AP Biology: Nervous System

Name ____________________
Date __________ Period __

ACTION POTENTIAL (nerve impulse)
All or nothing response!

Introduction
In this activity, you will set up a model to simulate how a neuron processes information. You will need to know the facts listed below to do the procedure and to learn about the action potential. An action potential is an electrical signal that depends on the flow of ions (positively or negatively charged atoms) across the cell membrane. Understanding how neurons process information is essential to understanding certain neurological disorders, such as epilepsy.

It's important to remember that all living things have an electrical difference across their plasma membranes.

Membrane potential = -50mV to -100mV (the inside of the cell is negative with respect to the outside)

Resting potential = -70mV

Fact 1 - There are more (10 x more) sodium ions (Na^+) outside the nerve cell than inside. There are more (30 x more) potassium ions (K^+) inside the nerve cell than outside. Sodium and potassium ions have a positive charge. In a real cell, there would be millions of ions, but there is not room enough for that many model ions.

Fact 2 - A positive charge attracts a negative charge, and vice versa. However, positive charges repel each other, and negative charges repel each other.

Fact 3 - Electrical charge (electrical potential) is the result of excess ions on one side of the membrane. This creates an electrical gradient (difference) across the membrane.

Fact 4 - One force acting on the ions is for them to move from areas of higher concentration to lower concentration. This force (concentration gradient) would tend to make the number of each ion on each side of the cell membrane exactly equal.

Fact 5 - The facts above describe all cells, even plant cells. However, nerve cells are unique: They have channels for sodium, potassium, and other ions that will only recognize one ion. If a sodium channel opens, sodium ions, but no other ions, can pass through. Channels are very narrow and ions must line up one at a time to pass through the channel, no matter which direction they go. Proteins are too big to fit through any of these channels and must stay inside the cell. In a nerve cell without any channels (gates) open, the charge inside the cell relative to the outside is negative (-70mV).

Materials: 60 red beans (potassium), 60 white beans (sodium), 6 toothpicks (for ion channels)
5 strips of paper to serve as the phospholipid bilayer of the cell membrane

You've got the potential ... that's a good thing!

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Procedure:

Use the provided materials to create a cell showing it at resting state. Make sure sodium and potassium ions are represented correctly on each side of the membrane. Use the toothpicks to make the sodium and potassium channels and show the correct number of gates and location (inside or outside) in the membrane. Use step 1 of Figure 37.1 (pg. 754) in the Biology in Focus book to help you accurately create the initial state of the neuron membrane and call Mrs. Vazquez over for verification when you think your model is accurate.

Questions:

1) Look at the numbers sodium ions inside and outside the cell. If the sodium channel(s) were suddenly opened so that sodium ions could move across the cell membrane:

   a) Which direction would they tend to move based on their concentration? Explain!
      into the cell OR out of the cell

   b) Which direction would they tend to move based on their charge? Explain!
      into the cell OR out of the cell

2) A sodium channel opens for about one millisecond (one 1000th of a second). Time yourselves for 10 seconds (this represents 1 millisecond). When you begin timing, open the sodium channel by opening the activation gate toothpick and dragging sodium through the sodium channel one at a time in the direction you think they will go until the 10 seconds are up. (Remember, the sodium ions cannot pass through other channels nor through the membrane where there is no channel.)

   a) Compare the numbers of sodium ions on each side of the cell membrane now to the number when the cell was at rest. What do you notice? Why?

   b) Look at the numbers of potassium ions inside and outside the cell. If the potassium channel were suddenly open so that potassium ions could move across the cell membrane, which direction would they tend to move based on their concentration - into or out of the cell? Explain!

   c) Which direction would they tend to move based on their charge - into or out of the cell? Explain!

