

**GOVERNOR'S INSTITUTE FOR LIFE SCIENCE EDUCATORS  
HIGH SCHOOL LESSON PLAN**

**Title:** Action potential modeling  
**Prepared by:** Michele Dubaich

**Date:** June 21 & June 28, 2000

**Intended grade level:** 11-12 (AP)  
**Time required:** 2 class periods (and/or as a tutorial)

**Description:**

In this activity students will simulate how an action potential is created in a neuron using dried peas and beans to represent ions. They will then apply what they know about action potentials under normal conditions to what may be happening in the central nervous system (CNS) disorder, epilepsy. Students may predict the mechanism of action of a drug used to treat epilepsy and do research to confirm their predictions.

**State Science/Technology Standards**

3.3.10B

3.3.12B

**National Science Standard**

Content Standard 9-12 C

**Instructional Objectives:**

- Students will be able to predict the movement of  $\text{Na}^+$  and  $\text{K}^+$  across a permeable membrane
- Students will be able to describe the mechanism that allows a neuron to remain at rest
- Students will simulate the electrical and chemical changes that occur in the cell during an action potential
- Students will be able to explain the relationships among  $\text{Cl}^-$  ions, the inhibition of action potentials, and epilepsy

**Background Information:**

Before participating in this activity students should know the following:

- the general concept of diffusion
- the structure and function of cell membranes
- how substances pass into and out of cell membranes
- the structure and function of a neuron

## Teacher Preparation:

Gathering of materials is time consuming the first time this lab is performed. It is essential to "package" kits of each group's supplies in ziploc bags to save time from year to year. You will receive 1 full model today. Simply duplicate it (probably 5 more for a classroom set of 6 for one class).

## Materials Needed (per model):

- 165 dried black-eye peas
- 130 dried baby lima beans
- 155 dried black beans
- construction paper cut into circles (labeled with a negative charge, as proteins, amino acids, phosphates, and sulfates) **\*\*\*these should be larger than the opening in the membrane and should outnumber the  $K^+$**
- sheet cardboard (106 X 90 cm)
- 5 red toothpick pieces
- 6 yellow toothpick pieces
- 2 blue toothpick pieces
- marker
- metric ruler
- 2 Post-it<sup>TM</sup> notes
- 3 snack size ziploc bags
- 3 sandwich size ziploc bags
- 1 large freezer ziploc bag
- stopwatch or clock with second hand

## Instructional Resources:

Campbell, N. E. (1996). Biology (4th ed.). Menlo Park, CA: Benjamin/Cummings.

Conley, T. & Shepley, B. (1996). Action potential-epilepsy. From Neuroscience laboratory and classroom activities. NABT & Society for neuroscience.

## Classroom Activities:

### Modeling the action potential with beans

Begin the activity by telling students that they are going to learn about how nerve cells function by utilizing a model.

