

PROGRESSIONS:  
PEER-LED TEAM LEARNING

## Module 10: Nerve Local Potentials and Action Potentials

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### I. Introduction

A *neuron* is a single cell that is specialized to transmit electric signals (called impulses) from one part of the body to another. A *nerve* is actually made up of many individual neurons bundled together. To understand how signals travel from a receptor in the skin to the central nervous system (CNS) or from the CNS to a muscle, we have to build on the membrane transport concepts that we have already learned. You already have the tools that you need to understand local and action potentials—now you'll just add information about where in the neuron they occur, and how one thing leads to another to cause nerve conduction.

Prepare for your workshop by reading in your textbook (Chapter 12: 444-475) and completing the Pre-Workshop Activities below, *really!* Show your work in these pages.

### II. Pre-Workshop Activities

**Activity A.** Define the following terms.

|                        |                                |
|------------------------|--------------------------------|
| action potential       | hyperpolarization              |
| afferent neuron        | impulses                       |
| axon                   | ligand                         |
| axon hillock           | ligand-gated potassium channel |
| axon terminal          | ligand-gated sodium channel    |
| cell body              | local potentials               |
| central nervous system | millivolt                      |
| dendrites              | myelin sheath                  |
| depolarization         | myelinated                     |
| efferent neuron        | neuron                         |

neurotransmitter

Na<sup>+</sup>/K<sup>+</sup>-ATPase

postsynaptic neuron

soma

presynaptic neuron

synapse

repolarization

threshold voltage

resting membrane potential

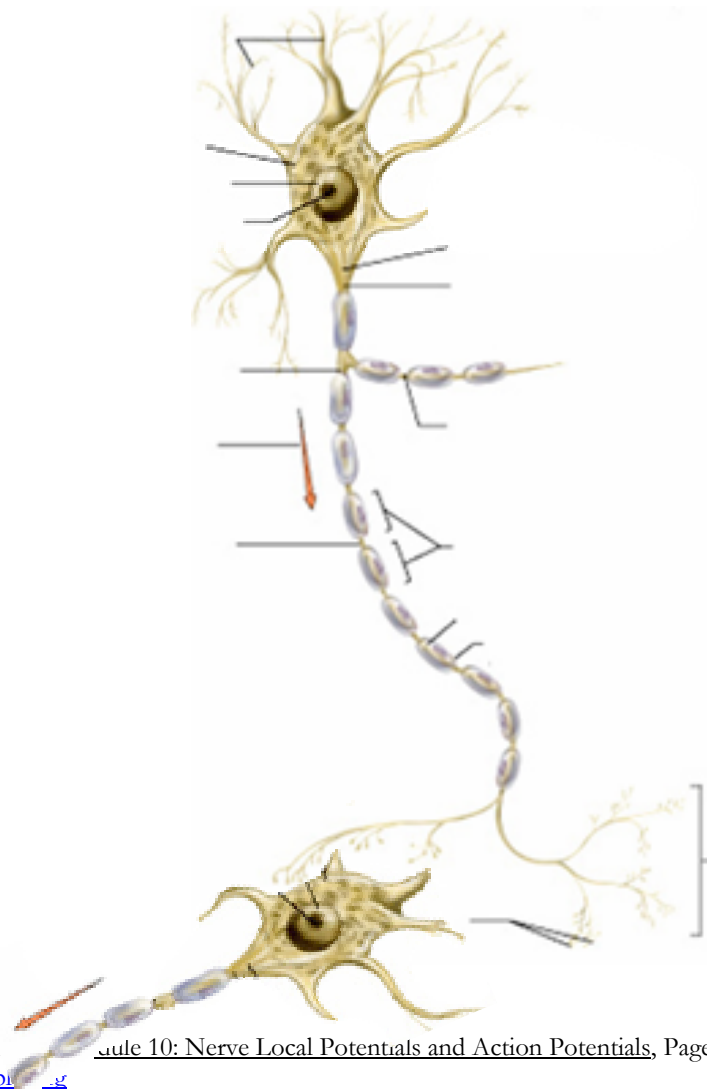
voltage-gated potassium channel

Schwann cell

voltage-gated sodium channel

**Activity B.** Label the figure to the right with the terms in bold print below. You may have to draw some items in yourself.