3) A potassium channel opens for one to three milliseconds. Time yourself for 10 seconds (to represent 1 millisecond) and drag the potassium ions through the potassium channel one at a time in the direction you think they will go until your time is up. (Remember, the potassium ions cannot pass through the other channels nor through the membrane where there is no channel.)

a) Compare the numbers of potassium ions on each side of the cell membrane to the number when the cell was at rest. What do you notice and why?

b) Do you think the internal medium of the cell is more negative or more positive than it was before you had opened the potassium channel (but after you had opened the sodium channel and moved the peas)? Explain.

4) In the nerve cell axon, something happens called **sodium channel inactivation**. This means that after the sodium gates open and close, they cannot open again for a few milliseconds. This time is called the **refractory** period. (Refractory means hard, durable, or immovable; the sodium channels cannot move to open). If you were to line up a number of your models to represent a longer stretch of a nerve cell axon, what effect would this have on the action potential?

5) In order to continue to function properly, the cell must now somehow get back to its resting state (electric charge and concentration of ions inside and outside the membrane). What are your ideas as to how the cell might do this?

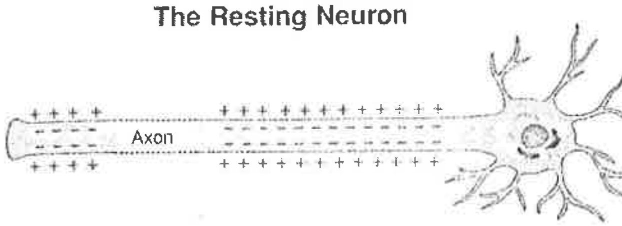
6) When an action potential reaches the end of the axon of the nerve cell, it will then pass on information to the next cell. What are your ideas as to how the cell might do this?

You've got the potential ... that's a good thing!

Action Potentials

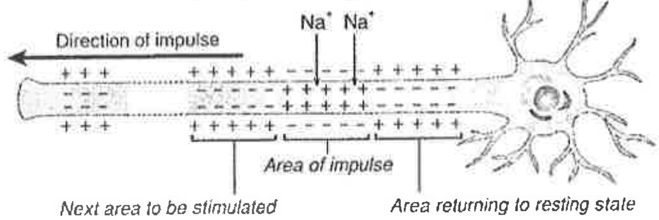
The plasma membranes of cells, including neurons, contain **sodium-potassium ion pumps** which actively pump sodium ions (Na^+) out of the cell and potassium ions (K^+) into the cell. The action of these ion pumps in neurons creates a separation of charge (a potential difference or voltage) either side of the membrane and makes the cells **electrically excitable**. It is this property that enables neurons to transmit electrical impulses. The **resting state** of a neuron, with a net negative charge inside, is maintained by the sodium-potassium pumps, which actively move two K^+ into the neuron for every three Na^+ moved out (below left). When a nerve is stimulated, a brief increase in membrane permeability to Na^+ temporarily reverses the membrane polarity (a depolarization). After the nerve impulse passes, the sodium-potassium pump restores the resting potential. The depolarization is propagated along the axon by local current in non-myelinated fibers and by **saltatory conduction** in myelinated fibers. Impulses pass from neuron to neuron by crossing junctions called **synapses**.

