## Initiation and conduction of nerve impulse

For the nervous system to function, neurons must be able to send and receive signals. These signals are possible because each neuron has a charged cellular membrane (a voltage difference between the inside and the outside), and the charge of this membrane can change in response to neurotransmitter molecules released from other neurons and environmental stimuli.

A nerve impulse may be defined as the electrochemical change in the nerve membrane which is generated by a stimulus and which flows along the nerve fibre up to its end. Nerve impulse is a wave of electrical depolarisation and repolarisation sweeping along a nerve fibre.

It is the signal transmitted along a nerve fibre either in response to a stimulus (such as touch, pain or heat), or as an instruction (such as causing a muscle to contract). It may be also defined as the sum total of physical and chemical events in the propagation of a wave of physiological activity along a nerve fibre.

### Neuronal Charged Membranes

The lipid bilayer membrane that surrounds a neuron is impermeable to charged molecules or ions. To enter or exit the neuron, ions must pass through special proteins called ion channels that span the membrane. Ion channels have different configurations: open, closed, and inactive. Some ion channels need to be activated in order to open and allow ions to pass into or out of the cell. These ion channels are sensitive to the environment and can change their shape accordingly. Ion channels that change their structure in response to voltage changes are called voltage-gated ion channels. Voltage-gated ion channels regulate the relative concentrations of different ions inside and outside the cell.

### Resting membrane potential

A potential difference arises when a membrane is selectively permeable to either cations or anions and the difference in concentration of some non-diffusible ions exist between the inside and outside of the membrane. Inside the neuron the cytoplasm is rich in potassium while the extra cellular fluid is rich in sodium. In addition, a large number of non-diffusible negatively charged proteins, organic phosphates, sulphate and nucleic acids are present and the inside of the nerve membrane becomes electronegative while the outside becomes electropositive. The nerve cell membrane contains different classes of proteins which act as ion pumps and channels. An important pump which plays a major role in the unequal distribution of ions across a neuron membrane is the electrogenic **sodium pump**. The pump expels three **$Na^+$** from inside the membrane in exchange of every two **$K^+$** entering inside from outside the cell per ATP consumed by active transport. This results in an unequal distribution of $Na^+$ and $K^+$ on the two sides of the membrane. The relative difference in electrical charge, or voltage, between the inside and the outside of a cell membrane, is called the membrane potential. The resting membrane potential of a neuron is about -70 to -80 mV (mV=millivolt). The nerve fibre membrane is said to be polarised in this stage. The resting potential results from two major factors:

i. selective permeability of the membrane
ii. differences in ion concentration inside the cell compared to outside.

NOTE: The cell possesses potassium and sodium leakage channels that allow the two cations to diffuse down their concentration gradient. The actions of the sodium potassium pump help to maintain the resting potential, once established. chloride ions ($Cl^-$) tend to accumulate outside of the cell because they are repelled by negatively-charged proteins within the cytoplasm.

| **Ion** | **Extracellular concentration (mM)** | **Intracellular concentration (mM)** |
|---|---|---|
| Na+ | 145 | 12 |
| K+ | 4 | 155 |
| Cl− | 120 | 4 |
| Organic anions (A−) | — | 100 |

**Action potential**

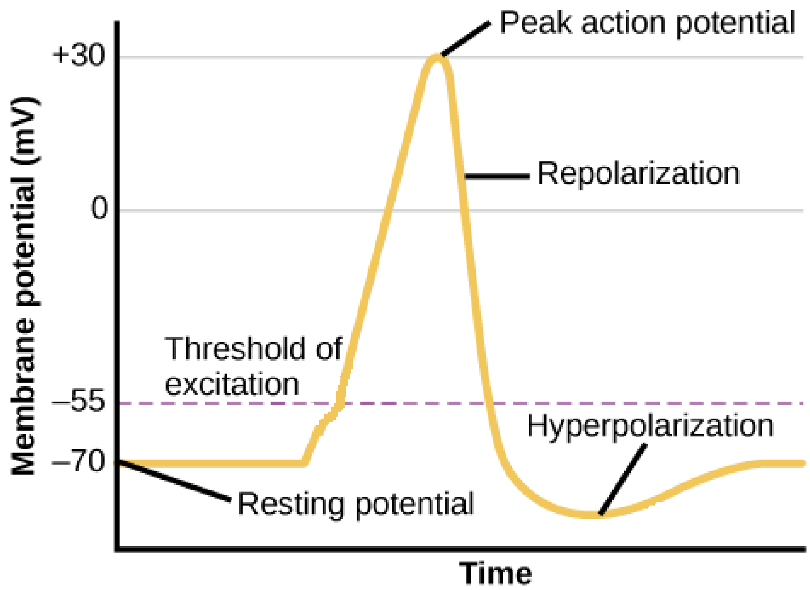
The action potential is an explosion of electrical activity that is created by a **depolarizing current**. This means that some event (a stimulus) causes change in permeability of the neuronal membrane and the resting potential to move toward 0 mV. When the depolarization reaches about -55 mV a neuron will fire an action potential. This is the **threshold**. If the neuron does not reach this critical threshold level, then no action potential will fire. Also, when the threshold level is reached, an action potential of a fixed sized will always fire for any given neuron, the size of the action potential is always the same. There are no big or small action potentials in one nerve cell - all action potentials are the same size. Therefore, the neuron either does not reach the threshold or a full action potential is fired - this is known as the "**ALL OR NONE**" principle.

**Depolarisation**

When the stimulus is strong enough it first causes sodium channels in the trigger zone to open. Because there are many more sodium ions on the outside, and the inside of the neuron is negative relative to the outside, sodium ions rush into the neuron. Sodium has a positive charge, so the neuron becomes more positive on the inside as compared to the extracellular environment. This reversal of electric charge is called depolarization. The initial or rising phase of the action potential is called the **depolarizing phase** or the **upstroke**. The region of the action potential between the 0mV level and the peak amplitude is the **overshoot**.

**Repolarisation**

The return of the membrane potential to the resting potential is called the **repolarization phase**. It takes longer for potassium channels to open. When they do open, potassium rushes out of the cell, reversing the depolarization. At about this time, sodium channels start to close. This causes the action potential to go back toward -70 mV (a repolarization). The action potential actually goes past -70 mV (a hyperpolarization) because the potassium channels stay open a bit too long. This phase is called the **undershoot** or the **hyperpolarizing afterpotential**. Gradually, the ion concentrations go back to resting levels and the cell returns to -70 mV.




**Propagation of the impulse across the myelinated and unmyelinated nerve fibers**

Conductibility is the capacity to conduct the electrical impulse along its pathway. Action potential propagation depends on the activation of voltage-gated sodium channels present all along the membrane of a neuron.  As the nerve fiber depolarizes, it triggers an increase in permeability of the **ligand-gated** sodium ion channels that causes sodium channels to open and sodium ions go into the nerve cell and reverse polarity because positively charged ions are flowing in.  This action potential is conducted along the length of the fiber by causing the next adjacent space **voltage-gated** sodium ion channels to open. A local circuit of current flow develops between the depolarised and the resting membrane. As a result the next adjacent area gets depolarised while the former gets repolarised. In this manner impulse is conducted all the nerve fibre. The nerve impulse is thus a selfpropagating wave of depolarisation followed by repolarisation moving down the fiber. Action potential propagation along **non-myelinated** axons requires activation of voltage-gated sodium channels along the entire length of the axon.

In myelinated neurons myelin sheath is an effective non-conducting insulator. The only places where this insulation is broken are small spaces called Nodes of Ranvier that are unmyelinated. Action potential propagation along myelinated axons requires activation of voltage-gated sodium channels only in the nodal spaces. Sodium ions can enter and potassium ions can exit just like an unmymelinated nerve fiber, except that this signal seems to jump from one node to the next. This form of propagation of nerve impulse where depolarisation of membrane occurs only at the nodes is called **saltatory conduction**. It comes from the latin word *saltaire* which means to jump or leap. Due to this skipping movement, saltatory conduction is up to 50 times faster and requires less energy than conduction through the fastest non-myelinated axons.

The velocity of conduction of the action potential along the nerve fiber depends on following factors:

i. it is 50-100 times faster in myelinated fiber compared to unmyelinated
ii. it increases with increase in diameter of the nerve fiber
iii. increase in temperature increases velocity
iv. it increases with increase in pH

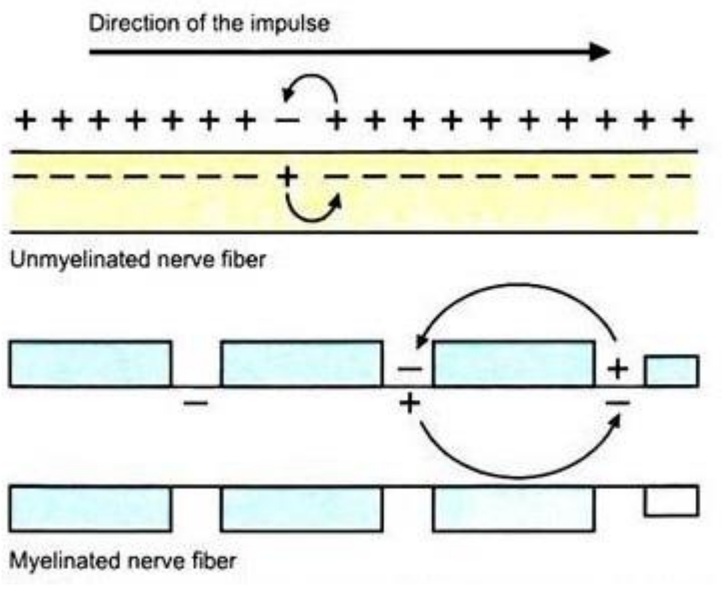



Figure: **Propagation of the impulse across the unmyelinated and myelinated nerve fibers**