1. Students should work in groups of four and each team should obtain a model set up.

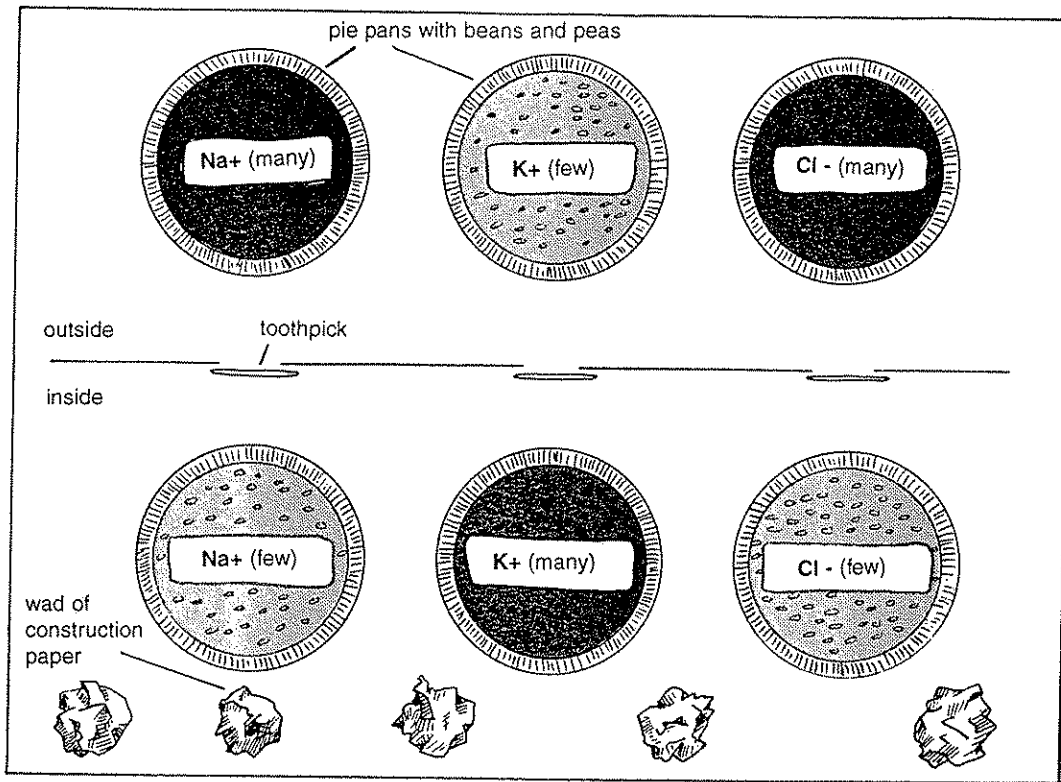
2. The students can put together the model with the help of the diagram or you can have them already set up.
3. Students should answer questions on the worksheet as they manipulate the model.  
\*\*Another idea is to let the students set up the model and (as a post lecture activity) use their notes and text to simulate what they have learned about neurons and the sodium-potassium pump.

### **Epilepsy extension project**

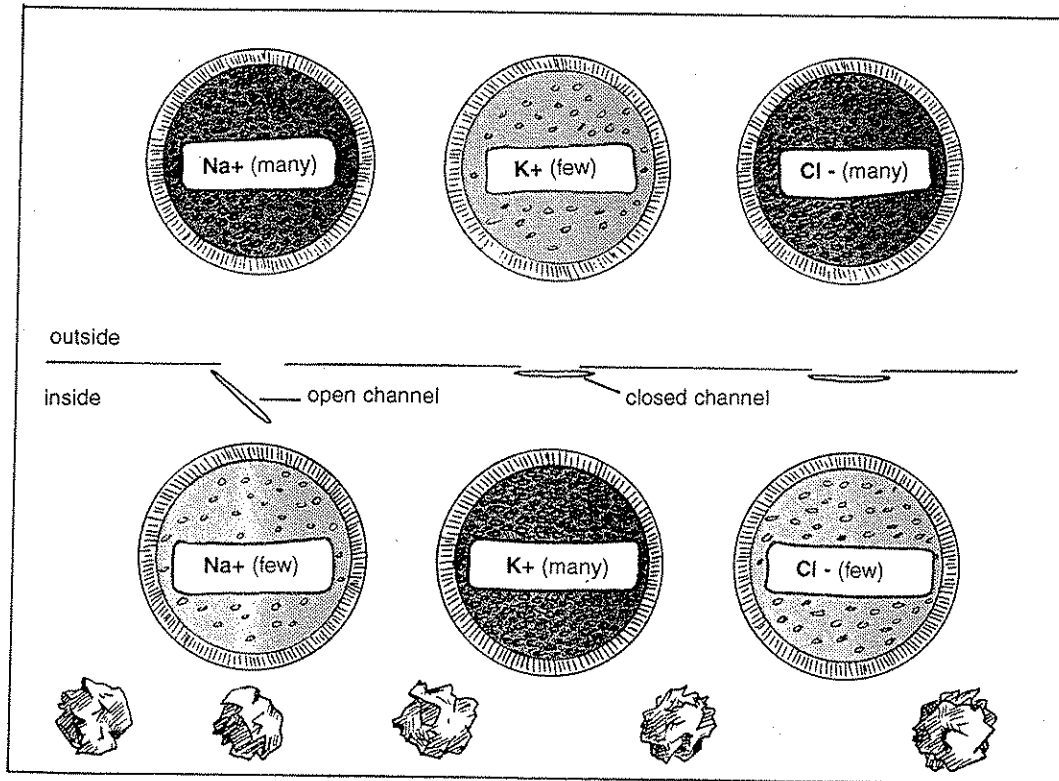
Students can expand on what they have learned by attempting to design a drug for epilepsy. Library research can be done or you can supply it to your students. After "designing" their drug they can write an essay comparing it to actual drugs used.