The Resting Neuron



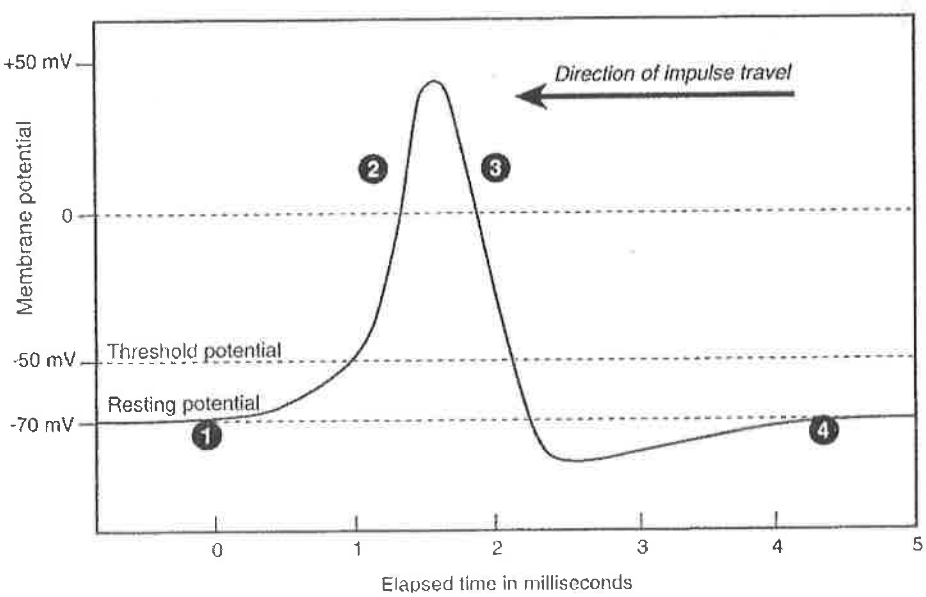
When a neuron is not transmitting an impulse, the inside of the cell is negatively charged relative to the outside and the cell is said to be electrically polarised. The potential difference (voltage) across the membrane is called the **resting potential**. For most nerve cells this is about -70 mV. Nerve transmission is possible because this membrane potential exists.

The Nerve Impulse



When a neuron is stimulated, the distribution of charges on each side of the membrane briefly reverses. This process of **depolarization** causes a burst of electrical activity to pass along the axon of the neuron as an **action potential**. As the charge reversal reaches one region, local currents depolarize the next region and the impulse spreads along the axon.

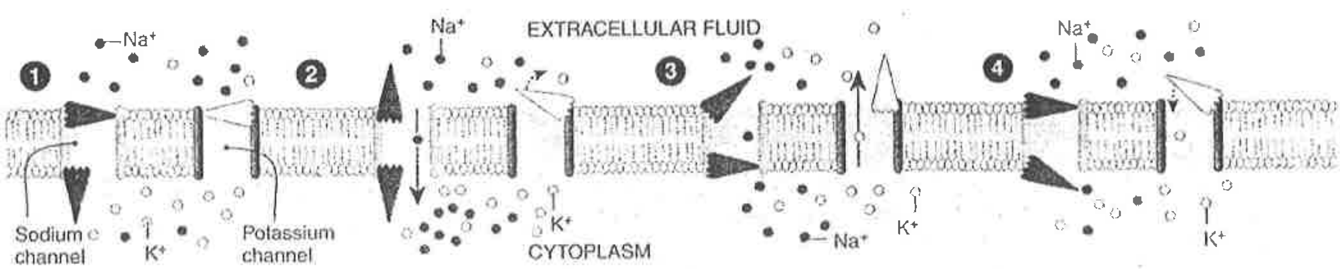
The Action Potential



The depolarization in an axon can be shown as a change in membrane potential (in millivolts). A stimulus must be strong enough to reach the **threshold potential** before an action potential is generated. This is the voltage at which the depolarization of the membrane becomes unstoppable.

The action potential is **all or nothing** in its generation and because of this, impulses (once generated) always reach threshold and move along the axon without attenuation. The resting potential is restored by the movement of potassium ions (K^+) out of the cell. During this **refractory period**, the nerve cannot respond, so nerve impulses are discrete.

Voltage-Gated Ion Channels and the Course of an Action Potential



Resting state:

Voltage activated Na^+ and K^+ channels are closed.

Depolarization:

Voltage activated Na^+ channels open and there is a rapid influx of Na^+ ions. The interior of the neuron becomes positive relative to the outside.

Repolarization:

Voltage activated Na^+ channels close and the K^+ channels open; K^+ moves out of the cell, restoring the negative charge to the cell interior.