A **neuron** is a single cell. The large part of the neuron containing the **nucleus** and many other organelles is called the **soma** or cell body. The **dendrites** are short projections that are continuous with the soma. In most neurons, there is a single very long projection from the cell body called the **axon**. The portion of the axon that is closest to the cell body is often enlarged. This enlarged portion is called the **axon hillock**. The axon hillock is important because it is the trigger zone, or site where action potentials begin (discussed later). The axon is the part of the neuron that transmits the electric signals most rapidly. The axon may or may not be covered in some sections by fatty layers of membrane called a **myelin sheath** created by **Schwann cells**. A myelinated axon (with a myelin sheath) can transmit electric impulses far more rapidly than an axon without myelin sheath because the impulse jumps from one **Node of Ranvier** to another



(these are the spaces between the Schwann cells). The end of the axon, furthest from the soma, is called the **axon terminal** or **synaptic knob**. There can be more than one of these branching off of an axon. The tiny space between the two neurons is called the **synapse**. Taking into consideration the **direction of the impulse**, the neuron before the synapse is called the **presynaptic neuron**. The neuron after the synapse is called the **postsynaptic neuron**. The presynaptic neuron can relay an impulse to the postsynaptic neuron by releasing chemicals into the synapse. These chemicals are called **neurotransmitters**.

## II. Workshop Activities

### Activity A. Jeopardy

The student that goes first will select a category and dollar amount. The peer leader will then read the question. The first person to raise their hand can try to answer the question. In Jeopardy, the "question" is actually a statement and the "answer" is to be phrased as a question. If a wrong answer is provided, another student will be given a chance to answer. Once a student has given the correct answer, "money" will be awarded and that student selects the next category and question.

#### Category 1: Anatomy of a Neuron

\$100: This is another name for the main cell body of a neuron.

\$200: This is a special name given to the junction of a neuron with another cell.

\$300: This is a long process that carries a nerve impulse away from the cell body to form a synapse with another cell.

\$400: To speed conduction, many axons are covered in *this*.

\$500: These small projections are the receiving part of the neuron.

#### Category 2: The Local News

\$100: This is where local potentials occur.

\$200: In order to trigger an action potential, a local potential must go above *this*.

\$300: We say that local potentials are *this* because some are small, and some are large depending on the strength of the stimulus.

\$400: Local potentials are *this* because they diminish in strength as they travel away from the point of origin.

\$500: Local potentials are *this* because as long as there is incoming signal, there is a local potential, but when the signal goes away, the membrane potential quickly returns to normal.

#### Category 3: And Action!

\$100: This is where action potentials begin.

\$200: We say that action potentials are *this* because either one happens and looks exactly the same as every other action potential or it doesn't happen at all.

\$300: Action potentials are *this* because they do not diminish in strength as they travel away from their point of origin.

\$400: Action potentials are *this* because once one gets started, there's no stopping it—even if the signal stops.

\$500: Action potentials travel in one direction because the area where the action potential just was is *this*.

#### Category 4: Getting Across the Membrane

\$100: This general kind of channel opens in response to the presence of a neurotransmitter.

\$200: This general kind of channel opens in response to a change in the membrane potential.

\$300: This membrane protein uses ATP to restore concentrations of Na<sup>+</sup> and K<sup>+</sup> to their "resting" levels.

\$400: A voltage-gated Na<sup>+</sup> channel propagates the action potential by using this kind of feedback.

\$500: When this ion crosses the membrane through specific channels, the membrane potential becomes more negative.

#### Category 5: Poles (all answers are variations of "polarization")

\$100: The resting membrane potential is *this* meaning that the inside is more negative than the outside.

\$200: When the membrane potential becomes more negative than the resting membrane potential, we say that it is *this*.

\$300: When the membrane potential becomes more positive, it is becoming *this*.

\$400: When K<sup>+</sup> channels open in response to depolarization, the membrane potential will begin to do *this*.

\$500: After depolarization, the membrane potential does *this* to return to the resting membrane potential.

### Activity B. Polarization.

*The inside of a neuron is typically -60 mV (resting membrane potential) which means that it is more negative than the extracellular fluid by 60 mV. This means the cell is polarized. When a ligand-gated Na<sup>+</sup> channel opens, Na<sup>+</sup> diffuses down its concentration gradient and enters the cell. Since Na<sup>+</sup> ions are positively charged, the inside of the cell becomes more positive. As the inside of the cell gains more positive charge, the membrane potential begins to move from the resting potential toward “0” (from -60 mV, to -59 mV, to -58 mV, etc.). This is called **depolarization**. If the cell then opens a K<sup>+</sup> channel (which will allow K<sup>+</sup> to exit the cell) the positive charge inside the cell will begin to decrease (or move back toward the resting membrane potential). This is called **repolarization**, and only occurs as the membrane voltage returns to the resting membrane potential after a depolarization. If the K<sup>+</sup> channel stays open too long, the membrane potential will actually become more negative than -60 mV (it’s like an overshoot). This is called **hyperpolarization**.*

Divide into 4 groups. In the situations below, indicate whether the membrane potential is becoming more positive, or more negative. Then indicate whether the membrane is depolarized, polarized, repolarized, or hyperpolarized. Assume that the cell is starting off at the resting membrane potential for each scenario. Each group will complete two of the rows in the table below then share their answers with the group.

|   |  |
|---|--|
| Na <sup>+</sup> enters the cell.  |  |
| K <sup>+</sup> leaves the cell <i>after</i> Na <sup>+</sup> has entered the cell. |  |
| K <sup>+</sup> leaves the cell.   |  |
| Cl <sup>-</sup> enters the cell.  |  |

In a single neuron, neurotransmitter-A may be binding to ligand-gated Na<sup>+</sup> channels and depolarizing the cell, at the same time, neurotransmitter-B may be binding to ligand-gated Cl<sup>-</sup> channels and hyperpolarizing the cell.

1. What will happen if there is more neurotransmitter A?
2. What will happen if there is more neurotransmitter B?
3. Which one will make it easier for an action potential to be generated? Which one will make it harder? Why?

### Activity C. Graphing the potentials.

Use Round Robin to complete the following exercise on graphs on the blackboard. Each person in the group should draw and label (i.e. “Na<sup>+</sup> in”) the portion of a graph that represents the actions described below.

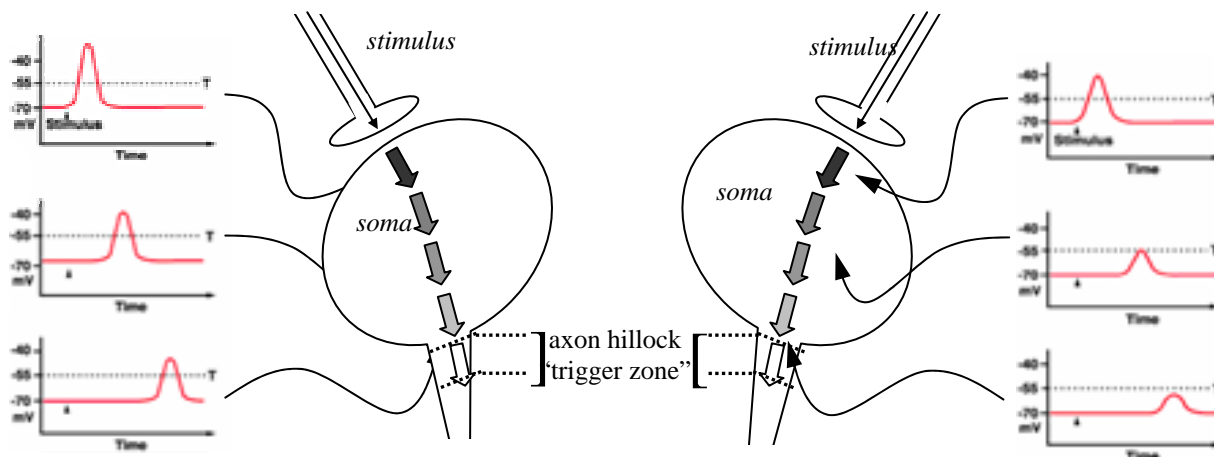
1. The resting membrane potential in a neuron is -70 mV.

2. A molecule arrives at the dendrite and binds to its receptor on a ligand-gated  $\text{Na}^+$  channel.  $\text{Na}^+$  enters the cell and makes the membrane potential slightly more positive (-60 mV), but it does not trigger an action potential.
3. The positive membrane potential causes a voltage-gated  $\text{K}^+$  channel to open and  $\text{K}^+$  exits the cell. The cell then returns to its resting membrane potential.
4. This time, many molecules arrive at the neuron's dendrite and bind to its receptors on a ligand-gated  $\text{Na}^+$  channels.  $\text{Na}^+$  enters the cell and makes the membrane potential more positive (-55 mV), and this time the membrane potential is positive enough to trigger a voltage-gated  $\text{Na}^+$  channel to open.
5. The voltage-gated  $\text{Na}^+$  channel opens and makes the membrane potential more positive which causes another voltage-gated  $\text{Na}^+$  channel to open and make the membrane potential more positive which causes another voltage-gated  $\text{Na}^+$  channel to open and so on. There is therefore a sharp rise (happens quickly) in the membrane potential (up to +50 mV).
6. As the membrane potential is increasing, the  $\text{Na}^+$  channels start to inactivate (kind of like they're getting worn out), and at the same time, voltage-gated  $\text{K}^+$  channels become activated.  $\text{K}^+$  exits the cell and the membrane potential repolarizes quickly.

