

ACTION POTENTIAL — EPILEPSY

Directions for Teachers

SYNOPSIS

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 library research to confirm their predictions.

LEVEL



Exploration and Concept/Term Introduction Phases



Application Phase

Getting Ready

See sidebars for additional information regarding preparation of this lab.

Directions for Setting Up the Lab

E Exploration

- Assign students to bring in materials for the **Exploration** and **Concept/Term Introduction** phases, or obtain these materials.

C Concept/Term Introduction

- Make photocopies and overhead transparencies of Figures 1 and 2 and Graph 1 (optional).

A Application

- Schedule a class visit to the school library (optional).

Teacher Background

The cortex, forming the outermost part of the brain, is made up of an extensive network of interconnected neurons that permits both serial and parallel processing of information. Because of the diversity of the interconnections, the cortex provides an organism with a wide variety of highly complicated communication networks. This, in turn, permits a wide variety of highly complicated behavioral possibilities.

The processes by which nerve cells transmit information are described in the following paragraphs.

The interior of all cells is negatively charged with respect to the outside environment. Nerve cells are unique in their capacity to *manipulate* the flow of charged ions across the cell membrane. Nerve cells deal in information, and charge alterations are the equivalent of information for neurons. In most neurons, the binding of neurotransmitter to receptors causes the

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STUDENT PRIOR KNOWLEDGE

Before participating in this activity students should be able to:

- Explain in general terms the concept of diffusion.
- Describe the structure and function of cell membranes.
- Explain how substances pass into and out of cell membranes.
- Describe the structure and general function of a neuron.

INTEGRATION

Into the Biology Curriculum

- Biology I, II
- Human Anatomy and Physiology
- AP Biology

Across the Curriculum

- Chemistry
- Mathematics
- Physics

OBJECTIVES

At the end of these activities, students should be able to:

- Predict the movement of Na^+ and K^+ across a permeable membrane.
- Describe the mechanism that allows a neuron to remain at rest.
- Simulate the electrical and chemical changes that occur in the cell during an action potential.

—Continued

OBJECTIVES

—Continued

- Explain the relationships among Cl^- ions, the inhibition of action potentials, and epilepsy.

LENGTH OF LAB

A suggested time allotment follows:

Day 1

- E** 20 minutes — Conduct the **Exploration**.
- 25 minutes — Begin the **Concept/Term Introduction**.

Day 2

- C** 30 minutes — Complete the **Concept/Term Introduction**.
- A** 15 minutes — Make predictions for **Application I**.

Day 3

- A** 30 minutes — Conduct library research to check predictions (optional).
- 15 minutes — Make predictions for **Application II**.

Day 4

- A** 30 minutes — Conduct library research to check predictions (optional).

MATERIALS NEEDED

- E** You will need the following for each group of four students in a class of 24:
 - 2 pounds (900 g) dried black-eyed peas
 - 2 pounds (900 g) dried baby lima beans
 - 2 pounds (900 g) dried black beans
 - 6 pie or cake pans, disposable aluminum, 8–9 inches (20–22.5 cm) diameter

—Continued

opening or closing of channels for specific ions. Because they respond to neurotransmitter by opening or closing, these are called *neurotransmitter-gated channels*. The combined action of all these channels generates a wave of passive voltage change that can travel throughout the cell. However, the size of this wave decreases with time and distance. When information is sent over a long distance, there is a tendency for charge to leak across the cell membrane and information is lost. To counteract this tendency, when nerve cells must send information over long distances, they use action potentials.

The passive wave of potential change is transmitted to the junction between the cell body and the axon. See Figure 1. Here, if the wave of voltage is large enough to trigger an action potential, the membrane is said to be at (or above) threshold.

As noted earlier, the internal composition of a neuron is markedly different from that of the fluid outside of it. Because of this difference, the voltage inside the neuron is about -70 mV at rest (that is, 70 millivolts more negative than the extracellular fluid surrounding it). This potential difference, in the absence of external stimuli, is called the *resting potential*. Different neurons have slightly different resting potentials. If positive ions cross the membrane, or negative ions move out, the difference in charge (or potential) between inside and outside is reduced (i.e., the cell, moving from -70 mV toward zero potential difference, is *depolarized*).

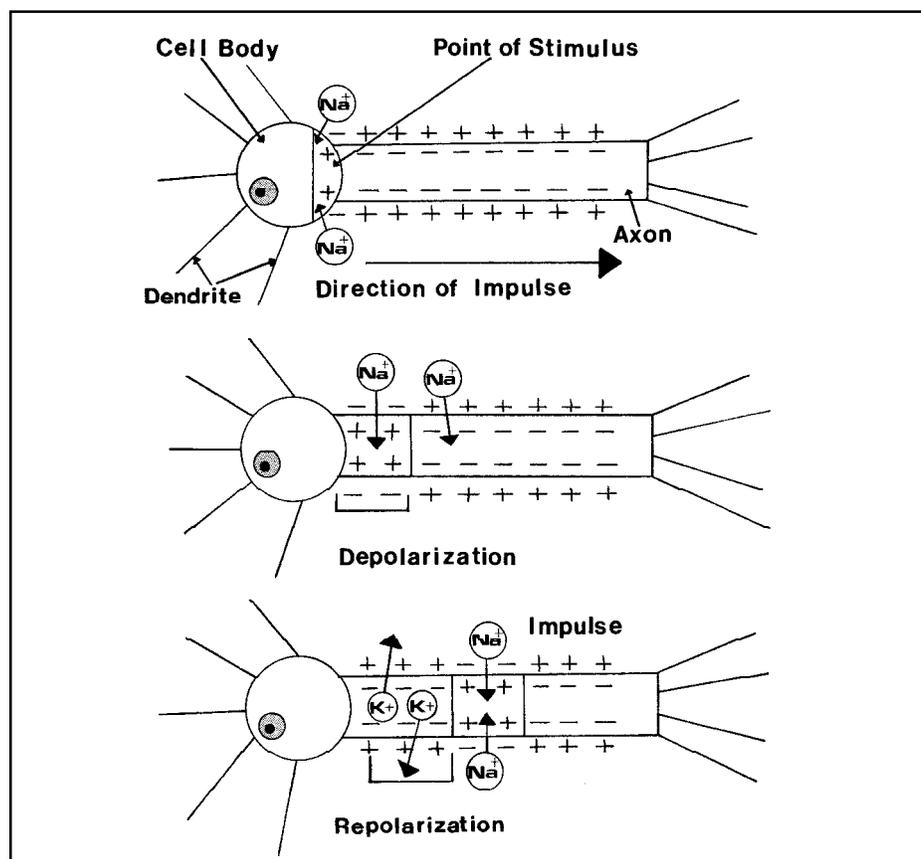


Figure 1. Stages in the generation of the action potential.

An easy way for students to remember whether the membrane potential is negative or positive is the following: If there are more negative charges inside the cell than outside, we say it has a negative membrane potential. If there are more positive charges inside than outside, we say it has a positive membrane potential. Either way, we assume the outside to be zero. In electrical terms, we would say the extracellular fluid is *grounded*.

The resting potential can be described as follows: Each ion (sodium, potassium, and chloride are usually considered) has its own equilibrium potential. This is the value at which two competing forces on the ions are equal and opposite: a diffusional force, carrying the ion down its concentration gradient, and an electrical force, moving the ion toward areas of opposite charge.

At rest, sodium is much more concentrated outside the neuron than inside. As explained earlier, the internal composition of the cell is more negative than the fluid outside. Therefore, if allowed to cross the membrane, both the diffusional and electrical forces tend to drive sodium ions into the cell.

Again considering a nerve cell at rest (-70 mV), potassium is much more concentrated inside the cell than in the extracellular fluid. If potassium is allowed to cross the membrane, the diffusional force is outward. However, because the inside of the cell is negatively charged, the electrical force (flow of positive ions to a negative region) is inward. In reality, at -70 mV, the diffusional force outweighs the electrical force and the net flow of potassium will be out of the cell.

For chloride, there is a higher concentration outside the cell than inside. The diffusional gradient tends to push chloride ions into the cell. But since the cell at rest is negatively charged, it will tend to expel negatively charged chloride ions, and so the electrical force pushes this ion toward the outside. These forces are close to being in balance (they exactly balance at about -60 mV). At rest the diffusional force is slightly stronger than the electrical force. Thus, chloride ions will tend to enter the cell when chloride channels are opened.

To generate an action potential, a passive voltage change (the sum of many individual postsynaptic potential changes) reaches the intersection of the cell body and its axon. See Figure 1. If this voltage change is greater than threshold, a group of sodium channels opens. These channels are transmembrane proteins that, at rest, will not allow sodium ions to pass. When the cell is slightly depolarized, they change shape, forming a pore through which only sodium can pass. For this reason, they are called *voltage-gated channels*. Contrast these to the neurotransmitter-gated channels described on page 192. These voltage-gated channels are only found in the axon and not in other parts of the neuron.

Another class of voltage-gated channels permits potassium ions to cross the membrane; again, these are found only in the axon. Other types of voltage-gated channels (e.g., for calcium) are common, but are not considered here.

The physical basis for the threshold state is the opening of a sufficient number of voltage-gated sodium channels that the process becomes explosive and self-regenerating. As the voltage increases (i.e., the cell depolarizes),

MATERIALS

—Continued

- 5 sheets black construction paper or typing paper
- 1 sheet cardboard, approximately 106 x 90 cm
- 3 toothpicks
- 1 marking pen
- 1 metric ruler
- 2 Post-it™ notes (optional)

(Note: The teacher will need a clock/watch with a second timer.)

PREPARATION TIME REQUIRED

E & C

- 3 hours — Locate and obtain materials, unless students are assigned to bring these in.
- 45 minutes — Make photocopies and overhead transparencies of Figures 1 and 2 and Graph 1 (optional).

A

- 15 minutes — Schedule a class visit to the school library (optional).



SAFETY NOTES

- Students should not eat beans and peas used in this lab.
- Students should avoid hand-to-mouth contact while handling the beans and peas. Commercially obtained beans and peas may have been treated with pesticides.
- Have students wash their hands with soap and water at the end of the lab.

TEACHING TIPS

- For Activity 1, the exact type of beans used does not matter. However, the smaller the bean, the better. In the model used here, light beans are used for positive ions and black beans for negative ions. The type of bean available will vary in different parts of the country.
- When students begin to simulate the action potential in the **Exploration** activity, it may help them to place a Post-it note marked “negative” on the inside of the cell membrane of the model and a note marked “positive” on the outside of the membrane. These notes will help remind them of the relative charges inside and outside the cell at rest. If students use these notes, however, make sure that they remove them after having moved the sodium ions, since the relative charges then change.
- Materials collected and made for the **Exploration** can be reused in subsequent years.
- One method to demonstrate the stimulus, threshold and the all-or-none response is to use a Slinky™. Set it at the top of the steps and begin to tap it easily. Increase the strength of your tap until the stimulus is great enough to cause the Slinky to move down the stairs.

more sodium channels open. As more sodium channels open, the cell becomes more depolarized, and so on. This process is stopped by two factors: The cell reaches a point where the diffusional and electrical forces on sodium balance, and so the opening of more channels produces no further change. Also, at about this time, the sodium channels close of their own accord and become inactive.

A group of potassium channels also responds to this voltage change. They begin to open just as the sodium channels are closing. At this point, which will form the peak of the action potential, the membrane potential has become positive (inside vs. outside) due to the entry of sodium ions. Unlike the situation described for the resting membrane, both the diffusional force (potassium is concentrated inside the nerve cell) and electrical force (potassium carries a positive charge, and the inside of the nerve cell is briefly positive) combine to force potassium out of the cell.

The action potential propagates down the axon, away from the cell body. As the potential spreads outward from the trunk of the axon, no voltage-gated channels are found toward the cell body, so only potential changes flowing away from the cell body encounter excitable membrane.

As the action potential begins its travel down the axon, the sodium channels in its wake (i.e., proximal to the cell body) remain refractory. They will not respond to voltage changes for several milliseconds. A fresh patch of unstimulated sodium channels lies ahead. These will open in response to the voltage change, and the action potential appears to travel down the axon.

Remember that at rest, the potassium ion concentration is higher and the sodium ion concentration is lower inside the cell with respect to the extracellular fluid. Note that as action potentials are repeatedly generated (fired), this differential would tend to be lost. Additionally, there is at rest a leakage of a small number of potassium ions out of the cell, and an even smaller number of sodium ions leak into the cell. To maintain the proper concentration gradient, the cell utilizes an energy-requiring protein, the *sodium/potassium pump* (sodium/potassium ATPase). The pump expels three sodium ions for every two potassium ions it brings into the cell, restoring the number of ions to resting levels.

Only a few sodium and potassium ions need traverse the channels to cause huge voltage changes at the membrane. Their number is tiny compared to the total number of ions found in even a very small compartment of adjacent cytoplasm or extracellular fluid. Because of this, many, many action potentials can be generated before the concentration gradient “runs down.”

As an action potential reaches the tips of the axon (at points called *boutons*, or *axon terminals*), it triggers the opening of voltage-gated calcium channels, which in turn cause release of neurotransmitter from vesicles into the synaptic cleft. The neurotransmitter diffuses across the cleft and binds to receptors that form or are linked to neurotransmitter-gated channels; the cycle begins again. See Figure 2.

The processes outlined in the previous paragraphs describe impulse transmission in an unmyelinated neuron. The presence of myelin in neurons greatly speeds up the nerve impulse transmission, though the process is basically the same as in unmyelinated neurons. Some of the differences between myelinated and unmyelinated neurons are discussed in the laboratory in this manual “No Pain, No Gain.” For a more detailed description of myelinated neurons, consult physiology textbooks.

The opening of channels on the postsynaptic cell can cause a depolarization of the membrane, called an *excitatory postsynaptic potential* or *EPSP*. Another possible response is that the cell membrane becomes more negative with respect to the outside, or hyperpolarizes; in this case, the response is an *inhibitory postsynaptic potential* (*IPSP*).

The neurotransmitter gamma-aminobutyric acid (GABA) serves to suppress action potentials. GABA binds to chloride channels, causing the channels to open and permit chloride ions to flood into the cell. This *inhibitory postsynaptic potential*, or *IPSP*, holds the dendrites and cell body at a voltage level below the threshold. Thus, any wave of potential that is generated is too small to reach threshold when it arrives at the axon.

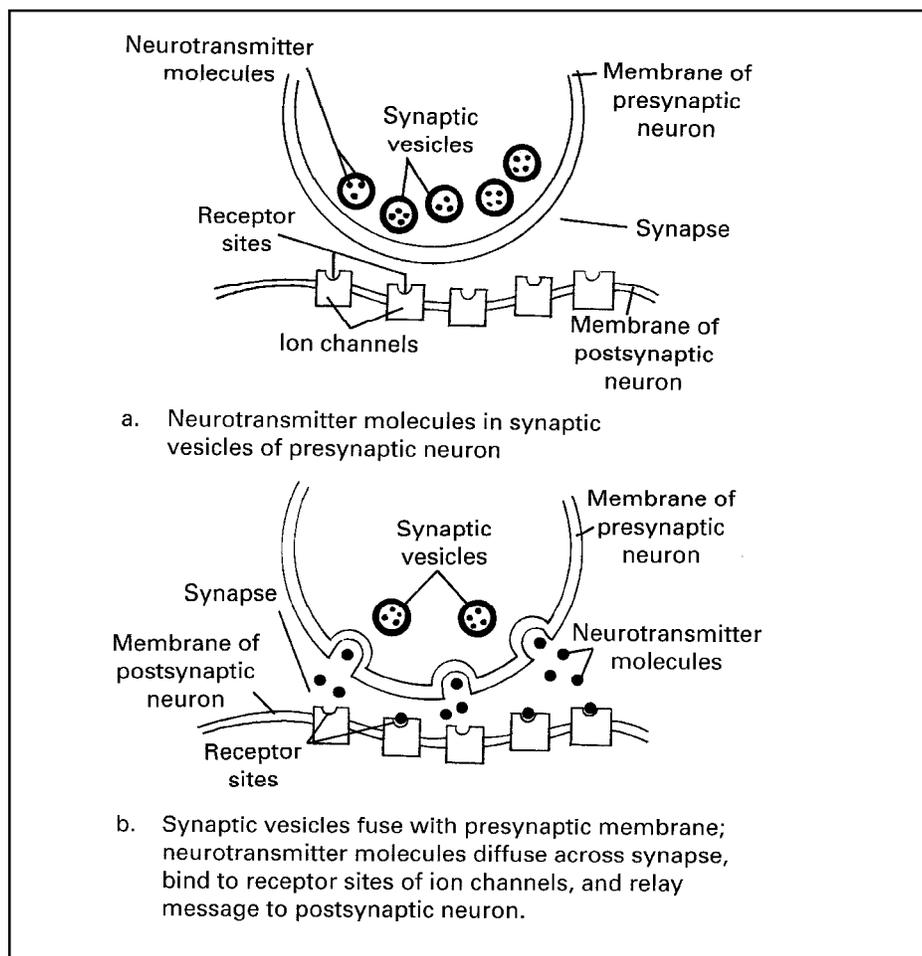


Figure 2. The passing of information from one neuron to another.