Returning to resting state:

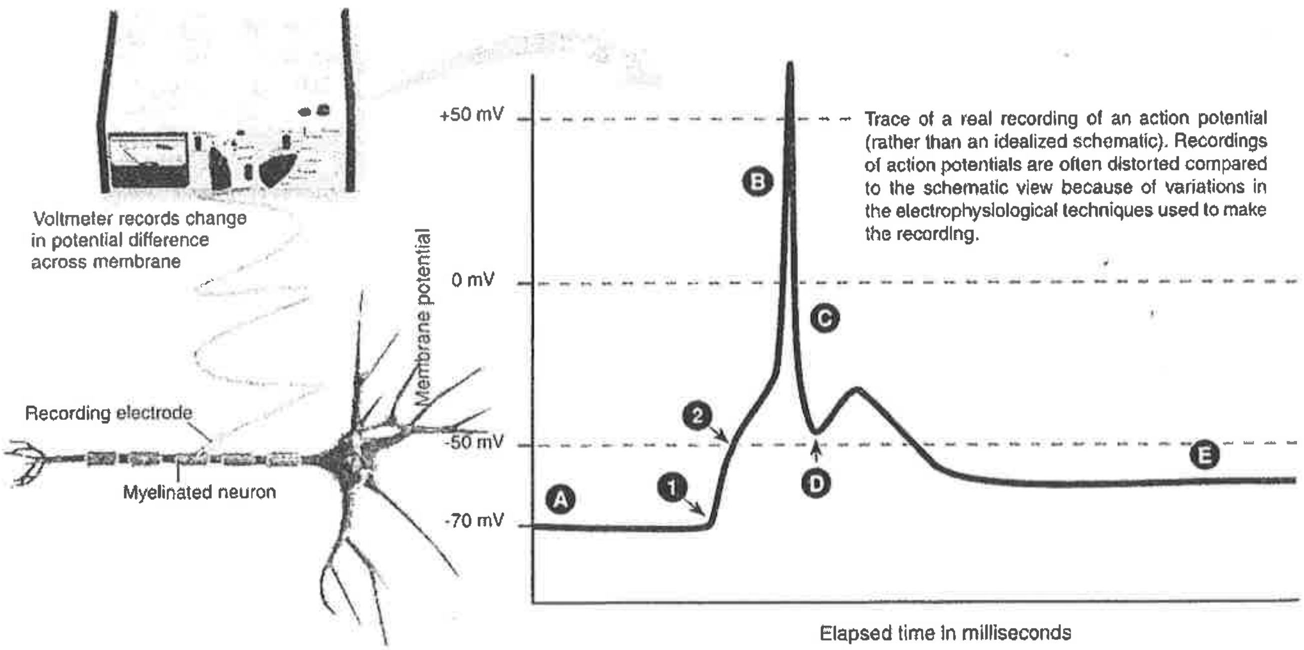
Voltage activated Na^+ and K^+ channels close to return the neuron to the resting state.

1. (a) Describe a defining feature of neurons:

(b) Explain how the supporting cells of nervous tissue (e.g. Schwann cells) differ from neurons:

2. Explain how an action potential is able to pass along a neuron:

3. Explain how the refractory period influences the direction in which an impulse will travel:



4. Action potentials themselves are indistinguishable from each other. Explain how the nervous system is able to interpret the impulses correctly and bring about an appropriate response:

5. (a) The graph above shows a recording of the changes in membrane potential in an axon during transmission of an action potential. Match each stage (**A-E**) to the correct summary provided below.

- [ ] Membrane depolarization (due to rapid Na^+ entry across the axon membrane.
- [ ] Hyperpolarization (an overshoot caused by the delay in closing of the K^+ channels.
- [ ] Return to resting potential after the stimulus has passed.
- [ ] Repolarization as the Na^+ channels close and slower K^+ channels begin to open.
- [ ] The membrane's resting potential.

(b) Explain what is happening at point **1** on the graph:

(c) Explain what is happening at point 2 on the graph: