APPENDIX 4

Neurons and seizures

Neurons are the smallest unit of the nervous system, and there are billions of them in the brain and spinal cord. They are electrically excitable cells and carry information (signals) between the central nervous system and the rest of the body as electrical impulses through a web-like structure from neuron to neuron, or from neurons to other cells in the body.[1]

Electrical activity moves through and out of a neuron to the next neuron or cell via a complex process, known as an "action potential."

The inside of a neuron at rest (not sending or receiving any signals) is negatively charged compared to the fluid surrounding it (containing ions). This is referred to as the "resting membrane potential" and is a measurement of the difference in electrical charge (voltage) between the inside and the outside of the neuron.

Figure A4.1 illustrates this concept for a typical resting membrane potential for a neuron.

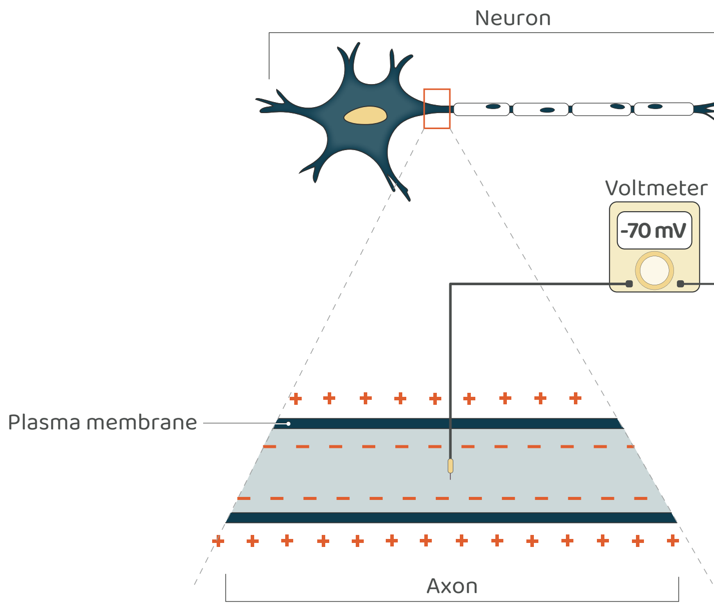

Figure A4.1 Resting membrane potential in a neuron. The plus (+) and minus (–) signs represent the net electrical charges of the ions inside and outside the cell. The barrier between the two spaces is the plasma, or cell, membrane. The net electrical charge outside the cell is positive, while net electrical charge inside the cell is negative. The resting membrane potential (–70 mV on the voltmeter*) is the difference between the inside of the cell relative to the outside of the cell.

The action potential process can be divided into stages. The neuron starts at the resting membrane potential phase and is then activated, causing a brief change from negative to positive, and then back to negative again. These stages are shown in Figure A4.2 and described below:[2]

- **Depolarization:** An event where a neuron's membrane potential briefly becomes less negative (for about 1 millisecond, or 1,000th of a second). This results when the cell body of a neuron receives enough signals to activate (when the threshold is met), causing a portion of the axon nearest the cell body to depolarize—becomes less negative for a moment (in about 1 millisecond).
- **Repolarization:** This occurs after the firing of the axon reaches the peak positive value and switches back to a more negative state by the movement of ions.
- **Hyperpolarization:** This is when the membrane falls below the resting potential based on movement of ions. While brief, this action is notable because the amount of stimulus needed to reactivate (or depolarize) this same neuron would be more than what triggered it to begin with, making it less likely that this same neuron would be immediately triggered again (within the next few milliseconds).

Additional terms related to action potentials and depicted in Figure A4.2 include:

- **Resting potential:** When no impulse is being received or sent and the neuron is "at rest." The voltage of the resting membrane potential is –70mV in the figure.

* An instrument that measures voltage. The unit of measurement for a membrane potential is a millivolt (1/1000th of a volt), expressed as mV.

- **Threshold:** The voltage at which the signals are of a large enough intensity to produce the effect (–55 mV in the figure).
- **Failed initiations:** The result of signals being insufficient to cause the membrane potential to reach the threshold, so depolarization does not occur. The action potential is an all-or-nothing process; that is, if the threshold is not reached, an action potential does not result, and no message is sent. Some failed initiations are depicted in the figure. Notice the peaks are below the threshold, so no depolarization occurs.