### **Assessment Procedures:**

Students can complete the student worksheet for evaluation. Students may also perform a mini-presentation to the class describing a part or all of the "action potential" model. Written step by step procedures "in their own words" can also be assessed to identify misconceptions.



a.



b.

Figure 3. Illustration of student model. (a) Nerve cell "at rest" with all channels closed. (b) Nerve cell with sodium channel having just opened.

Name: \_\_\_\_\_

### ACTION POTENTIAL MODELING

- I. Set up model according to the provided diagram.

Next to each model part, identify what it represents based on your knowledge of a neuron (be sure to indicate the charge if applicable). You may use your notes/text.

black-eye peas-

baby lima beans-

black beans-

construction paper-

red toothpicks-

yellow toothpicks-

blue toothpicks-

- II. Answer the following questions using your model:

1. Notice that the concentration (number) of ions is different inside and outside the cell.

Where is there a higher concentration of  $\text{Na}^+$ ? \_\_\_\_\_

Where is there a higher concentration of  $\text{K}^+$ ? \_\_\_\_\_

Where is there a higher concentration of  $\text{Cl}^-$ ? \_\_\_\_\_

These concentrations (in beans) are representative to the approximate concentration of ions in actual mammalian cells in mM per liter.

	$\text{Na}^+$	$\text{K}^+$	$\text{Cl}^-$
Inside the cell	15 mM	150 mM	10 mM
Outside the cell	150 mM	5mM	120 mM

**Check your answer to #1 to make sure you were correct.**

2. Considering the concentration gradient:

In which direction (into or out of the cell) would  $K^+$  tend to move? \_\_\_\_\_

In which direction (into or out of the cell) would  $Na^+$  tend to move? \_\_\_\_\_

3. Considering the electrical gradient:

In which direction (into or out of the cell) would  $K^+$  tend to move? \_\_\_\_\_

In which direction (into or out of the cell) would  $Na^+$  tend to move? \_\_\_\_\_

**CHECKPOINT:**

\* There is a large concentration gradient for diffusion of  $K^+$  out of the cell, and the membrane has a high permeability to potassium. Thus,  $K^+$  will move out of the cell.

\*As  $K^+$  exits, it transfers positive charge from the inside to the outside of the cell. Because the anions (proteins, amino acids, sulfates, phosphates and other negatively charged ions) stay in the cell, the inside of the cell becomes progressively more negative with respect to the outside. As positive charge is lost while negative charge is trapped within, an electrical gradient builds up across the membrane. **In essence this electrical gradient competes with the effect of the  $K^+$  concentration gradient:** The increasing negative charge inside attracts the  $K^+$  back inside the cell.

\*Potassium is not the only ion to which the plasma membrane is permeable to, however. Although the membrane is much less permeable to  $Na^+$  than to  $K^+$ ,  $Na^+$  can still cross. For  $Na^+$  both the electrical and the concentration gradients tend to move sodium into the cell.

