The Membrane Potential

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** It is suggested that you carefully label each ion channel in the graphics in this section. If this is not printed in color, you should also color code the ion channels and ions as follows:
Red: Sodium ion channels and sodium ions
Blue: Potassium ion channels and potassium ions
Green: Chloride ion channels and chloride ions

Page 1. Introduction

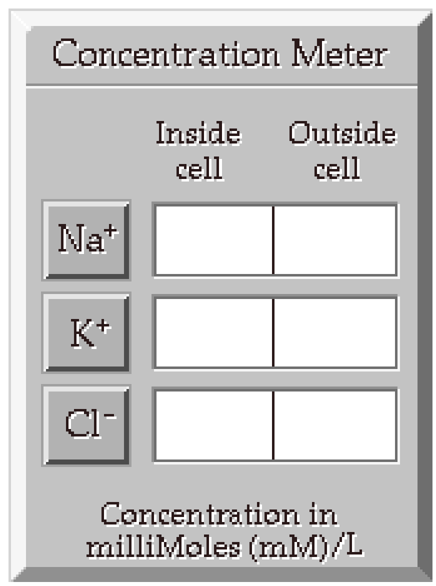
- Gradients cause ions to move across cell membranes. This results in a separation of charge across the membrane, which in turn creates an electrical potential, or force.
- The electrical potential is called the membrane potential.

Page 2. Goals

- To know the relative concentration of ions inside and outside of cells.
- To recognize that cells have selective permeability for ions.
- To understand the equilibrium potential for potassium.
- To understand that sodium and potassium determine the resting membrane potential.
- To realize that the sodium-potassium pump maintains the resting membrane potential.

Page 3. The Concentration of Ions Differs Inside and Outside the Cell

- Fill in this chart as you work through this page:

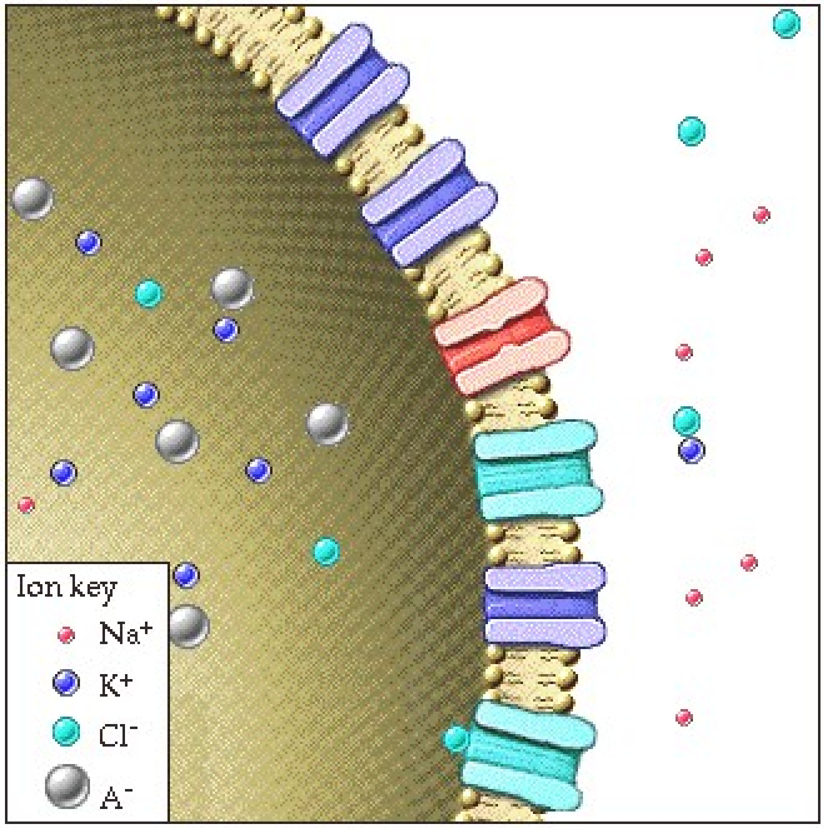


- Recall that the intracellular concentrations of sodium, potassium, and chloride differ from their concentrations outside the cell in the extracellular fluid.
- Inside the cell, the concentration of positive potassium ions is high. It is balanced by a high concentration of negatively charged proteins and other anions.
- In the extracellular fluid outside the cell, the concentration of positive sodium ions is high. It is balanced by a high concentration of negative chloride ions.

