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Notebook

Glossary
C2. Interaction and interdependence: Cells / C2.2 Neural signalling

Reading
assistance

The big picture

 0   (<https://intercom.help/kognity>)  

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? Guiding question(s)

- How are electrical signals generated and moved within neurons?
- How can neurons interact with other cells?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

Have you noticed how, in the presence of brilliance, the pupils of our eyes reflexively contract, providing protection from the sunlight? **Video 1** shows how the pupil of the eye constricts and dilates (expands) with changes in light intensity. In this response lies the magic of neural signalling, where the interplay between our eyes and the vast network of neurons orchestrates adaptation.

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Pupil reactions [HD]

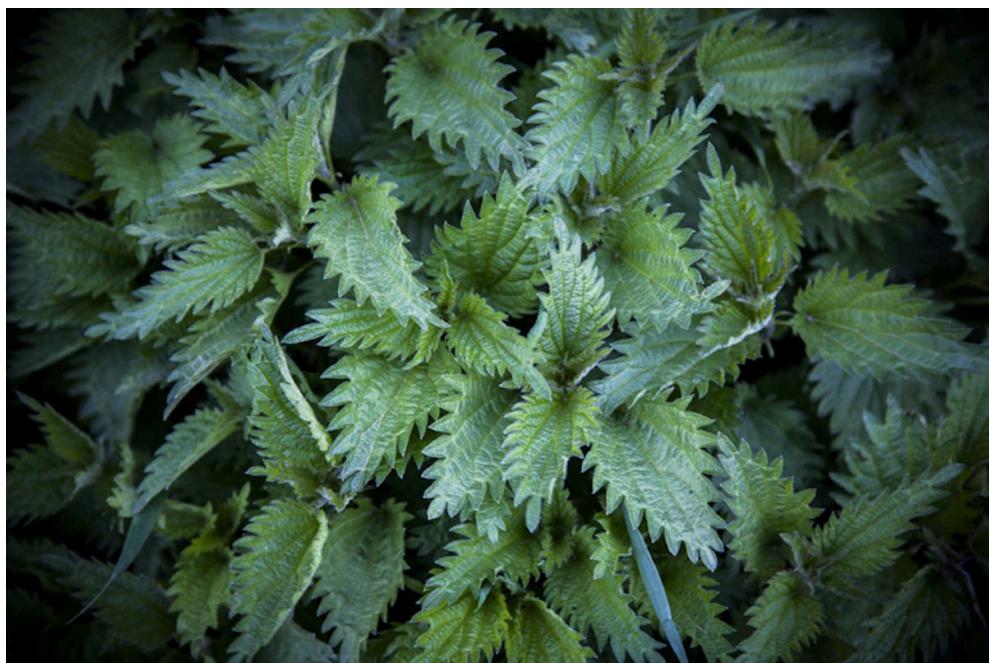


Video 1. Contraction and dilation of the pupil.

More information for video 1

The animated video captures how pupils react to the changes in light intensity. The video features a detailed view of a human eye, dominating the frame with its striking features. The iris is a soft blend of light grey and blue tones, contrasting with the dark brown lashes that frame it. Initially, a bright yellow light falls on the eye and causes the pupil to constrict. As the light on the eye decreases, the pupil gradually expands. The pupil's dark circular center becomes noticeably larger. Shortly afterward, as the light increases once again, the pupil constricts.

Similarly, we experience piercing pain when we touch a stinging nettle. The leaves of a stinging nettle plant have fine hairs that release an irritating chemical when they come into contact with the skin (**Figure 1**). The sensation travels from the site of touch to our brain and we are able to recognise this as 'pain'. But what is the mechanism of converting these stimuli into sensations?



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755105/o Certain chemicals stimulate a response in organisms through chemical signalling. There are millions of sensory receptors present in our body, in organs such as the eyes, nose, ears, mouth, skin and internal organs, which detect these stimuli and trigger a response. The stimuli include temperature, sound and light intensity from the external environment. Inside the body, there are several other stimuli such as pH, electrolyte balance and carbon dioxide concentration.

This information called sensory input is converted into electrical signals and transmitted via neurons to the brain. The brain makes decisions based on the sensory inputs that it receives and sends further signals to muscles to contract or flex, or to glands to produce their secretions. The muscles and glands are called effector organs as they cause an effect in response to the signals sent by the brain.

