5.3.4

Action Potentials

An action potential is where things really become interesting and exciting—no pun intended; but remember that only excitable tissues can experience action potentials. An **action potential** is simply a rapid and drastic depolarization of the membrane potential followed by a rapid repolarization to the resting membrane potential (see figure below). Unlike graded potentials, action potentials are not localized, but propagated throughout the entire cell membrane. The action potential is the basis for transmitting signals in nerve cells, inducing muscle contraction, and perception of all our senses. Action potentials are initiated when depolarizing graded potentials reach **threshold potential**. This is the specific membrane potential that induces activation of the **voltage-gated ion channels** responsible for action potentials and is most often the voltage-gated Na^+ channel. If a graded potential is not strong enough to bring the membrane potential up to threshold, it is called a sub-threshold stimulus. On the other hand, if threshold potential is met, or even exceeded, an action potential will result. This phenomenon is known as the “all or nothing principle.” Once an action potential is initiated, it will be the same predictable depolarization followed by repolarization; there are not different sizes of action potentials; hence, **ALL** of an action potential or **NOTHING**. Even if threshold potential is greatly exceeded by a super-large graded potential, an action potential of equal magnitude to any other action potential experienced by that cell is initiated. Unlike graded potentials, action potentials cannot be summed or added upon.

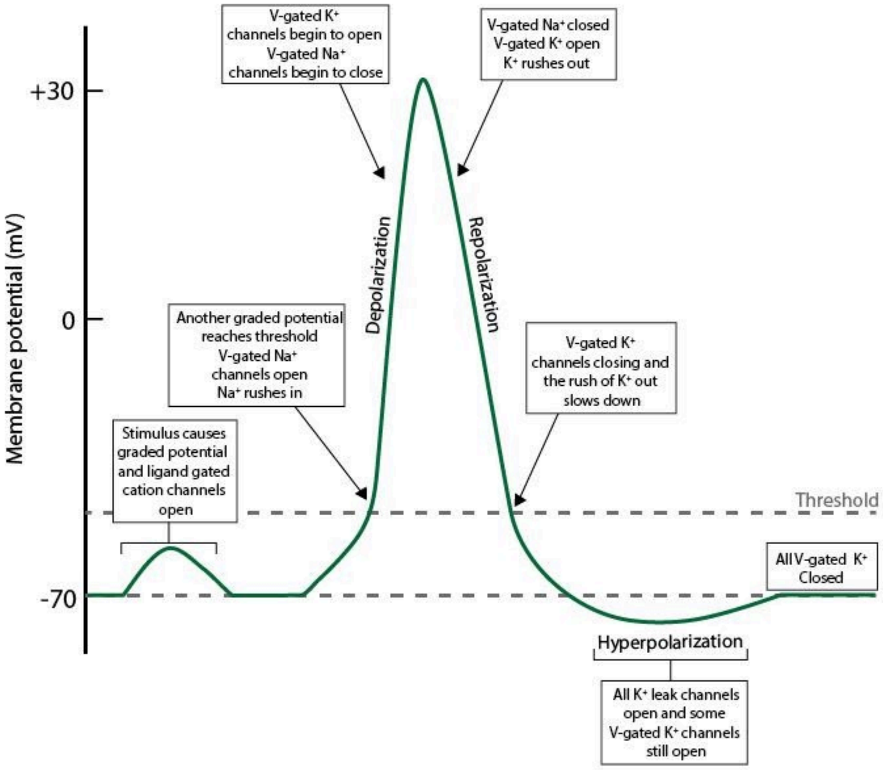
In a neuron at rest, there is very little diffusion of Na^+ across the membrane (very few Na^+ leak channels). However, if the cell membrane of the neuron experiences a graded potential (or multiple graded potentials) that is sufficient to depolarize the membrane to threshold potential (approximately -55mV), an action potent will initiate as the voltage-gated Na^+ channels change conformation allowing the “activation gate” to open (Review the section above on activating voltage-gated ion channels). Because the concentration of Na^+ is extremely high on the outside of the cell, the opening of Na^+ channels will cause a rapid influx of Na^+ down its concentration gradient, further depolarizing the membrane as more positive Na^+ ions attempt to diffuse into the cell. The membrane potential will increase to almost +30mV when the inactivation gate closes and no further Na^+ diffusion occurs. It is important to note that depolarization occurs with minimal changes in the overall concentration of Na^+ or K^+ (Only one out of every 100,000 Na^+ ions need to enter the cell to produce a 100mV change in membrane potential).

The activation and inactivation gates of the voltage-gated Na^+ channels are unique to this channel’s functions: The activation gate is very sensitive to voltage changes and is the basis of threshold (as described above). The inactivation gate is less sensitive to voltage, and thus slightly delayed compared to the activation gate, which allows the channel to transport Na^+ for a brief moment. As the membrane potential increases due to the activated voltage-gated Na^+ channels, voltage-gated K^+ channels begin to open resulting in an increased efflux of potassium out of the cell. This efflux, in addition to the efflux resulting from K^+ leak channels, is responsible for repolarization and even hyperpolarizing the membrane. There are many different types of voltage-gated K^+ channels expressed in neurons, some of which are activated at different membrane voltages. However, unlike voltage-gated Na^+ channels, voltage-gated K^+ channels only have activation gates. Because these voltage-gated K^+ channels lack inactivation gates, they are slower to close during repolarization. As a result, every neuronal action potential features a **zone of hyperpolarization** due to the additional diffusion of K^+ through voltage-gated K^+ channels that have yet to close AND leak channels. Once the voltage-gated K^+ channels close, the membrane will return to the resting potential established by the K^+ leak channels. The small diffusions of K^+ and Na^+ during each action potential are then reestablished by the Na^+/K^+ ATPase pump, however this is not necessary for another action potential. In fact, it has been demonstrated that the ion gradients within a neuron are sufficient to generate 10,000 action potentials without replenishment from the Na^+/K^+ ATPase pump.

Here are two videos about the resting membrane and action potentials to aid you in your learning and understanding:

https://books.byui.edu/-eEkp

https://books.byui.edu/-Bnd



Action Potential. *Image created by BYU-Idaho student, Kaylynn Loyd 2013*