Page 4. Cells Exhibit Selective Permeability

- Ions are not soluble in the lipid bilayer; they can only cross cell membranes by passing through watery pores called ion channels.
- If a cell has channels for a particular ion, we say it is permeable to that ion. Since most cells are permeable to some ions but not to others, they exhibit selective permeability.
- This cell membrane is impermeable to ions.
- This cell is permeable to potassium. Many cells in the body are selectively permeable only to potassium.
- Excitable cells are very permeable to potassium and slightly permeable to sodium.
- Neurons are selectively permeable to potassium, sodium, and chloride.
- Cells are impermeable to the negatively charged proteins and other large anions found inside them. These anions are too large to pass through the cell membrane.

• As you work through this page, color the potassium channels and the potassium ions blue, the sodium channels and the sodium ions red, and the chloride channels and the chloride ions green.



Page 5. Permeability Depends on the Number of Ion Channels

• The permeability of a cell for a particular ion depends on:
  1. The number of channels for that ion.
     • Permeability can be increased by increasing the number of channels for a given ion.
  2. The ease with which the ion can move through the channels.
     • If an ion is small compared to the size of an ion channel, it goes through easily.

• Adding or removing potassium ion channels to a cell will change the permeability of the cell to potassium.

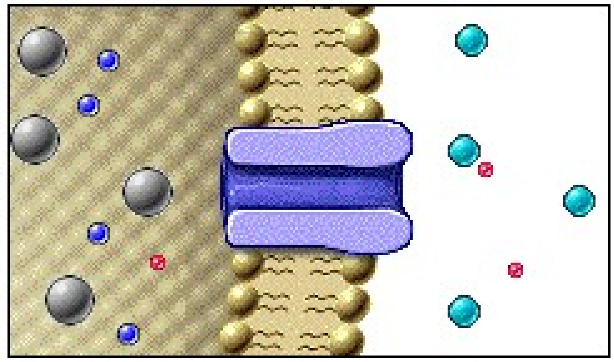
Page 6. Permeability Can Change Rapidly When Gated Ion Channels are Opened

• You have learned that some channels have gates that may be either open or closed.
• The permeability of a cell for a given ion increases when gated channels for that ion are opened. This is the mechanism used by the nervous system to produce rapid changes in membrane permeability.

Page 7. Potassium Diffuses Down Its Concentration Gradient

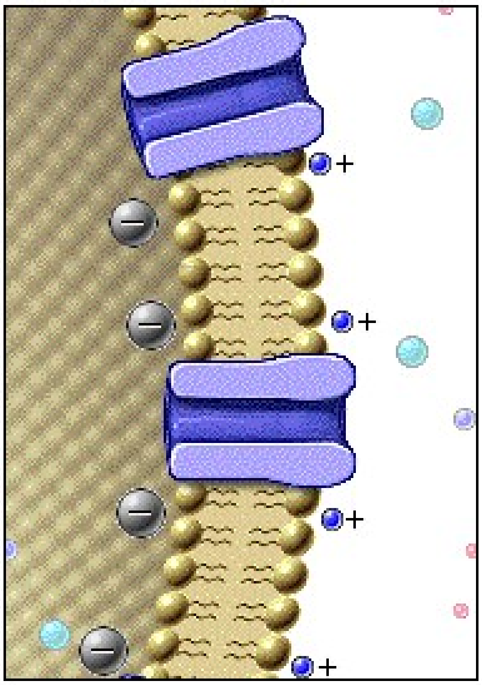
• We are studying neurons. But before we talk about how ions move across neuronal cell membranes, let's talk about a simpler cell, one that is permeable to only one ion.
• Many of the cells of the body are like this simple, non-excitable cell. When we understand it, we will learn how neurons are different because they are permeable to several ions.
• This cell is selectively permeable only to potassium.
• Gradients cause ions to move. Potassium will diffuse down its concentration gradient from the area where its concentration is high to the area where its concentration is low.
• Potassium diffuses out of the cell from its higher to lower concentration.
• The concentration gradient acts as a chemical force that pushes potassium out of the cell. The width of the arrow represents the relative strength of the chemical force.

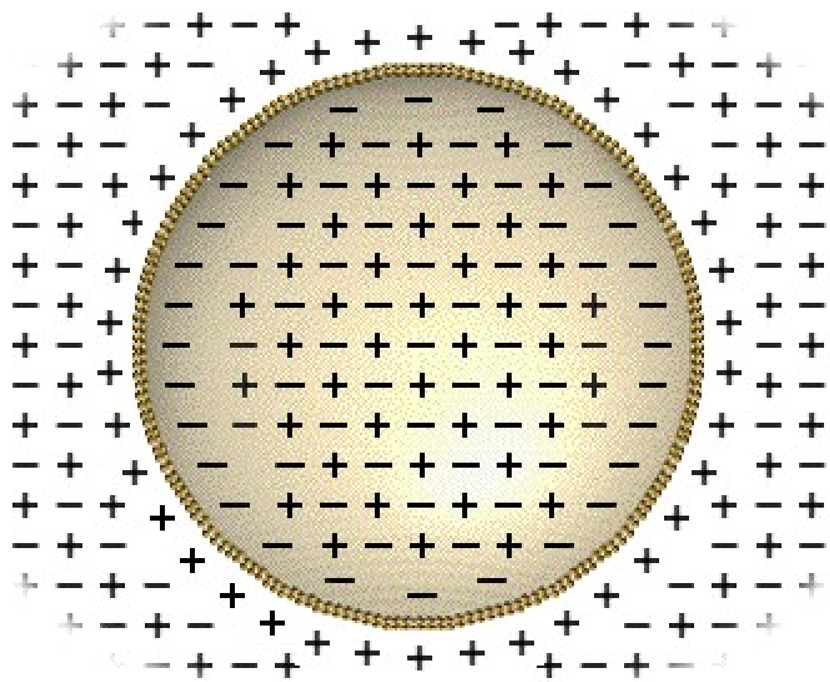
• Indicate the direction of the chemical force in a non-excitable cell with an arrow. Color code the ions and ion channel:



Page 8. Outward Diffusion of Potassium Creates an Electrical Potential

• As potassium ions diffuse out of the cell, they accumulate on the outside surface of the cell membrane, making it more positive than the inside surface of the membrane. This results in a separation of charge across the cell membrane.
• There is a net positive charge on the outside of the cell membrane, and a net negative charge on the inside.
• This separation of charge creates an electrical potential across the cell membrane.

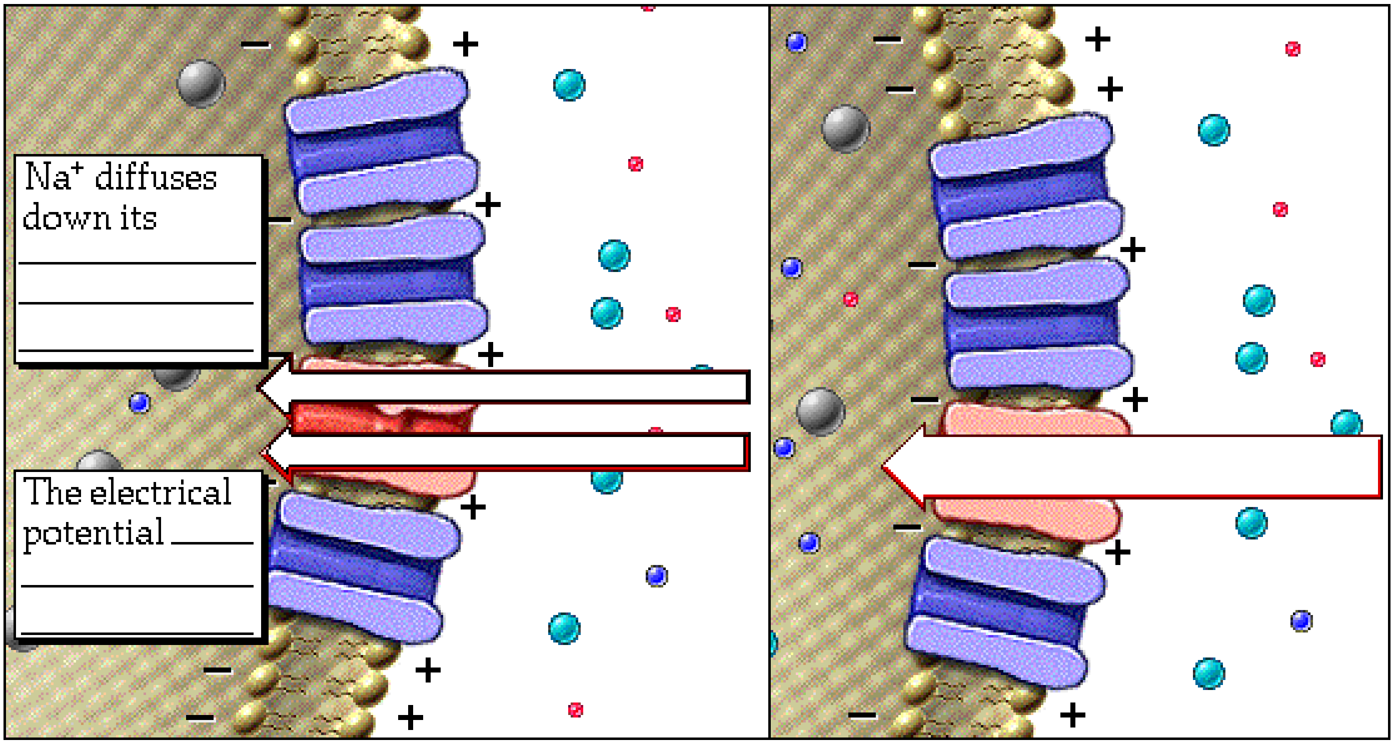




Page 9. The Electrochemical Gradient for Sodium Drives it into the Cell

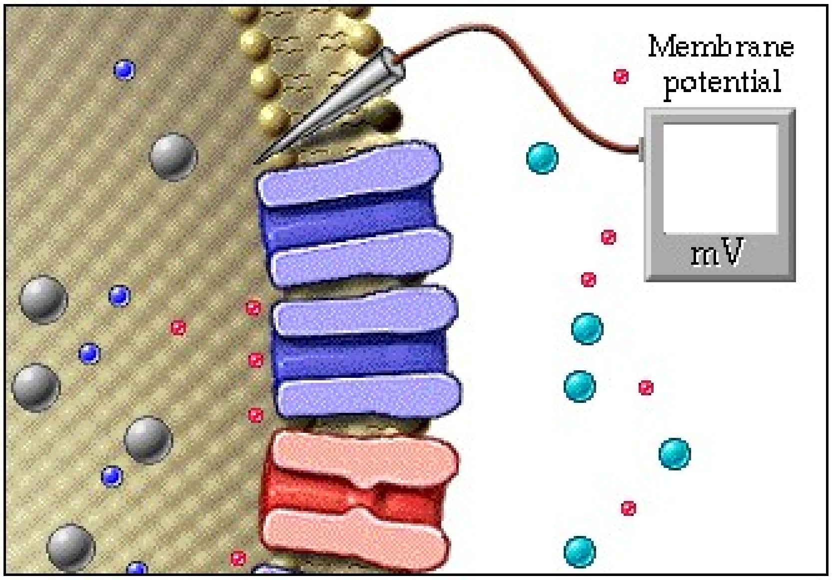
• Recall that neurons are permeable to more than one ion.
• Let's see how the membrane potential in such cells differs from the membrane potential in simple cells that are permeable only to potassium.
• When neurons are not generating electrical signals, we say they are at rest.
• Resting neurons are very permeable to potassium, and only slightly permeable to sodium. They are also permeable to chloride, but since it contributes little to the resting membrane potential, we will not consider it further.
• We have observed the movement of potassium ions across a very permeable cell membrane. Now let’s examine movement of sodium.
• The width of the arrow represents the relative strength of the chemical force.
• You have learned that when potassium diffuses out of a cell a charge separation develops, producing a net negative charge inside the cell. Neurons are very permeable to potassium, so they have a net negative charge inside their membrane.
• Since opposite charges attract each other, the electrical potential resulting from the charge separation acts as a force to pull sodium into the cell.
• The width of the arrow represents the relative strength of the electrical force.