Prior learning

Before you study this subtopic make sure that you understand the following:

- The cell structure and functions with detailed information about the cell membrane (see subtopics A2.2 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43253/) and B2.1 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43205/))
- The nervous system (central and peripheral) and its components (see subtopic C3.1 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43542/)).
- The role of ion channels and movement of ions across the cell membrane (see subtopic B2.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43205/)).

C2. Interaction and interdependence: Cells / C2.2 Neural signalling

Neurons and nerve impulses

C2.2.1: Neurons C2.2.2: Generation of resting potential C2.2.3: Nerve impulses C2.2.4: Variation in the speed of nerve impulses

Learning outcomes

By the end of this section you should be able to:

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- Describe the structure of a neuron having a cell body with elongated nerve fibres of varying length projecting from it.

- Describe the axon as a long single fibre helping in the conduction of electrical impulses and dendrites as multiple shorter fibres receiving and processing incoming signals.
- Describe how energy from ATP drives the sodium-potassium pump during resting potential.
- Explain the concept of membrane polarisation and membrane potential and the reasons for resting potential being negative.
- Compare the speed in myelinated and non-myelinated fibres.

The nervous system in our body regulates actions and allows us to interact with our environment, both external and internal. Along with the endocrine system, it helps to coordinate all bodily functions (see [section C3.1.11–13 \(/study/app/bio/sid-422-cid-755105/book/more-about-the-endocrine-system-id-46101/\)](#)). It is composed of two parts, first, the central nervous system (CNS) consisting of the brain and spinal cord and second, the peripheral nervous system (PNS) consisting of nerves which run to and from the CNS. These nerve cells are called neurons.

Structure of a neuron

A neuron consists of three parts (**Figure 1**): the cell body or soma, one or more dendrites and a single long axon.

The cell body has a nucleus and cytoplasm with the typical cytoplasmic organelles. However, it lacks centrioles because the neurons do not multiply. The cell body may also be called the soma.

Many short and branched nerve fibres project from the cell surface. These are called dendrites and help in making connections with other neurons. The branches increase the surface area for receiving signals. The number of dendrites may differ in neurons.

A conical projection that connects the cell body with the axon is called the axon hillock. It is the site at which an action potential is generated. An action potential is a rapid, temporary change in the electrical membrane potential of a neuron or other excitable cell, allowing the cell to transmit signals along its membrane.

An axon is a long single fibre moving away from the cell body. In myelinated neurons, the entire length of the axon is covered by Schwann cells. In the peripheral nervous system, these Schwann cells secrete myelin, which is mainly made up of lipids (75%) and proteins (25%). This wraps around the axon to form an insulating cover, called the myelin sheath (**Figure 2**). The lipid and proteins present in the myelin sheath help to maintain compaction of the sheath and

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support its adhesion to the axon. In the central nervous system, the oligodendrocytes are responsible for secretion of myelin. The unmyelinated gaps between the Schwann cells are called nodes of Ranvier. The terminal endings of the axon are called axon terminals or synaptic knobs because they are knob-like in appearance.

Structure of a neuron

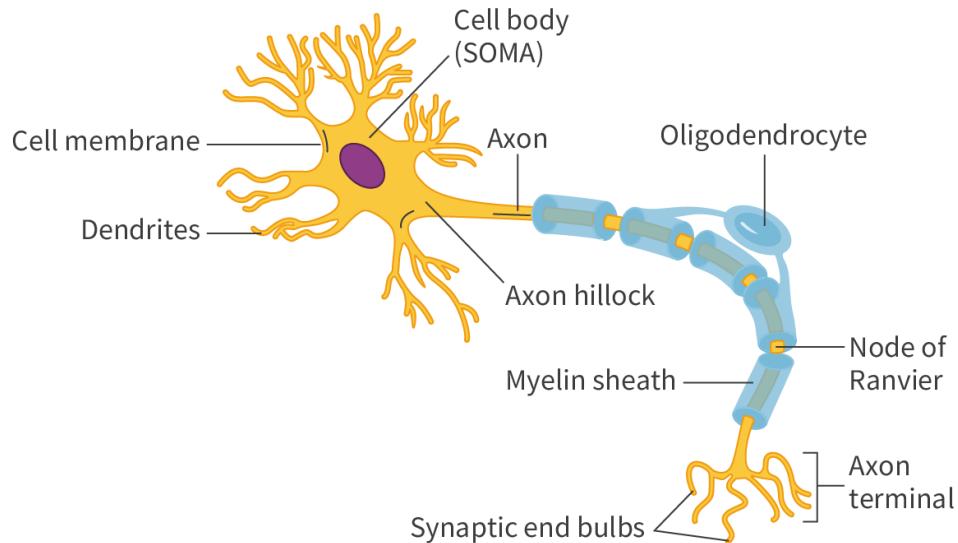


Figure 1. Structure of a neuron.