III. Sodium-potassium pump

The sodium-potassium pump is a protein that uses energy from ATP to drive the active transport of sodium back out of the cell, against its concentration and electrical gradients. At the same time, the pump moves potassium into the cell, thus restoring the concentration gradient for this ion as well. In essence, the

cell uses metabolic energy, in the form of ATP, to maintain the ionic gradients across the membrane that give rise to the steady-state membrane potential.

Remember that if the sodium and potassium of the neurons were allowed to reach equilibrium, no resting potential would be present, therefore disallowing action potentials (nerve impulses).

Neurons have special ion channels, called gated ion channels, that allow the cell to change its membrane potential in response to stimuli the cell receives. The effect of the stimulus on the neuron depends on the type of gated ion channel that is opened by the stimulus. If the stimulus opens a potassium channel, potassium will move out of the cell and the membrane potential will become more negative. Such an increase in the electrical gradient across the membrane is called a **hyperpolarization**. If the channel opened by the stimulus is a sodium channel, sodium will move into the cell and the membrane potential will become less negative. Such a reduction in the electrical gradient is called a **depolarization**.

If the depolarization is "great enough" to reach **threshold potential**, meaning it changes the cell's charge 15 to 20mV(+), a different type of response called an **action potential** will be triggered. (Hyperpolarization does not cause action potentials, in fact it makes it less likely that they will be triggered.)

1. Simulate depolarization by opening all of your sodium channels (left side goes up (activation gate), right side is down (inactivation gate)) and pushing your  $\text{Na}^+$  into the cell. Since this happens for about one millisecond (1/1000 of a second), time group members for 15 seconds as  $\text{Na}^+$  ions are pushed through one by one.

After this event, what is the charge of the interior of the cell?  
\_\_\_\_\_ (be sure to reverse the post-it notes if there is a charge reversal)

2. After the fifteen seconds, close the right gates (inactivation) and immediately open the potassium gates and push through the  $\text{K}^+$  out of the cell. This is called the **repolarization** phase. Why is it termed this?

When the cell has a negative charge on the inside and positive charge on the outside (remember to switch post-its again), it is called \_\_\_\_\_.

3. An action potential is a localized electrical event, a membrane depolarization at a specific point of stimulation. A neuron is stimulated at its dendrites; for the resulting action potential to

function as a signal, it must somehow "travel" along the axon to the other end of the cell. Actually, the action potential does not travel but is regenerated in a new sequence along the axon. The strong depolarization of one action potential assures that the next region of the neuron will be depolarized above threshold, triggering a new action potential, and so on down the axon.

How could you simulate this in class?

If this is possible (and permitted by your teacher) try it!!!

**\*\*Keep in mind that there is a refractory period (a time when the sodium channels cannot open) and this is why an action potential is usually a one-way event.**

4. The simulation you've demonstrated is with a model of an unmyelinated neuron. How would a myelinated neuron simulation differ?
  
  
  
  
  
  
  
  
  
  
5. Everything that was just demonstrated involved 1 neuron. How does an action potential travel to the next neuron to continue the impulse?

Optional: Improve your model to show this.

IV. Summarize what you know about nerve impulses.

**Assessment:**

Your team must present your drug idea to the class and utilize your model to help explain what it does to help epileptics.

Name: \_\_\_\_\_

## DESIGN A DRUG FOR EPILEPSY

### Background Information:

This complete network of neurons in the cortex of the brain is sometimes improperly stimulated. Epilepsy is the result of the abnormal synchronous firing of a large group of neurons. The resulting motor consequences produce the jerking and involuntary movements of an epileptic seizure. Students will research the causes of and treatments for epilepsy in the second part of this activity.

While 10% of all humans experience a seizure at some point in their lives,, only 1.5% of the human population has epilepsy. Epilepsy is defined as a condition involving uncontrollable recurrent seizures involving changes in brain wave activity (i.e., electroencephalogram [EEG] activity). Thus, epilepsy is a disorder of the CNS. Where epilepsy is concerned, this issue is not just one of experiencing seizures, but of experiencing recurrent seizures.

Partial, or focal, epilepsy is caused by synchronous activity of a group of neurons that begins in a small portion of the brain and then either remains localized or spreads only to adjacent portion of the cortex. Consciousness may even be disrupted. This is called a partial complex seizure. The nature of the seizure is defined by the region of the brain that is affected. So, if the motor cortex is affected, involuntary contractions of the muscles will result. If the limbic system structures of the temporal or frontal lobes areas affected, loss of consciousness may also result. General, or nonfocal, epilepsy affects large parts of the brain. As a result, both motor and psychomotor (i.e., involving abnormal or "imagined" sensations in addition to abnormal motor movement) seizures may occur.

Epilepsy can be thought of as the result of overstimulation. That is, too many cortical neurons are excited simultaneously. What originally causes epilepsy is unknown. It is known that epilepsy can be related to damage to the CNS before, during, or just after birth; to head injuries that can occur at any age; to some poisons (including lead and alcohol); diseases (such a measles and encephalitis); and brain tumors. Heredity is usually not a direct factor in epilepsy. But, some kinds of brain wave patterns associated with seizures do tend to run in families. In many cases of epilepsy, no cause can be identified.

**Objective:** Using your model and doing background research, design a drug that would help treat epilepsy. Keep in mind how action potentials occur and how they relate to the symptoms of epilepsy. (\*\*HINT\*\* Keep in mind that there is a part of the model you have yet to use)