- The forces from the concentration gradient and the electrical potential combine to produce a large electrochemical gradient for sodium.
- The width of the arrow represents the relative strength of the electrochemical gradient.
- This electrochemical gradient drives sodium into the cell.
- Label these diagrams:



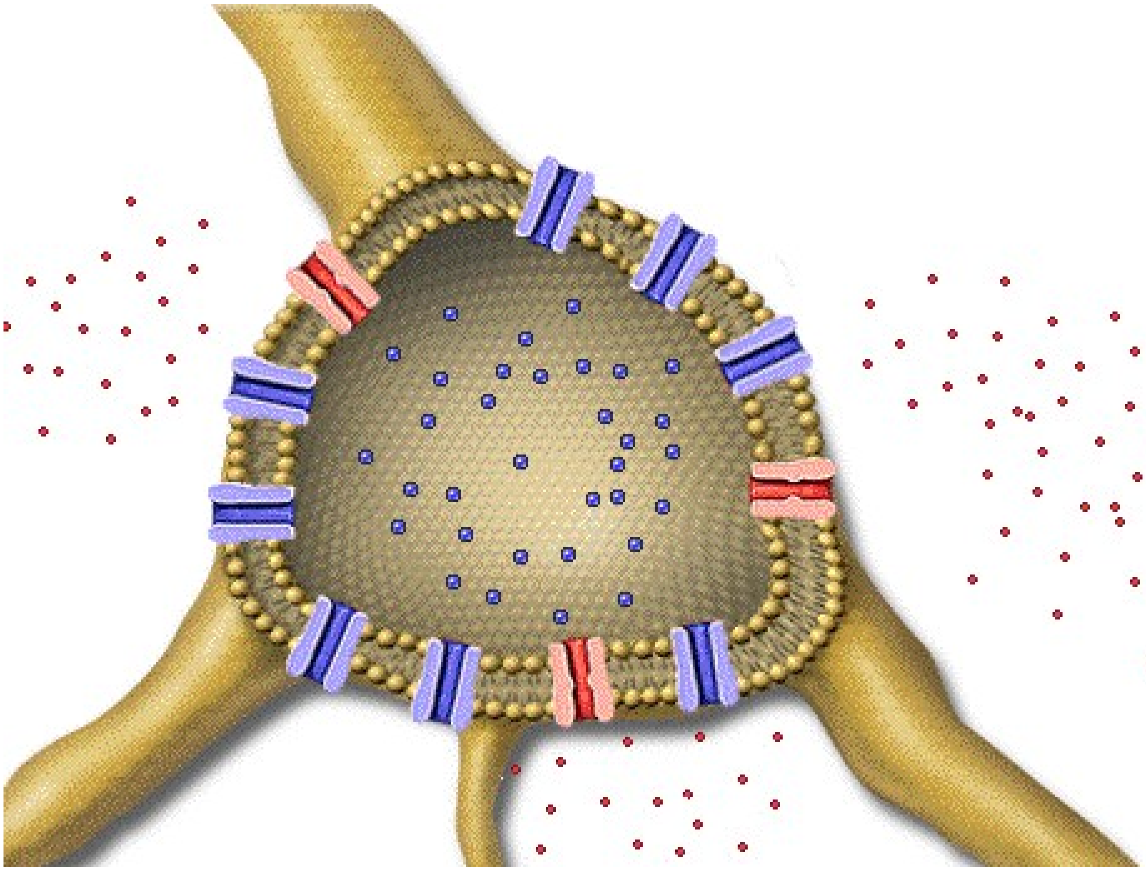
Page 10. The Resting Membrane Potential in Neurons Depends on Sodium and Potassium

- In neurons at rest, the membrane potential is called the resting membrane potential.
- If a neuron were permeable only to potassium, its resting membrane potential would be -90 millivolts, the equilibrium potential for potassium.
- However, resting neurons are also slightly permeable to sodium, and the electrochemical gradient for sodium causes it to move into the cell.
- The resting membrane potential results from the movements of both sodium and potassium ions. The positively charged sodium ions that have entered the neuron make the membrane potential more positive than -90 millivolts, which is the equilibrium potential for potassium. For many neurons the resting membrane potential is close to -70 millivolts.
- Color code this diagram and record the resting membrane potential for a typical neuron:



Page 11. Potassium Leaks Out of the Neuron and Sodium Leaks In

- When the resting membrane potential is not equal to the potassium equilibrium potential, the forces acting on potassium are no longer equal and opposite.
- At -70 millivolts, the chemical force pushing potassium out of the cell is greater than the electrical force pulling potassium back into the neuron. But only a little bit.
- The force on potassium is small, but the neuron is very permeable to potassium. As a result, a small amount of potassium moves continuously out of the neuron.
- At -70 millivolts, the force on sodium is very large, but the neuron is only slightly permeable to sodium. As a result, a small amount of sodium moves continuously into the neuron.
- At -70 millivolts, the resting membrane potential, potassium leaks out of the neuron, and sodium leaks into the neuron.
- Color-code this diagram. Use arrows to indicate the direction of leakage of sodium and potassium ions at resting membrane potential:



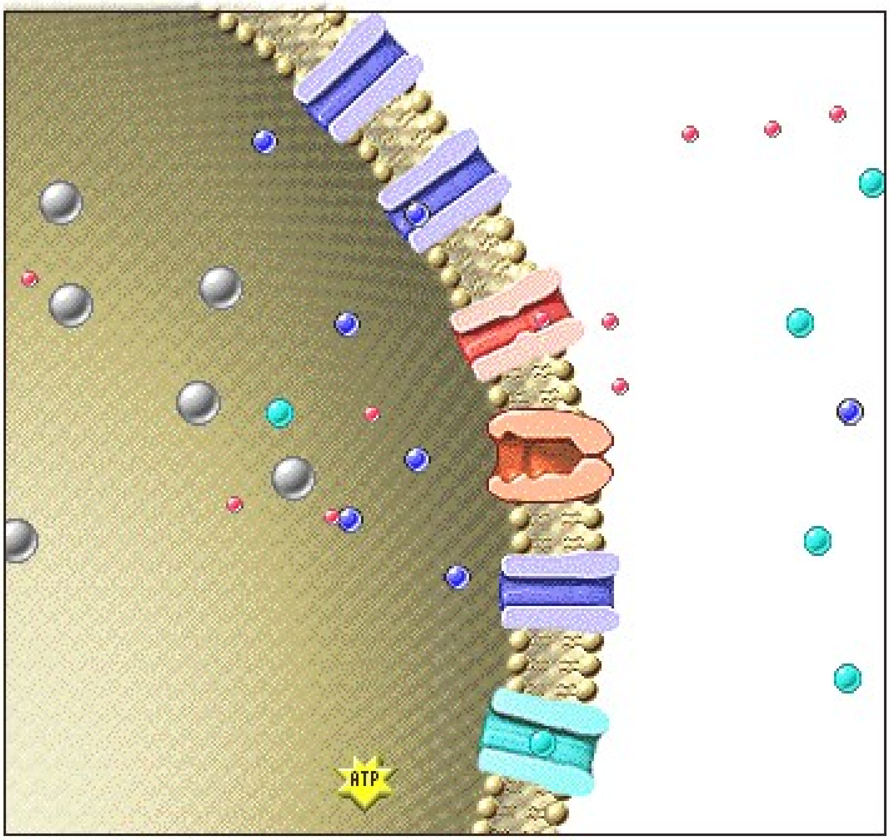
Page 12. The Neuron Must Compensate for Potassium and Sodium Leaks

- Just as a boat that begins to leak will eventually sink, a leaking neuron will eventually fail to function. If ions continue to leak, the neuron will be unable to communicate.
- If the ion leaks continue, the concentration gradients for sodium and potassium will decrease. As the concentration gradients decrease, the membrane potential moves toward zero.
- When there are no longer any chemical or electrical forces to move ions across the membrane, the neuron cannot send or receive the electrical signals it needs to communicate.
- The captain can keep her boat afloat by bailing water out as fast as it enters. Neurons can prevent the potassium and sodium gradients from running down by transporting potassium back into the cell and sodium back out of the cell.

Page 13. The Sodium-Potassium Pump Maintains the Resting Membrane Potential

- Of course, the neuron doesn't use buckets to move ions. A membrane enzyme called the sodium-potassium pump actively transports ions to compensate for the sodium and potassium leaks.
- This pump uses the energy of ATP to move sodium and potassium against their electrochemical gradients. Three sodium ions are pumped out of the neuron for every two potassium ions that are pumped in.
- The pump compensates for the sodium and potassium leaks, keeping the resting membrane potential at -70 millivolts.
- It is important to remember that the sodium–potassium pump does not create the membrane potential, its job is to maintain it.

- In the following diagram, color-code the ion channels and ions. Using arrows, show the direction of ions through each of the ion channels.



Page 14. Summary

- The concentrations of sodium and chloride are high outside cells in the extracellular fluid, and the concentrations of potassium and organic anions are high inside cells.
- The permeability of a cell for ions depends on the number and type of ion channels in the cell membrane.
- Potassium comes to equilibrium when the membrane potential for the cell is -90 millivolts.
- The resting membrane potential in neurons depends on the distribution of sodium as well as potassium across the cell membrane. Resting membrane potentials in neurons are commonly around -70 millivolts.
- The sodium-potassium pump is essential for maintaining the resting membrane potential in neurons.

Notes on Quiz Questions:

Quiz Question #1: The Truth about Neurons

- This question asks you to determine which statement about neurons is true.

Quiz Question #2: Permeability Changes

- This question asks you to determine what would happen if there is a sudden increase in permeability of sodium or potassium.

Study Questions on The Membrane Potential:

1. (Page 3.) Which of these ions have a high concentration outside the cell and which have a high concentration inside the cell? Na^+, K^+, Cl^-
2. (Page 4.) What is the only way that ions can get across the cell membrane?
3. (Page 4.) What does it mean to say that cells exhibit selective permeability with respect to ions.
4. (Page 4.) Which ion are most cells in the body permeable to?
5. (Page 4.) How do neurons differ from most of the other cells in the body with respect to ion permeability?

6. (Page 4.) What's the difference between a neuron's permeability to sodium and potassium?

7. (Page 5.) What two factors will affect the permeability of a cell for a particular ion?

8. (Page 6.) What mechanism used by the nervous system to produce rapid changes in membrane permeability?

9. (Page 7.) As opposed to neurons, simple, non-excitable cells are permeable only to one ion. What is that ion?

10. (Page 7.) What major factor causes ions to move through ion channels?

11. (Page 7.) What type of force is the concentration gradient?

12. (Page 8.) How does the cell membrane become more positive outside and more negative inside?

13. (Page 8.) What type of force is the separation of charge?

14. (Page 9.) Neurons are slightly permeable to sodium ions. a. In which direction is the chemical force for sodium? Why? b. In which direction is the electrical force for sodium? Why?

15. (Page 9.) What is the electrochemical gradient for sodium a combination of ? In which direction is the electrochemical gradient for sodium?

16. (Page 10.) What does the term "resting membrane potential" in a neuron mean. What is a typical value for the resting membrane potential.

17. (Page 10.) Why do non-excitable cells have a membrane potential of -90 mV while neurons have a resting membrane potential of -70 mV?

18. (Page 11.) At -70 millivolts, the resting membrane potential, why does potassium leak out of the neuron?

19. (Page 11.) At -70 millivolts, the resting membrane potential, why does sodium slowly leak into the neuron?

20. (Page 13.) What compensates for the leakage of sodium and potassium ions?

21. (Page 13.) Does the sodium-potassium pump move sodium and potassium with or against their gradients?

22. (Page 13.) What provides the energy to pump sodium and potassium against their gradients?

23. (Page 13.) The sodium-potassium pump pumps out ______ sodiums for every _____ potassiums that are pumped in.

24. (Page 13.) How does the sodium-potassium pump keep the resting membrane potential at -70 millivolts.

25. (Page 13.) The sodium–potassium pump ___________.
a. creates the membrane potential   b. maintains the membrane potential