Action Potential
**ACTION POTENTIAL:**
Rapid change in the membrane potential due to rapid changes in permeability to ions (Na\(^+\) and K\(^+\) for the neuron).
When signals from the dendrites and cell body reach the axon hillock and cause the membrane potential there to become more positive → depolarization (e.g. from -70 mV to -56 mV)
If the stimulus that reach the axon hillock is great enough, the neuron depolarizes by about 15 mV and reaches a trigger point, **threshold**.

At the threshold, an action potential is generated.

Weak stimuli do not produce an action potential. Action potential (AP) is an **all-or-none event**.

AP always have the same amplitude and same duration.

Threshold for this neuron is -55mV
DEPOLARIZATION

At the threshold, depolarization opens more voltage-gated Na⁺ channels. This causes more Na⁺ to flow into the cell, which causes the cell to depolarize further and opens more voltage gated Na⁺ channels.

This loop produces the rising phase of the action potential.
BEGINING OF REPOLARIZATION

The rising phase of the action potential ends when the positive feedback loop is interrupted by:

- Inactivation of the voltage-gated Na\(^+\) channels
- Opening of the voltage-gated K\(^+\) channels

Voltage-gated Na\(^+\) channels are time-sensitive, they close after for a certain period of time.

Voltage-gated K channels respond slowly to depolization. They begin to open as the membrane depolarizes, but they respond very slowly.
Characteristics of the voltage-gated sodium (top) and potassium (bottom) channels, showing successive activation and inactivation of the sodium channels and delayed activation of the potassium channels when the membrane potential is changed from the normal resting negative value to a positive value.
REPOLARIZATION

The slow voltage-gated K channels remain open after the cell membrane has repolarized. $K^+$ ions continue to move out of the cell, causing the membrane potential to became more negative than the resting membrane potential.

By the end of the hyperpolarization all the K channels are closed.
All-or-none principle

• The amplitude of an action potential is independent of the amount of current that produced it.
• In other words, larger currents do not create larger action potentials. Therefore, action potentials are said to be all-or-none signals, since either they occur fully or they do not occur at all.
• Greater intensity of stimulation does not produce a stronger signal but can produce a higher frequency of firing.
REFRACTORY PERIOD

The action potential is followed by a brief period of diminished excitability, or refractoriness, which can be divided into two phases.

1. **The absolute refractory**: during this period it is impossible to excite the cell no matter how great a stimulating current is applied.

2. **The relative refractory period**: during this period it is possible to trigger an action potential but only by applying stimuli that are stronger than those normally required to reach threshold.

These periods of refractoriness, which together last just a few milliseconds, are caused by the residual inactivation of Na+ channels and increased opening of K+ channels.
THE ABSOLUTE REFRACTORY PERIOD
Many Na\(^+\) channels are inactive and will not open, no matter what voltage is applied to membrane.

THE RELATIVE REFRACTORY PERIOD
The cell can generate action potential, but only applying stimuli that are stronger than those normally required to reach threshold. Some of the Na\(^+\) channels are still inactive and some K\(^+\) channels are still open.
INFORMATION FLOW IN NEURONS IS DIRECTIONAL

Incoming signals are integrated, and if the summed signal is large enough an outgoing signal (AP) is generated at the axon hillock.
THE ACTION POTENTIAL IS PROPAGATED ALONG THE AXON

After the AP is generated at the axon hillock, it is propagated down the axon.

Positive charge flows along the axon, depolarizing adjacent areas of the membrane, which reach threshold and generate an AP.

AP moves along the axon as a wave of depolarization traveling away from the cell body.
To be carried successfully to the rest of the nervous system, the local signal must be amplified—it must generate an action potential.

The voltage response in a passive neuronal process decays with distance due to electronic conduction.
Schwann cell wraps around and around the axon and forms myelin sheath.
MYELINATION

Neighboring Schwann cells do not touch each other, so there are gaps in the myelin sheath at intervals of 1-2 mm. These gaps (nodes of Ranvier) are essential for conduction of the action potential.
**SALTATORY CONDUCTION**

Saltatory (from the Latin saltare, to jump)

Action potentials in myelinated nerves are regenerated at the nodes of Ranvier

Voltage gated Na channels are concentrated at the nodes, thus an AP can be generated only at this region

Equivalent circuit

• The lipid bilayer acts as an insulator between the intracellular and extracellular solutions of conducting ions, and therefore serves as a good **capacitor**.

• Voltage-gated channels can be modelled as a conductor (resistor) with an arrow through it.