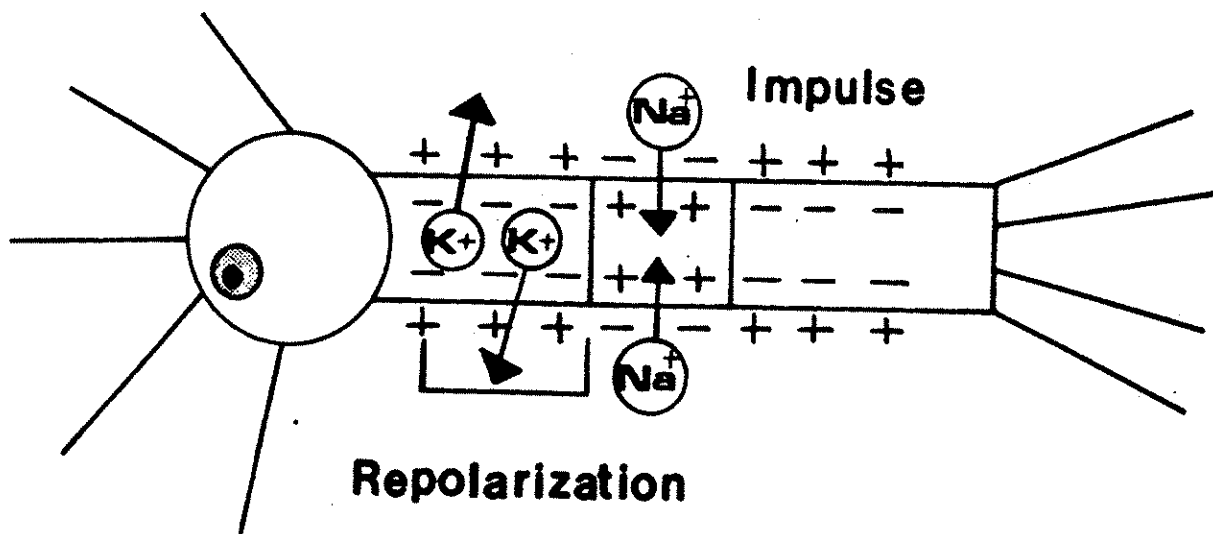
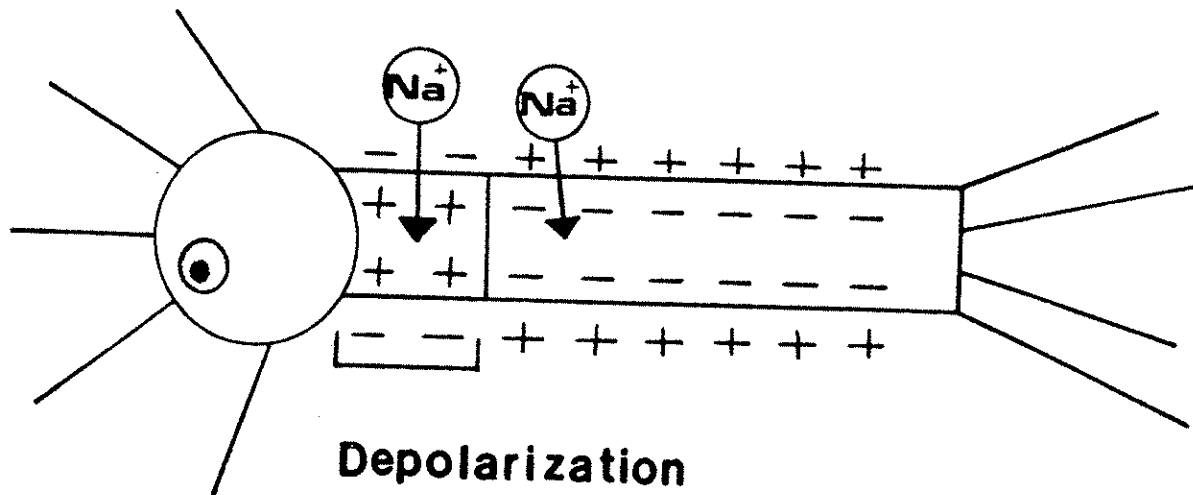
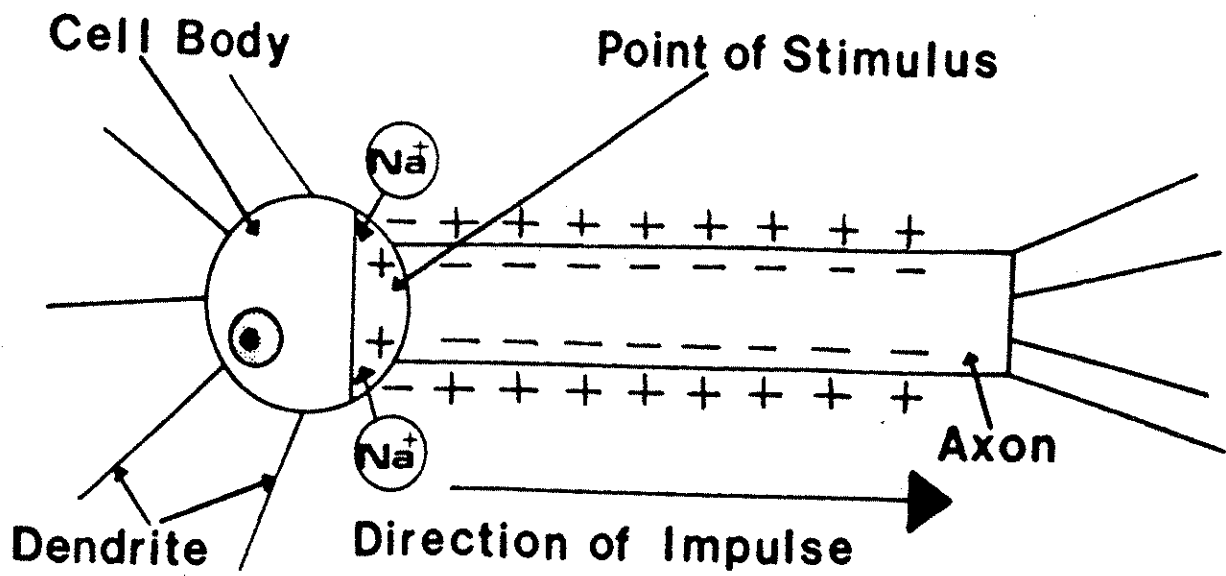
