# NERVOUS SYSTEM

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## NERVE IMPULSES

Nerve impulses are caused by the movement of ions which trigger changes in the **membrane potential** of nerve cells (neurons). When a neuron is **not** sending an impulse, sodium-potassium pumps will maintain a **resting potential** of –70mV. These pumps use active transport to shuttle three sodium ions outside of a cell for every two potassium ions brought in, making the inside of the neuron negative relative to the outside. The nerve cell fires when ion channels change the resting potential into an **action potential** (about 30mV). An action potential will only occur if an external stimulus triggers a sufficient change in membrane polarity (**threshold potential** = –55mV). Action potentials consist of both depolarisation and repolarisation. During depolarisation, voltage-gated sodium channels open to allow for an influx of sodium ions (inside becomes more positive). Then repolarisation occurs, whereby potassium channels trigger an efflux of potassium ions to restore the membrane potential to a negative value. After an action potential, the resting potential must be re-established by sodium-potassium pumps before the neuron can fire again (this is a **refractory period**).

## OSCILLOSCOPE TRACE

Oscilloscopes are scientific instruments that measure the membrane potential across a neuron membrane.

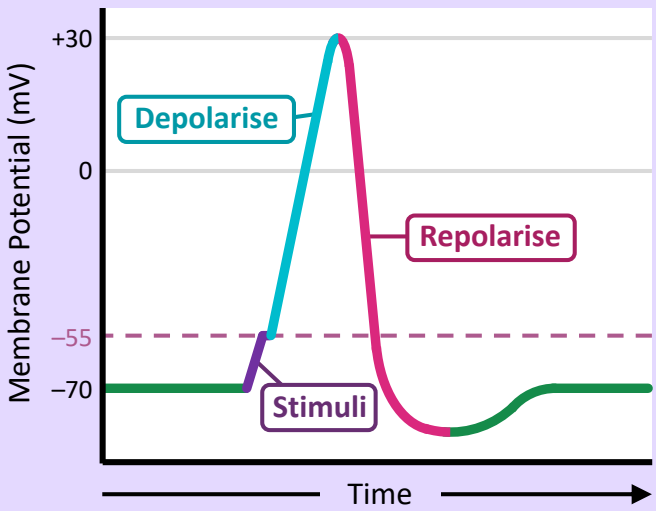
An action potential lasts for 3 – 5 milliseconds

Before an action potential, the neuron should be in an idle state (resting potential = –70mV)

An action potential will only occur if a certain threshold potential is reached (about –55mV)

Depolarisation causes a membrane potential to spike (+30mV) due to an influx of $Na^+$ ions

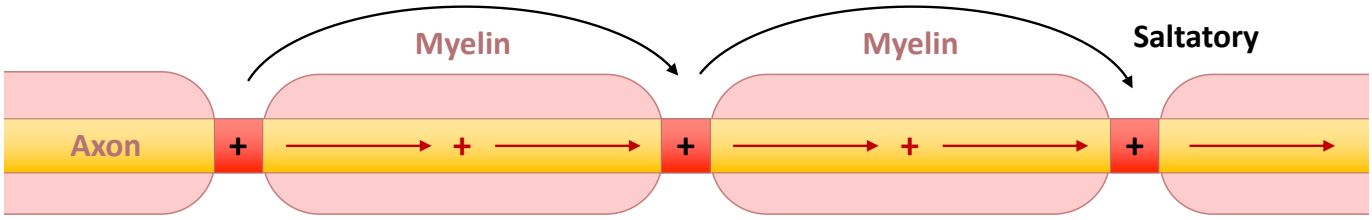
Repolarisation causes a membrane potential to return to a resting state (via $K^+$ ion efflux)



## IMPULSE PROPAGATION

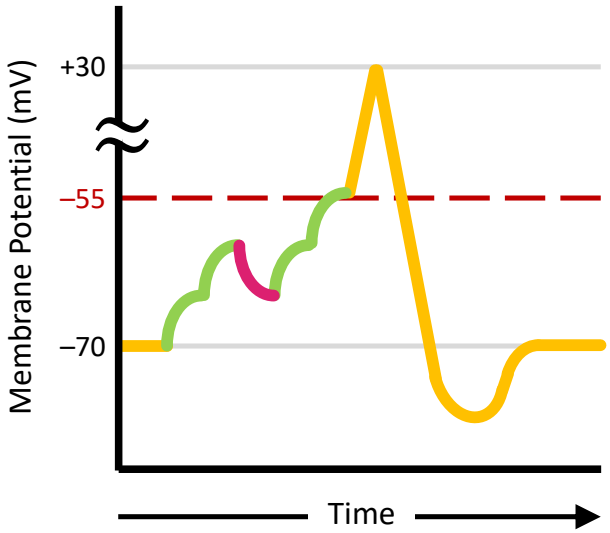
The sodium and potassium channels along an axon are **voltage-gated** and open when a threshold potential is reached. A voltage change in one segment of an axon will trigger the opening of ion channels in the next segment of an axon. This causes the action potential to spread along an axon in a unidirectional wave. The refractory period ensures that an impulse can only be transmitted in a single direction (dendrite → axon).


Transmission speed can be increased when the axon is covered by **myelin**, which forms an insulating sheath around the axon. The sheath is structured into segments, with ion channels clustered at the gaps between each segment (called the **nodes of Ranvier**). This forces the action potential to 'hop' between the nodes of Ranvier, increasing transmission speeds by up to 100-fold. This transmission is called **saltatory conduction**.




## SUMMATION

Nerve impulses involve changes to the distribution of ions across a membrane and cannot continue across a synaptic cleft. Neurotransmitters are chemicals released into a synapse that bind to receptors on a post–synaptic neuron to open **ligand-gated** ion channels, triggering small changes in membrane polarity (**graded potentials**). Neurotransmitters can be either *excitatory* and cause depolarisation, or they can be *inhibitory* and cause hyperpolarisation. The combination of graded potentials in the post-synaptic neuron is known as **summation**. *Cancellation* occurs when excitatory and inhibitory graded potentials cancel each other out, so that no threshold potential is reached. *Spatial summation* occurs when excitatory post-synaptic potentials are generated from multiple presynaptic neurons simultaneously to reach the threshold, whereas *temporal summation* involves multiple signals being generated from a single presynaptic neuron in quick succession. Summation allows different neural pathways to become integrated and result in more complex patterns of information processing (enabling high order functions like coordinated movements, perception or thought).




**Summation of Graded Potentials:**

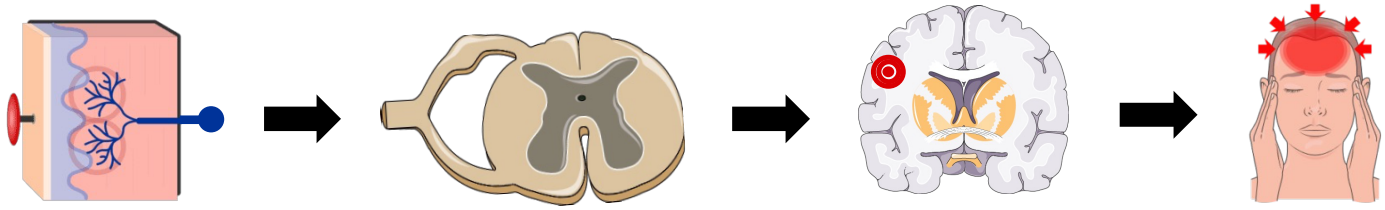
Specific neurotransmitters can generate either excitatory post-synaptic potentials (EPSP = green) or inhibitory post-synaptic potentials (IPSP = red)

Summation of EPSPs and IPSPs determines if a threshold is reached for an action potential (action potentials are classed as 'all or none')

Summation can be spatial (via multiple neurons) or temporal (one neuron signalling repeatedly)

## PAIN PERCEPTION

The initial generation of a nerve impulse requires an external stimulus that is detected by a receptor on a sensory organ. Stimuli include temperature (thermoreceptors), movement or touch (mechanoreceptors), light (photoreceptors), chemicals (chemoreceptors) or pressure (baroreceptors). Receptors that perceive pain are classed as **nocireceptors**, which are located on free nerve endings of sensory neurons in the skin. The nerve endings contain channels that open to allow an influx of positively charged ions into the neuron, triggering depolarisation. The impulse is then relayed via the spinal cord to the cerebral cortex of the brain, where pain is perceived. The initial stimulus to trigger a perception of pain can be mechanical (e.g. a pinch), thermal (e.g. extreme temperatures) or chemical (e.g. acids or chemicals such as capsaicin in chili peppers).



## DRUG INTERACTIONS

Exogenous chemicals are substances that enter an organism from an external source and can interfere with the way neurons process signals from neurotransmitters. They can include medications, venoms and drugs.

### Neonicotinoid Pesticides

Acetylcholine is a neurotransmitter released at neuromuscular junctions and triggers **muscular contraction**. Neurons produce an enzyme *(acetylcholinesterase)* that acts to break down acetylcholine within a synapse to prevent overstimulation. Neonicotinoids are pesticides that are structurally similar to acetylcholine and can bind irreversibly to cholinergic receptors. Neonicotinoids mimic the action of acetylcholine, but cannot be broken down by acetylcholinesterase. This results in the overstimulation of the muscles, leading to **fatal convulsions**. Insects have higher levels of cholinergic receptors, making neonicotinoids effective pesticides.

### Cocaine

Dopamine is a neurotransmitter released within the mesolimbic system of the brain to trigger sensations of **euphoria**. Cocaine is a drug that binds and blocks *dopamine reuptake pumps* on presynaptic neurons in the dopamine reward pathway. This causes dopamine to accumulate in the synapse and continue stimulation.

## CONSCIOUSNESS

Neurons can form multiple synapses with other neurons, creating a vast array of adaptable communication pathways. Additionally, many neurons can release multiple different neurotransmitters, allowing for varying responses to specific stimuli. This diversity of potential neural pathways will enable the brain to perform more complex behaviours. **Emergent properties** are functions that arise when many individual components interact or coordinate to create a novel outcome. One example of an emergent property that may arise from the combined interaction of multiple different neurons is *consciousness* – this is a state of being aware and responsive to one's surrounding conditions. A human brain is estimated to contain over 80 billion neurons, each with thousands of connections – creating quadrillions of pathways.