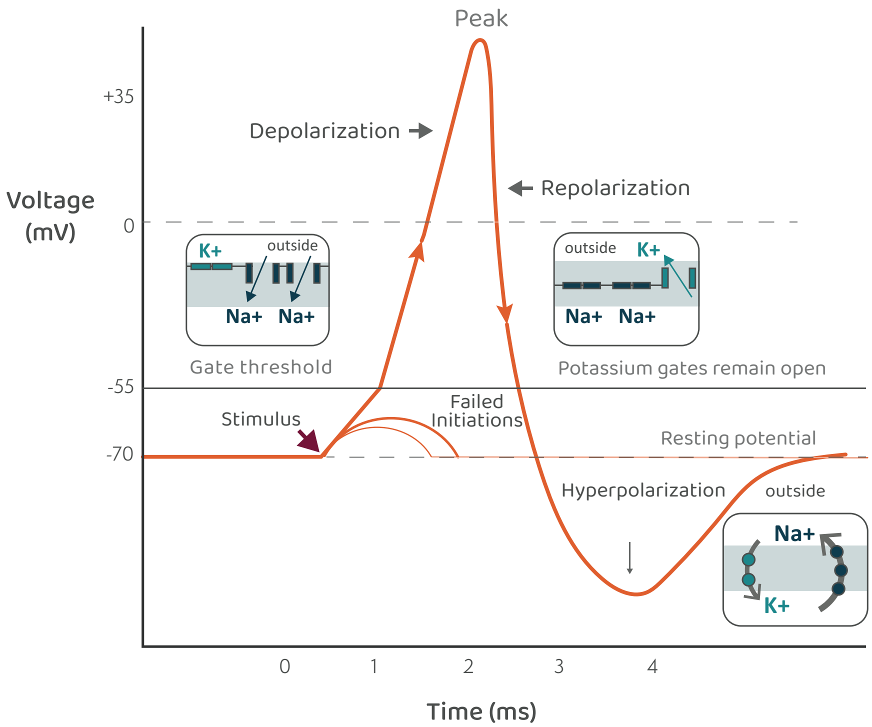

Figure A4.2 Stages of an action potential. Na+ = sodium; K+ = potassium.

The action potential process continues down the axon of the neuron with the changes from one segment of the axon triggering depolarization in the next section and so on until it reaches the end of the axon.

Many ions exist in the body and in and around the neurons, and the movement of these ions (traveling in the impulse) across the axon's membrane (the outer surface) creates the action potential. Action potentials allow neurons to communicate signals rapidly and efficiently. However, during a seizure, neurons fire excessively and uncontrollably, and the ability of the neurons to regulate signals is disrupted. This leads to uncontrolled electrical activity, seen as a seizure.

Most often, sodium and potassium ions generate the action potentials. A "sodium-potassium pump" is an energy-consuming mechanism within cells that moves these ions in and out of the cells, changing the net electrical charge, allowing the membrane to return to the resting potential and prepare for another action potential. The action potential process is illustrated in Figure A4.3.

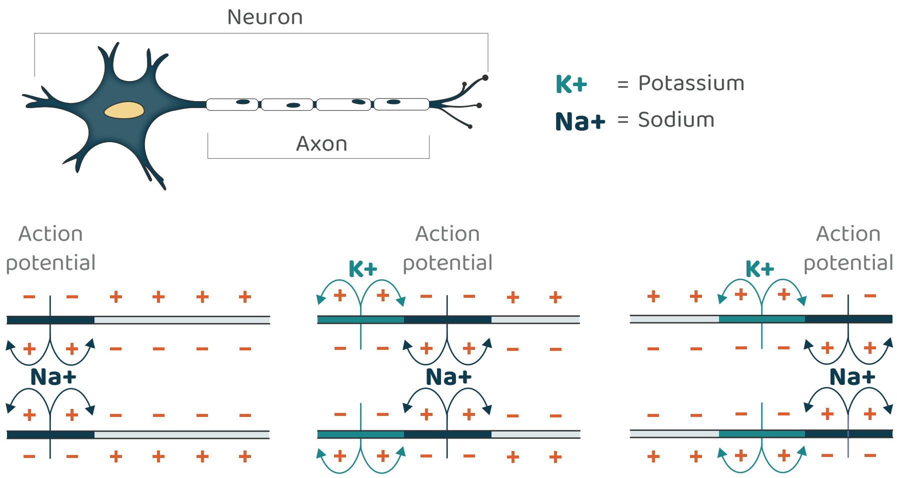

Figure A4.3 Action potential traveling down a neuron's axon. Potassium (K+) and sodium (Na+) ions move into and out of the neuron (the double lines represent the plasma, or cell, membrane, with the inside of the cell located between the lines) as the electrical charge changes. The three images along the bottom represent a sequence at three time points: the curved arrows indicate the movement of the ions, and the color of the plasma membrane signifies the specific ion moving. In this way, the message, or impulse, moves down the length of the axon from left to right.

References

1 Sirven JI, Osborne Shafer P, Fisher R (2013) *Staying safe*. [online] Available at: <https://www.epilepsy.com/preparedness-safety/staying-safe> [Accessed September 25 2024].

2 Grider MH, Jessu R, Kabir R (2023) *Physiology, Action Potential*. [e-book] Treasure Island (FL), StatPearls. Available at: https://www.ncbi.nlm.nih.gov/books/NBK538143/> [Accessed December 16 2024].