

Tutorial 5: Sodium and Potassium Gradients at Rest

[Intro](#) | [Figure 5a](#) | [Figure 5b](#)

[Part 1: Image-Mapped Tutorial \(Printable Version\)](#)

[Part 2: Matching Self-Test](#)

[Part 3: Multiple-Choice Self-Test](#)

[Return to main tutorial page](#)

The first studies of the electrical characteristics of neurons were conducted in the 1930's using "giant" squid axons. The swimming mechanism of the squid (an aquatic animal found in the Atlantic Ocean) consists of an enlarged tubular structure or giant axon that is several times larger than the biggest human axon. These axons were large enough to easily measure the membrane potential (or difference in charge across the membrane) using carefully placed microelectrodes. The charges found both inside and outside the cell membrane were recorded using an oscilloscope, an instrument that uses a fluorescent screen to display a visual representation of electrical variations. Neuroscience now has the micro-technology to measure directly from microscopic elements of the human neuron. A commonly used microelectrode is made of glass tube that is tapered to a tip diameter of 0.0005 millimeters or less and filled with a solution of a current conducting salt such as potassium chloride.

This research has identified the electrochemical conditions existing while a neurons is inactive or at rest. This resting *membrane potential* of -70 millivolts (mV) is due to the difference in electrical charge found on the inside of the cell versus the outside of the cell, and is similar to the electrical condition found in a battery. The potential inside a neuron is approximately 70 mV less than that measured outside the neuron. As shown in [Figure 5a](#), sodium ions, potassium ions, chloride ions, and protein molecules are the charged substances that underlie the membrane potential. These ions are formed when *electrolytes* dissolve in water and split into two parts with opposite electrical charge. Ordinary table salt (NaCl), for example, when dissolved splits into a positively charged (*cation*) sodium ion (Na⁺) and a negatively charged (*anion*) chloride ion (Cl⁻). [Figure 5b](#) illustrates the mechanisms that maintain the different concentrations of each of these substances on either side of the neuronal membrane.

The unequal charge or *polarity* across the neuronal cell membrane at rest is due primarily to the unequal distribution of sodium ions (Na⁺), potassium ions (K⁺), chloride ions (Cl⁻), and protein molecules. This difference in distribution of charged substances is due to the interaction of both passive and active forces.

The random movement of substances down the concentration gradient creates the first passive force; molecules and ions move from high to lower concentration in an effort to distribute equally and create a homogeneous environment. This movement is called *diffusion*. The second passive force is due to the tendency for similarly charged substances to move away from each other, and of oppositely charged substances to move toward each other. This force is known as *electrostatic pressure*. This force underlies a system's tendency to equalize electrical charge.

Forces that underlie the differential charge across the neuronal membrane (the membrane potential) are *selective permeability* and active transport. The selective permeability of a neuronal membrane affects the ease with which particular molecules pass through the membrane, and therefore interacts with the concentration and electrostatic gradients. *Gates* or pores/channels embedded in the membrane control the rate of passage for some important ions. In some cases, the size of a pore or channel and the size of the ion or molecule passively determine the permeability

of a membrane to the substance. In other cases, energy is expended at a *channel* which then actively pumps a substance in or out of the cell. This process is called *active transport*.

When the neuron is at rest, potassium and chloride are allowed to pass at a moderate rate while *sodium channels* remain closed. The final mechanism for maintaining the concentration gradient involves active transport of sodium and potassium ions via the sodium-potassium pump. The sodium-potassium pump ejects three sodium ions for every two potassium ions pumped into the cell; energy is needed for this process. The energy expended by the neuron in maintaining the resting potential is justified because the resting potential increases the neuron's ability to respond rapidly to stimulation. When the neuron is excited and the *sodium channels* are opened, the concentration and electrical gradients for Na⁺ (maintained by active transport) result in an explosion of Na⁺ into the cell. This neuronal response to stimulation, the action potential, will be described in [Tutorial 6](#).

Advanced

Structural and functional integrity of the membrane of a neuron is essential to maintaining the resting potential, generating an action potential, and propagating a neuronal impulse (Arms & Camp, 1995). The neuronal membrane is composed of two fat layers (phospholipids) with protein molecules embedded between and within. The phospholipid molecules have a water-attracting head (which form the outer and inner boundaries of the membrane where contact is made with extra-cellular fluids and cytoplasm) and two water-repelling tails (which form the internal layer of the membrane. The membrane is approximately eight nanometers thick, or less than 0.00001 millimeters. This molecular structure provides the neuron with an adequately firm, yet flexible boundary that can control the movement of substances into and out of the cell. See [Tutorial 2](#) for additional information on the neuronal cell membrane.

Reference

Arms, K. & Camp, P. (1995), *Biology* (4th ed.). New York: Harcourt Brace College Publishers.

Suggestions for further study

SUGGESTED READINGS:

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Neher, E. & Sakmann, B. (1992, March). The patch clamp technique. *Scientific American*, 266(3), 28-35.

Regan, D. (1979, December). Electrical responses evoked from the human brain. *Scientific American*, 241(6), 134-146.

RELATED LINKS:

http://www.epub.org.br/cm/n09/fundamentos/transmissao/voo_i.htm

(How Nerve Cells Work)

Silvia Helena Cardoso, PhD and Renato M. E. Sabbatini, PhD, (*Brain and Mind*- Electronic Magazine), Cardoso, State University of Campinas, Brazil

<http://psych.hanover.edu/Krantz/neural/actionpotential.html>

(Physical Factors Underlying the Action Potential)

Krantz - Psychology Tutorials

<http://www.sfn.org/briefings/nmda.html>

(NMDA Receptors)

from Society for Neuroscience - *Brain Briefings*, 1994.

NMDA receptor blockers and the prevention of neuronal damage due to stroke, epilepsy, Huntington's Disease, and AIDS.