### Activity D. The Local Potential versus the Action Potential

There are several characteristics of the local potential that set it apart from an action potential. First, local potentials occur on *dendrites and soma* of a neuron whereas action potentials originate at the *axon hillock* (or the part of the axon closest to the soma). Local potentials occur as a result of a *stimulus* whereas action potentials occur as a result of *local potentials*. Second, the stronger the stimulus, the larger the local potential becomes—this is called a “*graded*” response. Action potentials are “*all or none*” phenomena which means that when one happens it’s the same size as every other action potential, or it doesn’t happen at all. Third, a local potential diminishes in strength as it moves away from the site of the original stimulus—this is called “*decremental*” (decreasing in increments). This means that the local potential is not a very good way to get a signal over long distances—thus the name “local”. Action potentials are the *same size* at the axon terminus as they were when they started at the axon hillock because the signal is constantly regenerated.

In the figure below, two neurons are each receiving a stimulus which generates a local potential (see the graph from the electrode which measures the local potential near the stimulus). However, only one of them will trigger an action potential. Which one is it? Explain your selection in terms of a graded response and the threshold for an action potential.



### Activity E. Poisons and anesthetics

Back in the old days before anesthetics were known in the Western World, surgical operations had to be done very quickly. The world record for a leg amputation is 15 seconds, and was performed by Dominique Larrey, Napoleon's chief surgeon.

Anesthetics go back a long way in history. The Ancients knew of alcohol, opium and hemp. Around 1800, the British chemist Sir Humphrey Davy discovered that nitrous oxide could, after it made you silly, also make you unconscious. William Morton, an American dentist is given credit for the discovery that ether could be used as a general anesthetic after he showed it off in a public demonstration of a tooth extraction in 1846. Within six months, the use of ether as an anesthetic had spread around the world. Although ether and chloroform are no longer used as general anesthetics in developed countries, other inhalational anesthetics still are. These fluoride compounds (halothane, isoflurane, enflurane, etc.) are much more effective and have fewer side-effects.

All of these are general anesthetics—which means that they provoke a loss of consciousness, and a partial loss of memory (the memory of the surgical operation is erased) in addition to making the body motionless

Charles Darwin was so disgusted by the suffering that he gave up a promising career in medicine, and that's how we ended up with the

(though it still reacts to painful stimuli). Local anesthetics do the same thing, but without a loss of consciousness or memory. Some poisons and anesthetics are global—meaning that they affect all parts of the nervous system; others affect only motor nerves or sensory nerves.

This is a very challenging activity. You may simply read this section for the ‘wow’ factor, or you can try to figure out the mechanisms. If you choose to figure these out, you should work in groups of 2-4 students. Each group should choose one anesthetic or poison to work on. Use the questions below as a rough guide to think about what actually happens to nerve conduction with the compound that you choose. Share and compare answers with the group afterwards.

*What does this channel respond to (voltage? ligand?)? What is the normal concentration gradient of the ion that goes through this channel (which way does the ion want to go)? What is the normal role of this channel in nerve physiology (describe in terms of polarization, is it important for local potentials? action potentials?)? If this channel fails to respond normally (either won't work at all, or won't stop working), what will be the outcome (in terms of polarization)? What will be the general outcome?*

|                     |                               |   |
|---------------------|-------------------------------|---|
| Local Anesthetic    | Novocaine, Xylocaine          | Blocks voltage gated Na <sup>+</sup> channels |
| General Anesthetics | Ether, Chloroform, Isoflurane | Blocks voltage gated K <sup>+</sup> channels  |
|                     | Diazepam (Valium)             | Opens Cl <sup>-</sup> channels                |

The following are poisons that exert their effects through interference with nerve conduction.

|                         |                         |   |
|-------------------------|-------------------------|---|
| Agitoxin, Charybdotoxin | Scorpion                | Blocks potassium “leaky” channels                   |
| Dendrotoxin             | Green Mamba             | Blocks voltage-gated potassium channels             |
| Phoneutriatoxin         | Banana spider           | Slows inactivation of voltage-gated sodium channels |
| Batrachotoxin           | Poison Arrow Frog       | Prevents sodium channels from closing               |
| Brevetoxin              | Red Tide Dinoflagellate | Activates sodium channels                           |
| Maculotoxin             | Blue-Ringed Octopus     | Blocks sodium channels                              |

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