SUGGESTED MODIFICATIONS FOR STUDENTS WHO ARE EXCEPTIONAL

Below are possible ways to modify this specific activity for students who have special needs, if they have not already developed their own adaptations. General suggestions for modification of activities for students with impairments are found in the AAAS *Barrier-Free in Brief* publications. Refer to p. 19 of the introduction of this book for information on ordering **FREE** copies of these publications. Some of these booklets have addresses of agencies that can provide information about obtaining assistive technology, such as Assistive Listening Devices (ALDs); light probes; and talking thermometers, calculators, and clocks.

Blind or Visually Impaired

- Provide all diagrams as raised line drawings using a Sewell Drawing Kit or make tactile diagrams using string, liquid glue, or any found items that have textures for a student with no vision. Use photo-enlarged diagrams for students with limited vision.
- A student who is blind would be able to participate as a data recorder as the model is being manipulated.
- Provide the text of **Directions for Students** in braille format or on audiotape for a student who is blind. For students with low vision, provide this text as photo-enlarged copies.

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SUGGESTED MODIFICATIONS — Continued

Mobility Impaired

- Have the student with limited use of his/her arms act as an advisor and data recorder in constructing and manipulating the model. Students with other physical disabilities should have no difficulty with this activity.

This complex 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 as part of the **Application** phase 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 central nervous system (CNS). Where epilepsy is concerned, the issue is not just one of experiencing seizures, but of experiencing recurrent seizures.

Partial, or focal, epilepsy is caused by the 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 an 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 are 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 as 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.

Epilepsy is, however, ultimately a problem with the brain’s inability to control the excitability of neurons. Too many neurons are firing at the same time. Understanding how neurons are excited and inhibited, as described in the previous paragraphs, will help students understand what happens in an individual cell during a seizure.

GABA-mediated inhibition is thought to act as a “shock absorber” to prevent the excessive excitation of networks of neurons. In epileptic seizures, the inability of the brain to dampen overstimulation may be the result of a combination of events, including a lack of GABA-mediated inhibition of action potentials.

A group of drugs, called *benzodiazepines* (a brand name students may have heard of is Valium™), controls seizures by causing the chloride channels to remain open for longer than would normally occur. This influx of chloride

ions inhibits further action potentials. In epileptic seizures, there is a regenerative series of events not unlike the regenerative opening of sodium channels during the action potential: As more cells fire action potentials, more cells that are postsynaptic to these fire action potentials. Drugs such as Valium break this cycle by stopping some of the cells from firing; an analogy would be the damping of a nuclear reaction by carbon rods or the damping of a bumpy road by shock absorbers on a car. Seizures are like a car with broken shocks: every bump in the road causing an uncontrollable bumping of the car (i.e., a firing of a few action potentials sets off the firing of many, many action potentials).

Students will probably be able to think of other drugs that affect the nervous system, such as cocaine (crack), heroin, marijuana, amphetamines (speed), and caffeine. If they do library research on how these drugs act, they will always find some mention of the channels discussed in this lab. Information on some of these drugs may be found in the following references: Cooper, Bloom & Roth (1986); Van Dyke & Byck (1982); Herkenham (1992).

Nerve cells must pass information from one cell to the next. In a few rare instances, the cells are hooked together like conjoined (Siamese) twins; if one cell experiences an action potential, the other one does too (the cells are said to be *electrically coupled*). One advantage of this type of connection is that electrical coupling is rapid and is not subject to failure. It is used in biological systems where it is essential that one nerve cell has a strong effect on another. The disadvantage is that it is not modifiable. If one cell fires, the other must fire too. In a nervous system such as that of a human, this is of little use. These electrical synapses (also called gap junctions) are virtually absent in the mammalian nervous system, but are common in invertebrates, especially in nerve cell circuits that trigger an escape reflex.

Definitions of Terms

For your convenience, some of the terms discussed in the **Teacher Background** are defined below.

Hyperpolarization: The cell's membrane potential becomes more negative; the voltage (-polarization) moves further away from zero (hyper-). Sometimes used interchangeably with *inhibition*: hyperpolarized cells are less likely to fire an action potential.

Depolarization: The cell's membrane potential becomes more positive; the voltage (-polarization) moves closer to zero, the voltage outside the cell (de-). Sometimes used interchangeably with *excitation*: depolarized cells are more likely to fire an action potential.

Inhibitory postsynaptic potential (IPSP): Occurs at the *synapse*, the site of contact where information is passed from one nerve cell to another. One cell sends information (is *presynaptic*), while the other receives it (is *postsynaptic*). If the postsynaptic cell becomes hyperpolarized when the synapse is active, this small voltage change is called an IPSP.

Excitatory postsynaptic potential (EPSP): A small depolarization that occurs in a postsynaptic cell. Both *IPSPs* and *EPSPs* are tiny (less than 1 mV) and by themselves cannot trigger or stop an action potential.

Summation of EPSPs and IPSPs: When the many tiny *IPSPs* and *EPSPs* are added together, the postsynaptic cell uses the sum of all these to “decide” whether or not to fire an action potential of its own. This decision point is called the *axon hillock* or *initial segment*. In general, the dendrites and cell body of a nerve cell do not have the machinery necessary to trigger an action potential. The junction between the cell body and the axon is the first place this machinery exists, so it is the decision point. This arrangement also ensures that the action potential moves away from the cell body, and toward the far end of the axon, where the neuron makes contact with another cell.

Procedure

Exploration

Modeling the action potential with beans

Begin the activity by telling students that they are going to learn about how nerve cells function by constructing a model. Assign students in groups of four roles as follows:

- Materials coordinator 1
 - Materials coordinator 2
 - Bean mover
 - Data recorder.
1. The two materials coordinators should fill the pans with peas or beans as follows. They can estimate the proportions by just looking at them. (Note: In the directions below, the word “many” means enough peas or beans to fill the pan; the word “few” means just enough peas or beans to cover the bottom surface of the pan.)
 - Black-eyed peas (sodium ions): many in one pan, few in another
 - Baby lima beans (potassium ions): many in one pan, few in another
 - Black beans (chloride ions): many in one pan, few in another.
 2. Materials coordinator 1 should mark the poster board down the center, along its long dimension, with a line that is interrupted in several places for 2 to 3 cm. These interruptions will represent the ion gates. Materials coordinator 1 should place toothpicks along the line where the interruptions have been made to “close” the gates; the toothpicks will be pivoted to “open” the gates. Materials coordinator 1 should also mark one side of the line “Inside the cell,” and the other “Outside the cell” (see Figure 3).
 3. Materials coordinator 1 should wad each piece of the construction paper into a tight ball. These five wadded-up balls will represent negatively charged proteins that cannot pass through the cell membrane.

4. If Post-it notes are being used (Refer to **Teaching Tips**), the materials coordinator 1 should place a Post-it note marked “negative” on the inside of the cell membrane of the model and a note marked “positive” on the outside of the membrane.
5. Materials coordinator 2 should arrange the pans and wads of paper on the poster board as shown in Figure 3.
6. Have students read “Facts 1–5” under the **Exploration** phase of **Directions for Students**. Then have students answer Question 1 in the **Exploration** section in their groups. As students answer Questions 2 and 6 they can move beans and peas around in the model. The bean mover in each group can move the peas and beans, and the data recorder can record the results.
7. Have the students read Question 2, then time them for 10 seconds as they follow the directions in the question for opening the sodium channel.
8. Have students work in their groups as they answer Questions 3, 4, and 5.
9. Discuss student answers to Questions 2–5 as a group. Before going on to the next question, make sure they understand the meanings of the following terms. You may want to photocopy and/or make an overhead transparency of Figure 1 as you and your students discuss the following concepts presented in this phase of the activity:
 - Membrane potential
 - Threshold
 - Action potential.
10. Have the students read Question 6, then time them for 10 seconds as they follow the directions in the question for closing the sodium channel and opening the potassium channel.
11. Have students work in their groups as they answer Questions 7 and 8.
12. Discuss student answers to Questions 7 and 8 as a group. Before going on to the next section, make sure they understand the meaning of a voltage-gated channel.

Concept/Term Introduction

13. Show students a graph of the action potential and ask them to relate what the graph shows to what they just learned using their model. Refer to Graph 1 for a sample graph. You may want to make photocopies and an overhead transparency of this graph to discuss with students.
14. Have students work in small groups as they answer Question 9. If enough desk or floor space is available, several groups can actually line their cell models up, as the question describes. They can look at this longer stretch of nerve cell “axon” as they consider the answer to the question. (If students actually line up their models, it will probably avoid spillage if they return all peas and beans to their respective pans for the resting state.)

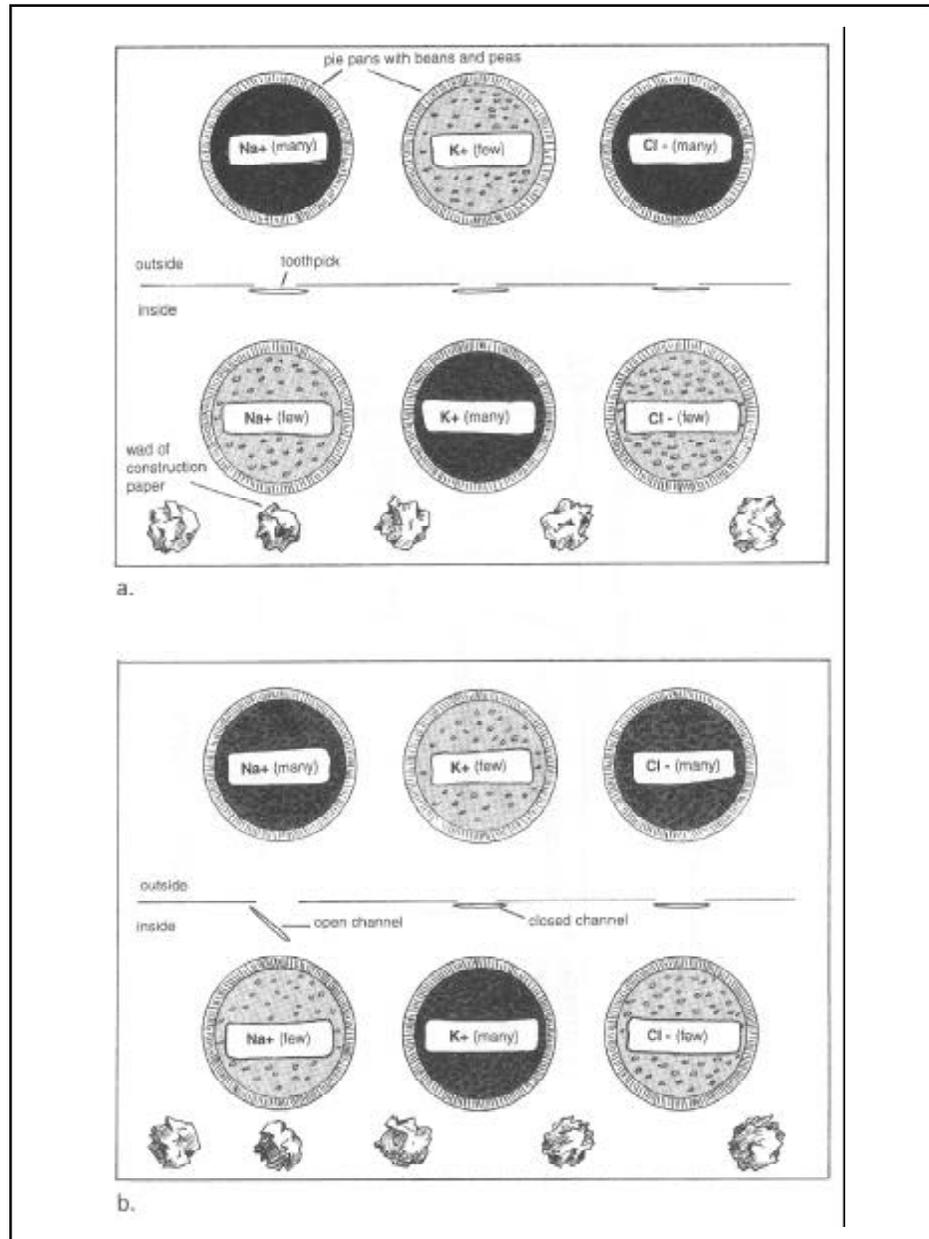
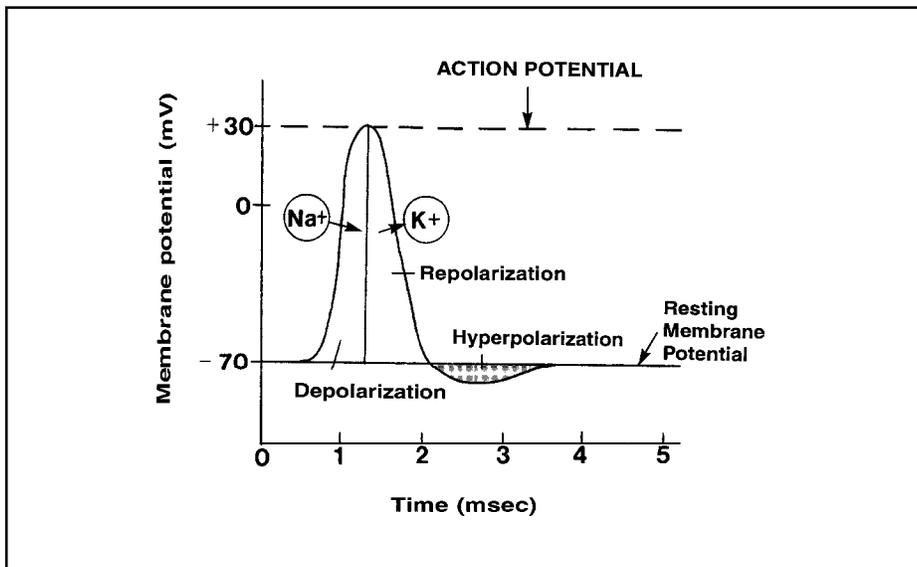


Figure 3. Illustration of student model. (a) Nerve cell "at rest" with all channels closed. (b) Nerve cell with sodium channel having just opened.

15. Discuss student answers to Question 9 as a group. Before going on to the next question, make sure they understand the meanings of these terms:
 - Sodium channel inactivation
 - Refractory period.
16. Have students work together in their small groups to answer Questions 10 and 11. Then have each group share its ideas with the class. If students have not already begun discussing it, lead them through a discussion of the sodium-potassium-ATP pump. Refer to the **Teacher Background** for more information about the pump.



Graph 1. Sample graph of action potential.

17. Have students work together in their small groups to answer Question 12. Then have each group share its ideas with the class. If students have not already begun discussing it, lead them through a discussion of how neurons pass information on using neurotransmitter-gated channels. You might want to give the students copies of Figure 2 as you discuss this information. Before going on to the **Application** phase, make sure students understand the meanings of these terms:

- Axon terminal
- Neurotransmitter-gated channel
- Excitatory postsynaptic potential (EPSP)
- Inhibitory postsynaptic potential (IPSP).

Refer to the **Teacher Background** for more information about these concepts.

A Application

Students can now build on their previous experiences and learn more about how neurons transmit impulses, as well as what happens when abnormal firing of neurons occurs. Have them follow the instructions in **Directions for Students** for the **Application** section for one or both of the **Application** activities.

Answers to Questions in “Directions for Students”

Exploration

Focus Questions

- 1a. Into the cell. Diffusion will tend to make the sodium ions move into the cell because they are more concentrated outside the cell.
- 1b. Into the cell. The positively charged sodium ions are attracted to the negative charges inside the cell.
2. The predictions students make about which direction the sodium ions will move will vary depending on their answers to Questions 1a and 1b. If they answered 1a and 1b correctly, they will predict that the sodium ions will move into the cell.
3. Answers will vary depending on their answers to Questions 1 and 2. If they answered Questions 1 and 2 correctly, there will now be more sodium ions inside the cell than before.
4. Answers will vary depending on student answers to Questions 1, 2, and 3. If these questions were answered correctly, the internal medium of the cell should now be more positively charged than it was before.
- 5a. Out of the cell. Diffusion will tend to make the potassium ions move out of the cell because they are more concentrated inside the cell.
- 5b. Out of the cell. The positively charged potassium ions are attracted to the negative charges outside the cell. (Note: The outside of the cell is now more negative than at rest, since positively charged sodium ions have moved into the cell.)
6. The predictions students make about which direction the potassium ions will move will vary depending on their answers to Questions 5a and 5b. If they answered 5a and 5b correctly, they will predict that the potassium ions will move out of the cell.
7. Answers will vary depending on their answers to Questions 5 and 6. If they answered Questions 5 and 6 correctly, there will now be fewer potassium ions inside the cell than before.
8. Answers will vary depending on student answers to Questions 5, 6, and 7. If these questions were answered correctly, the internal medium of the cell should now be more negatively charged than it was before opening the potassium channel, but after opening the sodium channel.

Concept/Term Introduction

Focus Questions

9. If the action potential is started in the middle of a long line of such models, it will move in both directions from the original site. If, on the other hand, it starts at one end, it is forced to move in one direction. Since the sodium channels “behind” the action potential are inactive, they cannot open. This is the situation at the axon hillock or initial segment, where the nerve cell body gives rise to the axon: There are no

voltage-gated sodium channels in the cell body membrane, so it's like starting at one end of a long line of models.

10. No, the sodium and potassium ions would not continue to move as they did during the action potential because the forces driving them to move as they did (chemical and electrical gradients) have changed.
11. The student may either invent or remember something like the sodium/potassium pump in response to this question. The teacher will probably have to help most students come up with this answer, however. Refer to the **Teacher Background** for more information about this topic.
12. The students may develop an idea similar to chemical neurotransmitters interacting with neurotransmitter-gated channels on the postsynaptic cell. The teacher will probably have to help most students come up with this answer, however. Refer to **Teacher Background** for more information about this topic.

A Application

Application I

Focus Question

1. Students' answers will vary. However, some may come up with the idea that seizures and epilepsy result from overstimulation of neurons. Normally, nerve cells fire action potentials as the situation warrants; at any time, only a few are opening and closing voltage-gated channels. Seizures result when a large group of nerve cells all fire action potentials simultaneously. If the nerve cells are found in the area of the brain that controls movement of the arms, for example, the arms may wave about wildly as the signals to move the arms are sent over and over again by action potentials.

Application II

Focus Questions

- 1–3. Student designs of drugs will vary, as well as the drugs they research in the library. One possibility they might research is a group of drugs, called *benzodiazepines* (a brand name students may have heard of is Valium), which controls seizures by causing the chloride channels to remain open for longer than would normally occur. Refer to **Teacher Background** information for more information on the mechanism of action of these drugs.

References

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Suggested Reading

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ACTION POTENTIAL — EPILEPSY

Directions for Students

Introduction

In this activity, you will set up a model to simulate how a neuron processes information. The model will include such items as peas, beans, and construction paper. You will need to know the facts listed below to do the **Exploration** and to learn about the action potential. Understanding how neurons process information is essential to understanding certain neurological disorders, such as epilepsy.

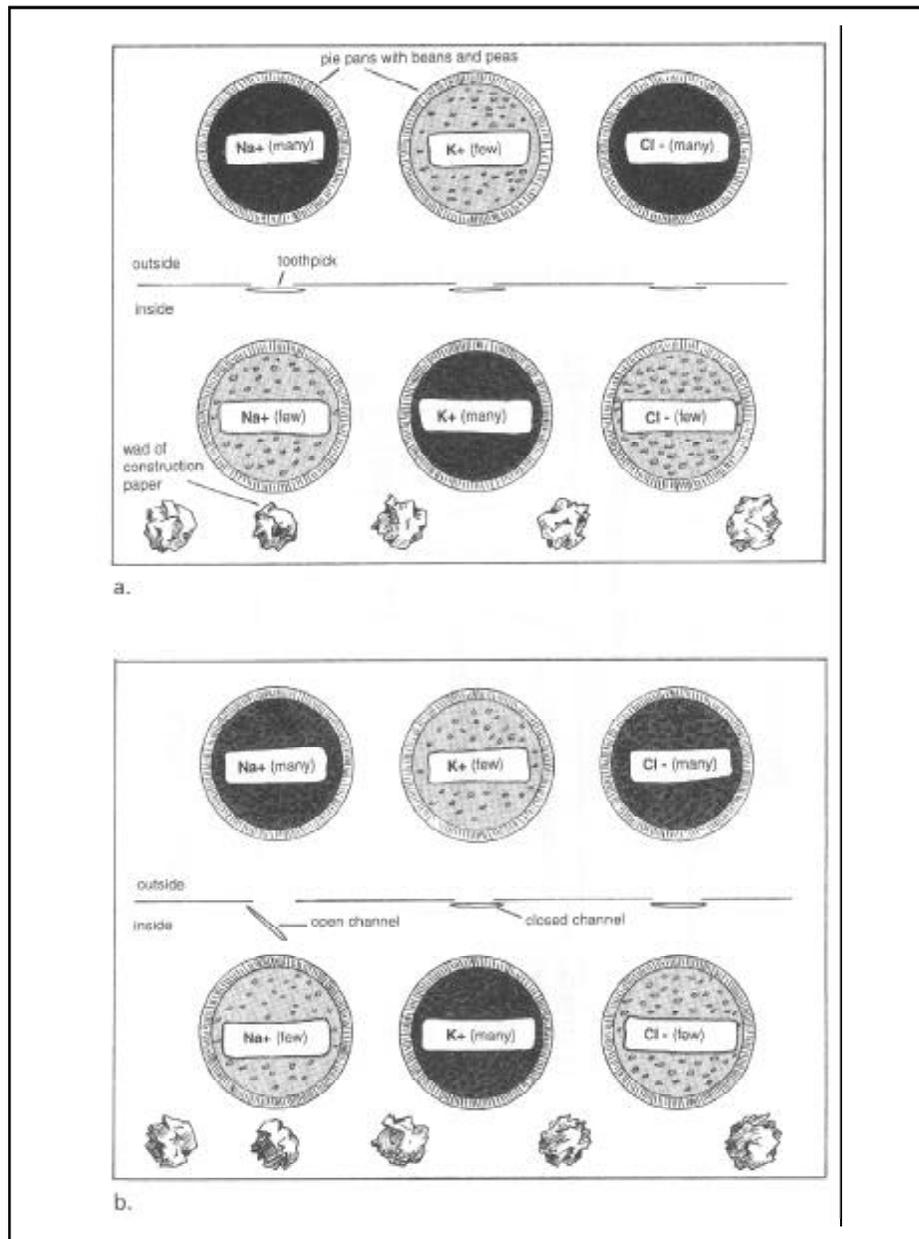


Figure 1. Illustration of student model. (a) Nerve cell "at rest" with all channels closed. (b) Nerve cell with sodium channel having just opened.

MATERIALS

Materials will be provided by your teacher and consist of the following per group:

- 2 pounds (900 g) dried black-eyed peas
- 2 pounds (900 g) dried baby lima beans
- 2 pounds (900 g) dried black beans
- 6 pie or cake pans, disposable aluminum, 8–9 inches (20–22.5 cm) diameter
- 5 sheets black construction paper or typing paper
- 1 sheet cardboard, approximately 106 x 90 cm
- 3 toothpicks
- 1 marking pen
- 1 metric ruler
- 2 Post-it™ notes (optional)

SAFETY NOTES

- Do not eat the beans and peas used in this lab.
- Avoid hand-to-mouth contact while handling the beans and peas. Commercially obtained beans and peas may have been treated with pesticides.
- Wash your hands with soap and water at the end of the lab.

Fact 1. Black-eyed peas represent sodium ions. There are more sodium ions outside the nerve cell than inside, so there are more peas in the “outside” pan. Lima beans represent potassium ions, black beans represent chloride ions, and the wads of construction paper represent proteins. In a real cell, there would be millions of ions, but there is not room enough for that many peas and beans on your poster board. Sodium and potassium ions have a positive charge, while chloride ions and proteins carry a negative charge.

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.

Fact 4. One force acting on the ions is for them to move from areas of higher concentration to lower concentration. Using sodium as an example, this force would tend to make the number of black-eyed peas in the pans 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, chloride, 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 (–70 mV).

Procedure

Exploration

Follow your teacher’s directions as you set up your nerve cell model. You will use your model cell to answer the questions below. It may help to take the beans and peas (ions) out of the pans and move them around to visualize the answer to your question. The bean mover in your group can move the peas and beans, and the data recorder can record the results.

FOCUS QUESTIONS

1. Look at the numbers of black-eyed peas representing the sodium ions in the pans inside and outside the cell. If the sodium channel were suddenly opened so that sodium ions (peas) could move across the cell membrane:
 - a. Which direction would they tend to move based on their concentration: into the cell or out of the cell? Explain.

FOCUS QUESTIONS

—Continued

- b. Which direction would they tend to move based on their charge: into the cell or out of the cell? Explain. (Remember, the inside of the cell is negative with respect to the outside at rest.)
2. A sodium channel opens for about one millisecond (one 1000th of a second). Your teacher will time the opening of the sodium channel for 10 seconds, representing one millisecond. Before he/she begins timing, decide which direction the sodium ions will move based on your answers to Questions 1a and 1b. When the teacher begins timing, open the sodium channel by moving the toothpick as shown by your teacher. Then take the peas out of the pan and drag them through the sodium channel one at a time in the direction you think they will go until the teacher stops the timing. (Remember, the sodium ions cannot pass through other channels nor through the membrane where there is no channel.)
(Note: Leave the sodium ions where they are now as you answer Questions 3–8, but close the sodium channel. If you have used Post-it notes to mark “negative” and “positive,” remove these notes now.)
3. Look at the numbers of sodium ions on each side of the cell membrane now. Compared to the number in each pan at rest, are there:
 - a. More sodium ions inside the cell now than there were before, or
 - b. Fewer sodium ions inside the cell now than there were before?
4. Based on your answer to Question 3, do you think the internal medium of the cell is:
 - a. More negative than it was before, or
 - b. More positive than it was before?Explain.
5. Look at the numbers of lima beans representing the potassium ions in the pans inside and outside the cell. If the potassium channel were suddenly open so that potassium ions (beans) could move across the cell membrane:
 - a. Which direction would they tend to move based on their concentration: into the cell or out of the cell? Explain.
 - b. Which direction would they tend to move based on their charge: into the cell or out of the cell? Explain.
6. A potassium channel opens for one to three milliseconds. Your teacher will time the opening of the potassium channel. Before he/she begins timing, decide which direction the potassium ions will move based on your answers to Questions 5a and 5b. When the teacher begins timing, open the potassium channel. Take the beans out of the pan and drag them through the potassium channel one at a time in the direction you think they will go until the teacher

FOCUS QUESTIONS

—Continued

stops the timing. (Remember, the potassium ions cannot pass through other channels nor through the membrane where there is no channel.)

7. Look at the numbers of potassium ions on each side of the cell membrane now. Compared to the number in each pan at rest, are there:
 - a. More potassium ions inside the cell now than there were before, or
 - b. Fewer potassium ions inside the cell now than there were before?
8. Based on your answer to Question 7, do you think the internal medium of the cell is:
 - a. More negative than it was before you had opened the potassium channel (but after you had opened the sodium channel and moved the peas), or
 - b. 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.

Concept/Term Introduction

FOCUS QUESTIONS

9. 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 nerve cell axon, what effect would this have on the action potential? Does it make a difference if you start at one end of the long line, or in the middle?
10. After a lot of action potentials have occurred, will enough peas/beans/ions move to change significantly the concentration gradients you set up initially when your model was at rest? Would the sodium and potassium ions continue to move as they did during the action potential you simulated in the **Exploration** activity?
11. In order to continue to function properly, the cell must now somehow get back to its resting state. Do you have any ideas as to how the cell might do this? Your teacher may give you additional

FOCUS QUESTIONS

—Continued

information to help you answer this question.

12. When an action potential reaches the end of the axon of the nerve cell, it will then pass on information to the next cell. Do you have any ideas as to how the cell might do this? Your teacher may give you additional information to help you answer this question.

A Application

Application I: Abnormal Processing of Information by Neurons

FOCUS QUESTIONS

1. Can you think of situations in which it would be important for the postsynaptic cell to be stimulated (*EPSP*)? inhibited (*IPSP*)? What kinds of problems might occur if it were not possible to control whether postsynaptic neurons were inhibited or stimulated? For example, what if postsynaptic neurons were always stimulated?
2. Do library research to learn about the neurological basis of seizures and epilepsy.

Application II: “Designing” a Drug to Treat Seizures

The neurotransmitter gamma-aminobutyric acid (GABA) suppresses action potentials. GABA binds to chloride channels, causing the channels to open and permit chloride ions to flood into the cell. This *inhibitory postsynaptic potential*, or *IPSP*, holds the dendrites and cell body at a voltage level below the threshold. Thus, any wave of potential that is generated is too small to reach threshold when it arrives at the axon.

GABA-mediated inhibition is thought to act as a “shock absorber” to prevent the excessive excitation of networks of neurons. In epileptic seizures, the inability of the brain to dampen overstimulation may be the result of a combination of events, including a lack of GABA-mediated inhibition of action potentials.

Almost all drugs that affect the nervous system act by causing channels in certain nerve cells to open or close. Ethyl alcohol may be the only exception, but this is a subject of continuing study by neuroscientists (individuals who study brains) and pharmacologists (individuals who study the effects of drugs on the body).

FOCUS QUESTIONS

1. Based on what you know about how neurons transmit information, how might a drug be “designed” to treat epileptic seizures? How would such a drug act on the neurons? Make diagrams to illustrate your idea, if these would be helpful.

FOCUS QUESTIONS

—Continued

2. Do library research to learn about the names and mechanisms of action of the most up-to-date types of drugs used to treat epilepsy.
3. Were there differences between the drug you “designed” and drugs currently in use to treat epilepsy? Do you now understand how these drugs act to control seizures?

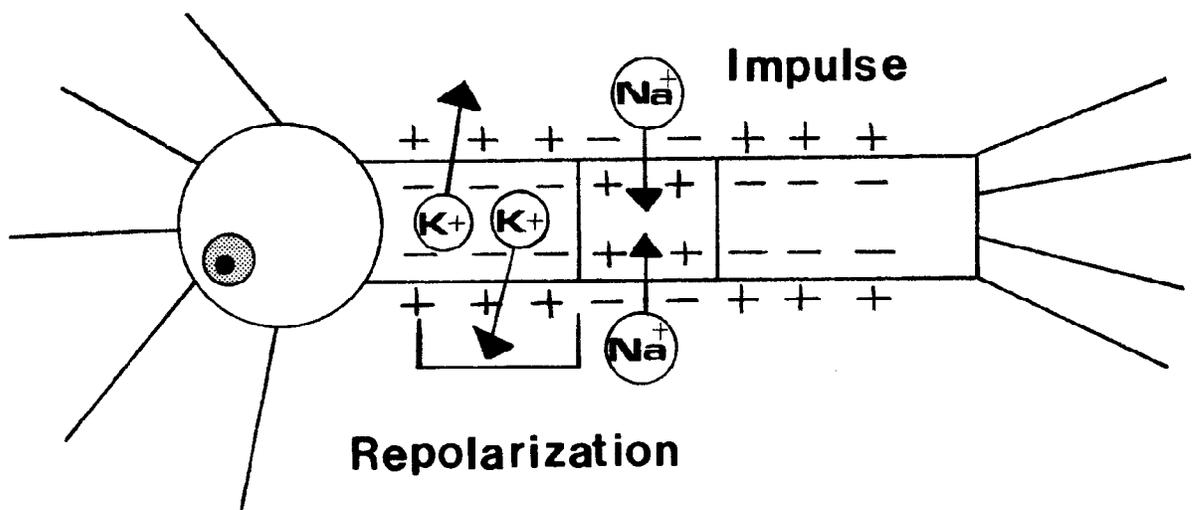
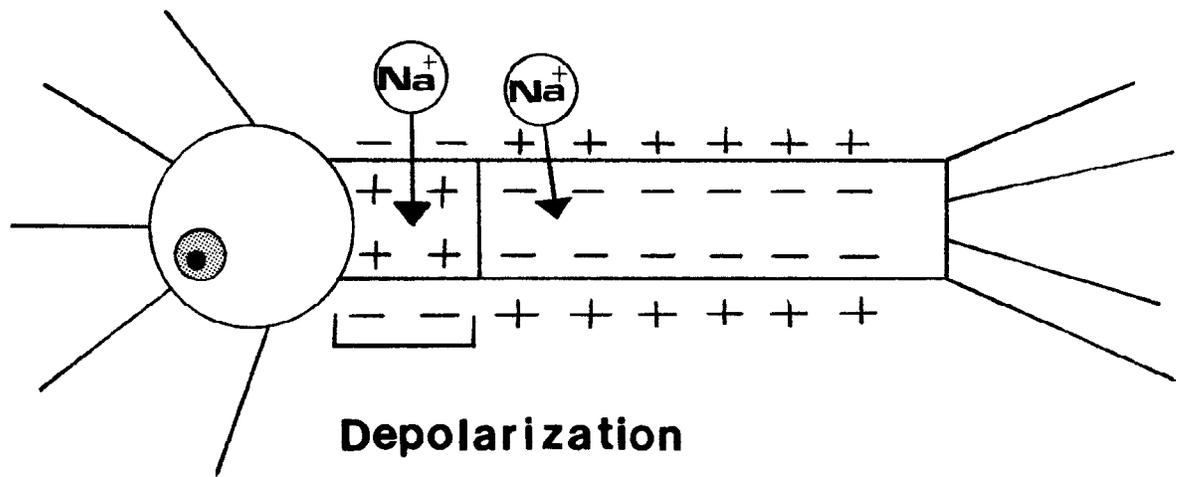
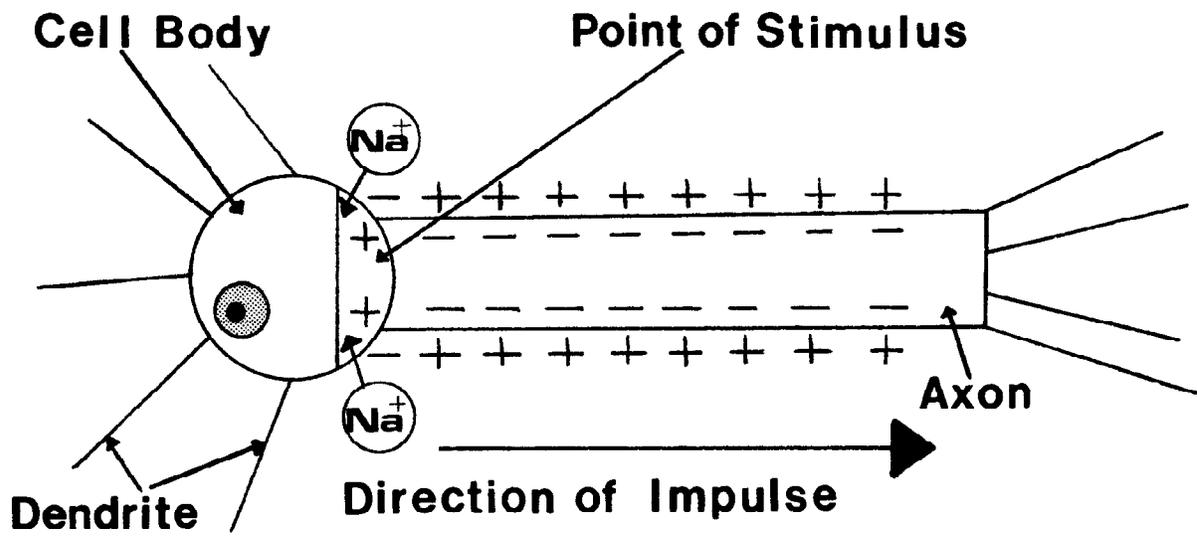
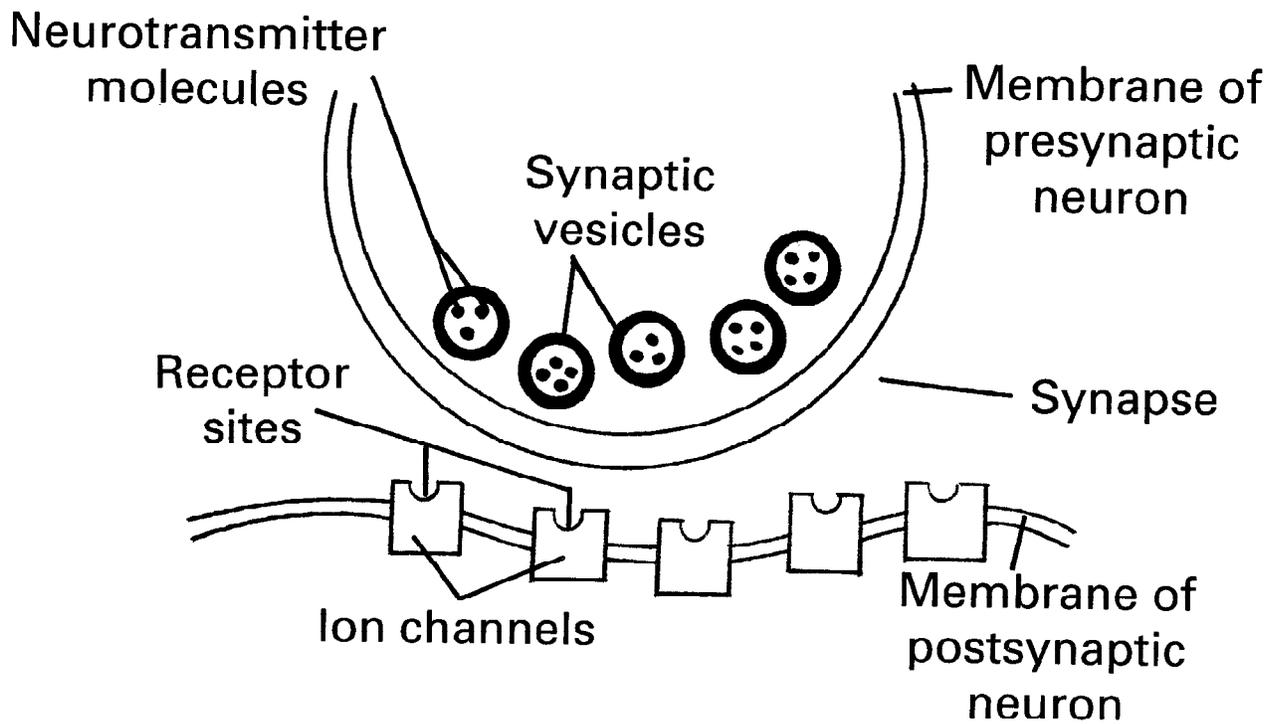
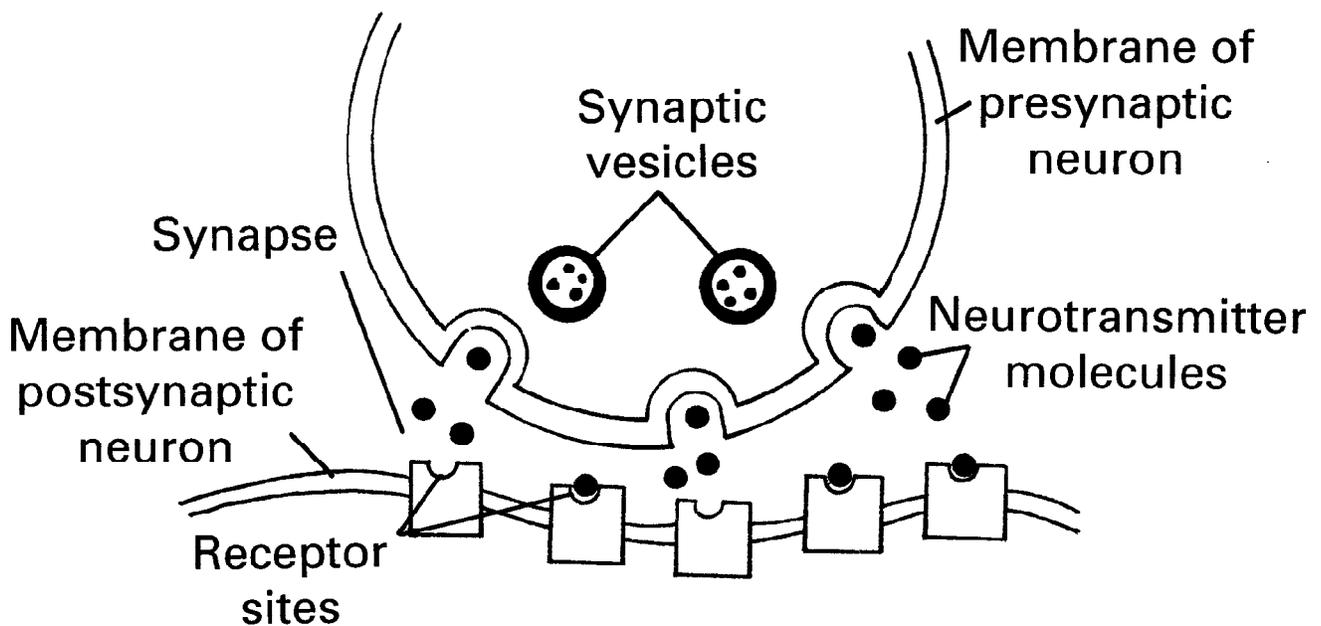


Figure 1. Stages in the generation of the action potential.

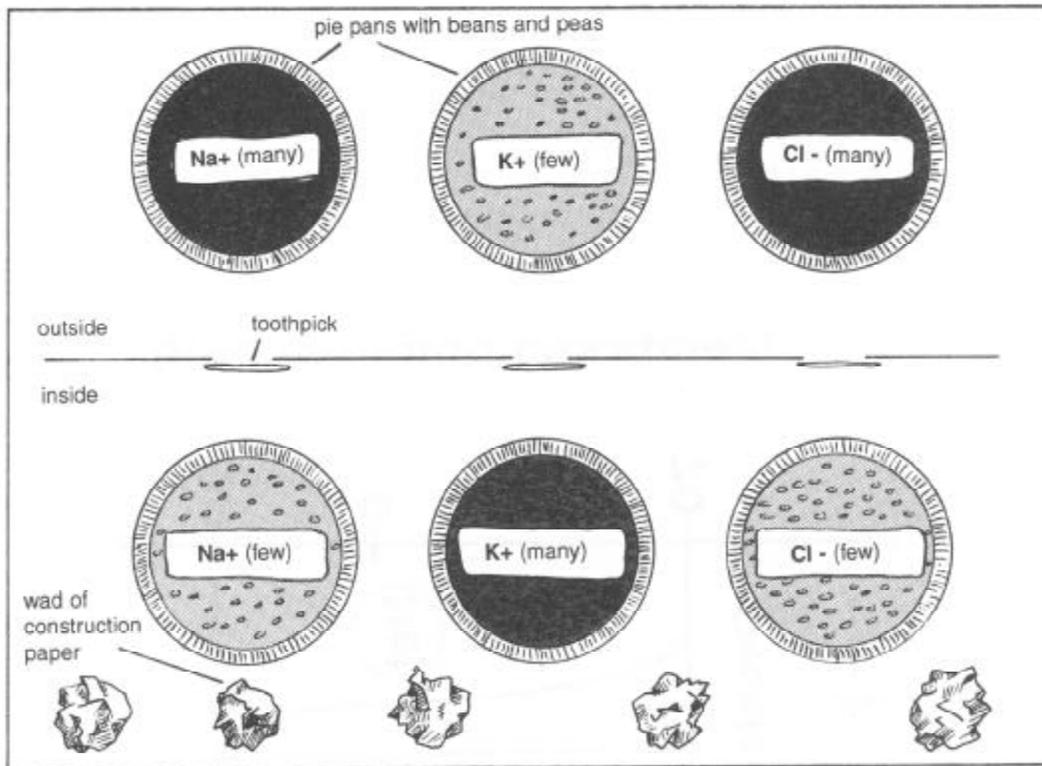


- a. Neurotransmitter molecules in synaptic vesicles of presynaptic neuron

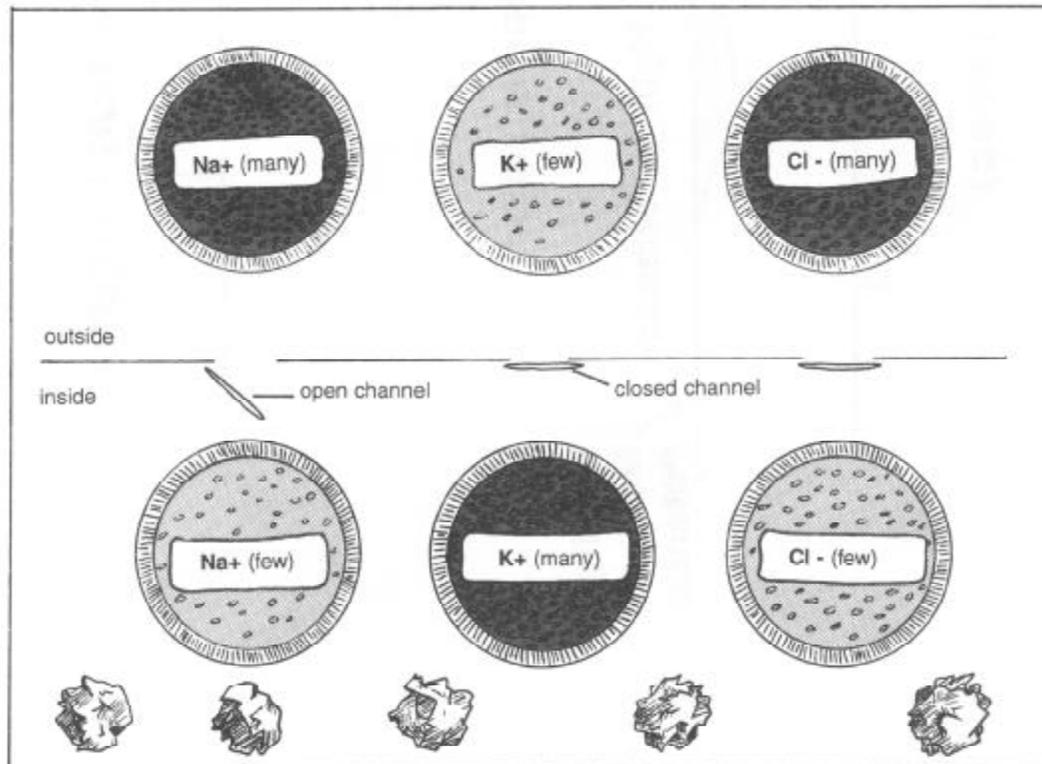


- b. Synaptic vesicles fuse with presynaptic membrane; neurotransmitter molecules diffuse across synapse, bind to receptor sites of ion channels, and relay message to postsynaptic neuron.

Figure 2. The passing of information from one neuron to another.

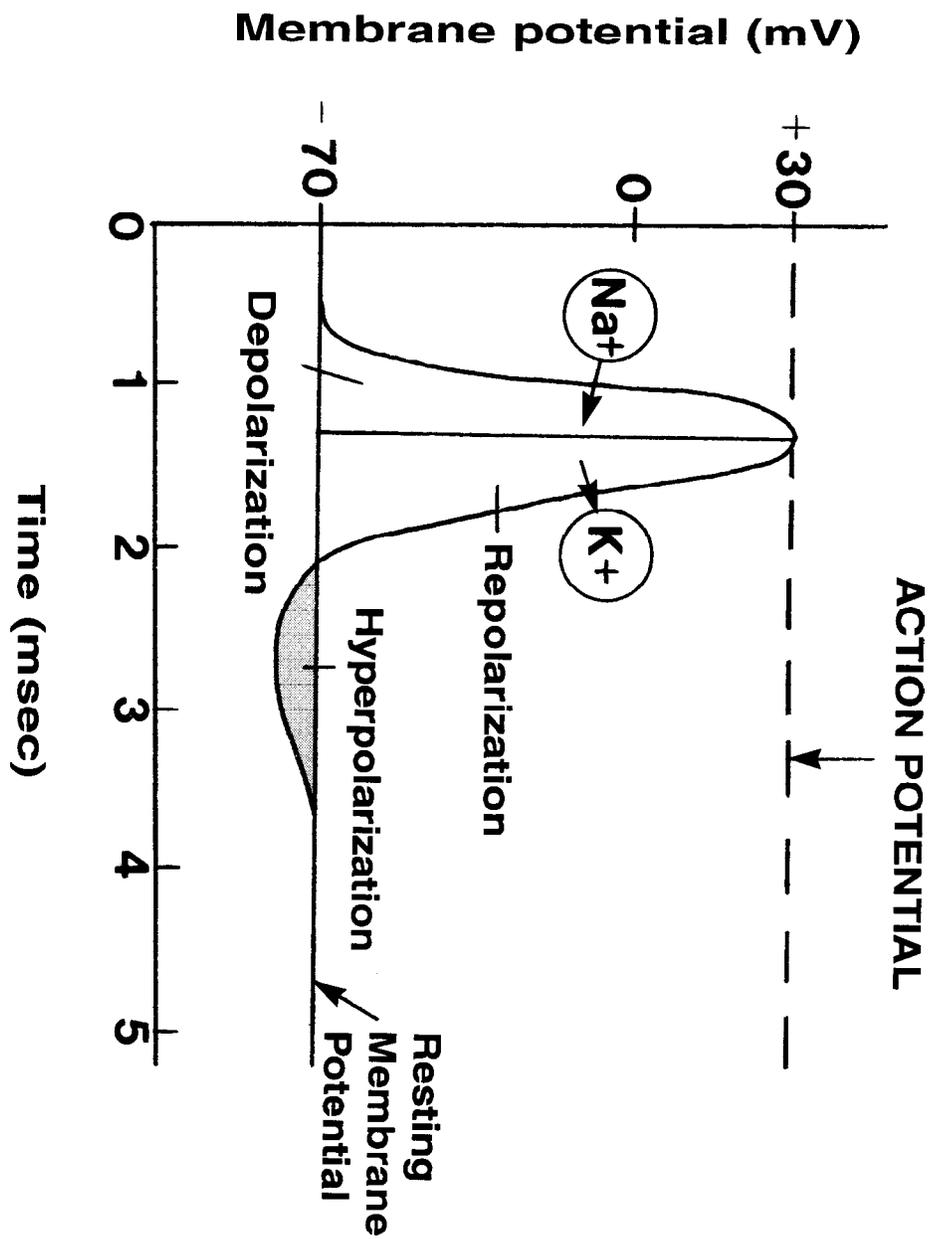


a.



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.



Graph 1. Sample graph of action potential.