside of the neuron is negatively charged and the inside is positively charged

(B) the outside of the neuron is positive and the inside is negative

(C) both outside and inside of the neuron are negatively charged

(D) both outside and inside of the neuron are positively charged

Quick Review (cont.)

3. Which cells wrap around an axon forming a myelin sheath:

(A) other neurons (B) Schwann cells (C) axons of other neurons
(D) dendrites of other neurons

4. Which of the following is <u>not</u> involved in the process of synaptic transmission:

(A) the release of a neurotransmitter from synaptic vesicles at the pre-synaptic neuron

(B) the destruction of the post-synaptic membrane after the neurotransmitter has come in contact with it

(C) diffusion of the neurotransmitter across the synaptic cleft

(D) destruction of the neurotransmitter after transmission of the impulse has taken place

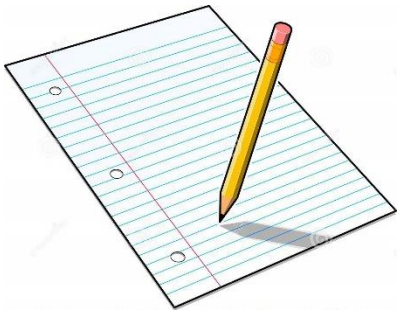
Learning Outcomes Review

By the end of today's lesson <u>you will know</u>:

- ✓ the main anatomical structures of the neuron and its membrane
- ✓ how the membrane potential is maintained

After completing all the assignments <u>you will be able to</u>:

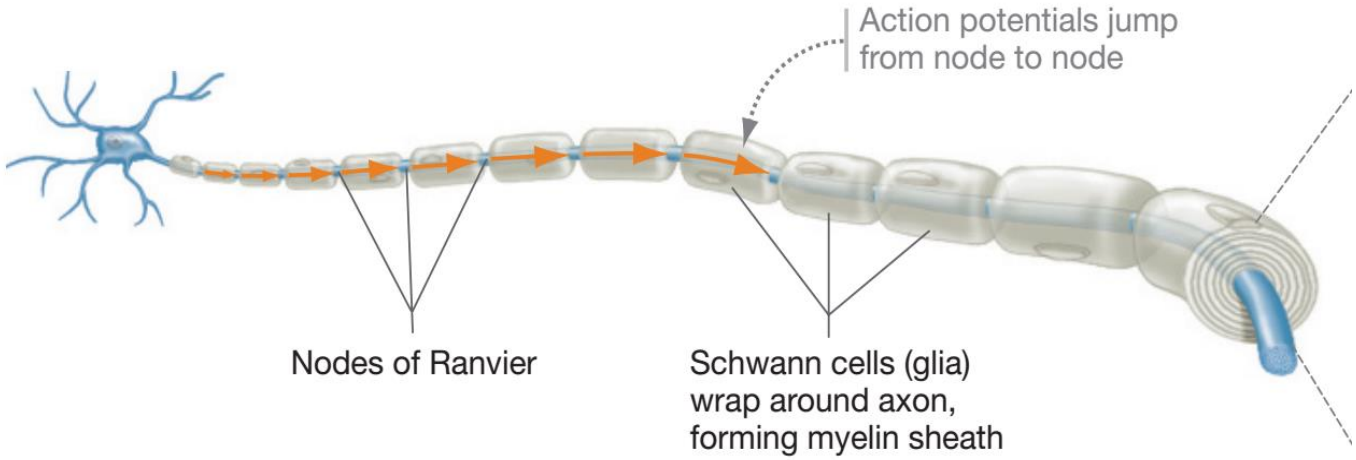
- ✓ explain how the neurons communicate with each other
- ✓ describe the mechanisms underlying the neuronal action potential
- ❑ evaluate how neuronal damage (such as demyelination) might affect the transmission of nerve impulses (Homework!)



Homework

How does demyelination cause diseases like multiple sclerosis?

Normal propagation of action potential in the neuron:



What will happen if the myelin sheath is destroyed?