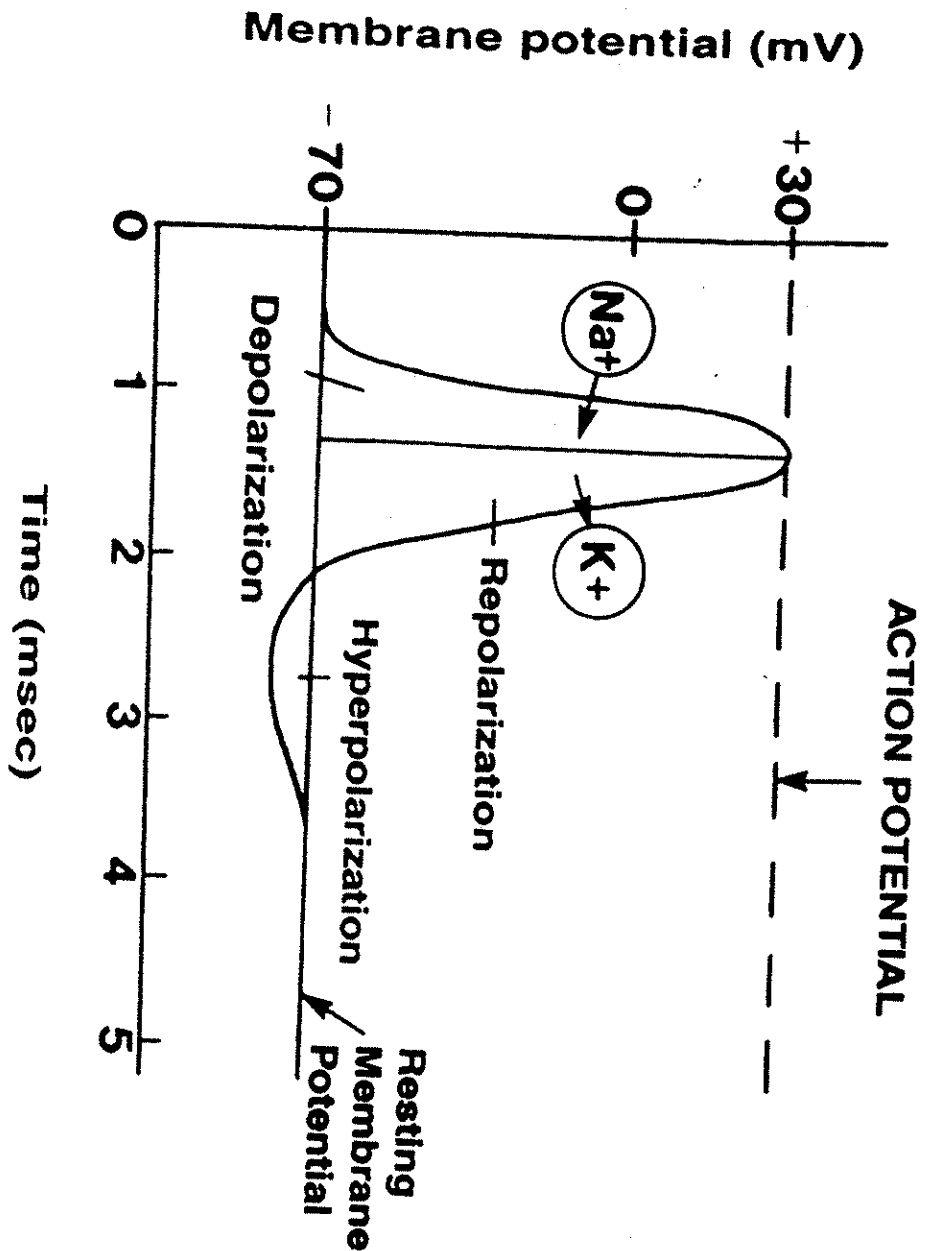


Figure 1. Stages in the generation of the action potential.



Graph 1. Sample graph of action potential.