More information for figure 1

The diagram illustrates the structure of a neuron, highlighting its major components and their arrangement. Starting from the left, the neuron has a main body known as the 'cell body' or 'soma,' which contains a purple nucleus. Extending from the cell body are multiple branch-like structures called 'dendrites.'

Moving to the right, the 'axon hillock' is identified as the narrow section adjacent to the soma where the axon begins. The 'axon' itself is a long extension emanating from the axon hillock, depicted passing through a series of blue-enclosed sections labeled as 'myelin sheath,' insuated by 'Schwann cells'. Each section of the myelin sheath is separated by gaps known as the 'node of Ranvier.'

Further to the right, the neuron diagram illustrates an 'oligodendrocyte' connected with a blue branching structure associated with the myelinated sections, indicating its role in myelination within the central nervous system.

The diagram concludes with the 'axon terminal' or 'synaptic end bulbs,' which are located at the end of the axon, depicted as knob-like structures where synaptic connections occur.

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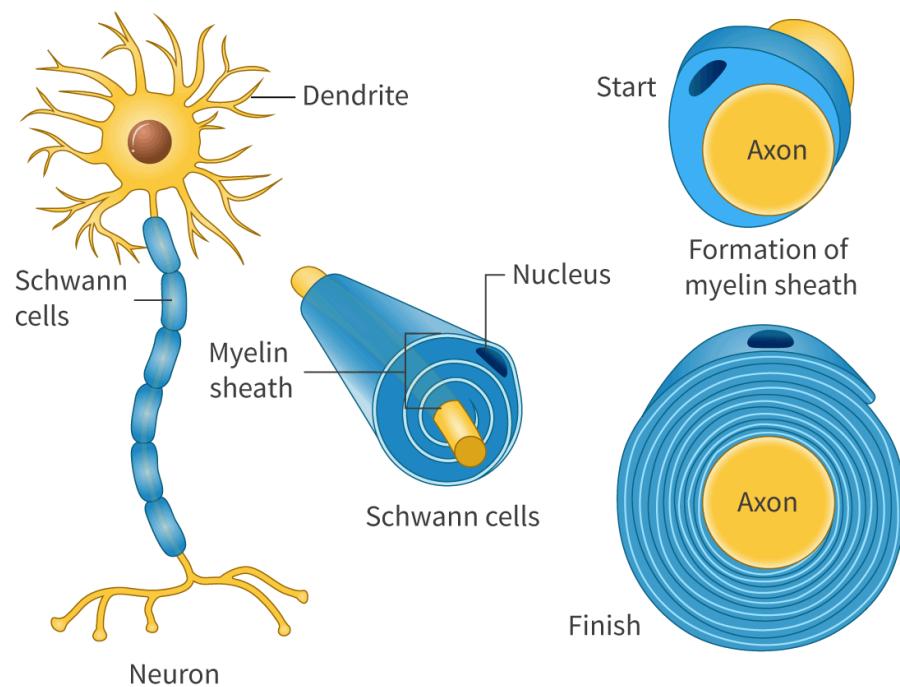


Figure 2. Formation of myelin sheath.

More information for figure 2

A detailed diagram illustrates the structure of a neuron and the formation of the myelin sheath. On the left, a neuron is depicted with a cell body, highlighted dendrites extending outward, and an axon coated in a sequential series of Schwann cells forming the myelin sheath. The labels include "Neuron," "Schwann cells," "Myelin sheath," and "Dendrite."

To the right, the process of myelin sheath formation around an axon is shown in cross-section views. The upper right section is labeled "Start" with a circle indicating the axon surrounded by the initial layers forming the sheath. The label "Formation of myelin sheath" indicates this is the phase where the layers begin wrapping around the axon tightly. The lower section labeled "Finish" shows a complete view of a fully wrapped axon with concentric myelin layers. Key labels in this section include "Axon" and "Nucleus" to indicate the central parts inside the myelin wrapping.

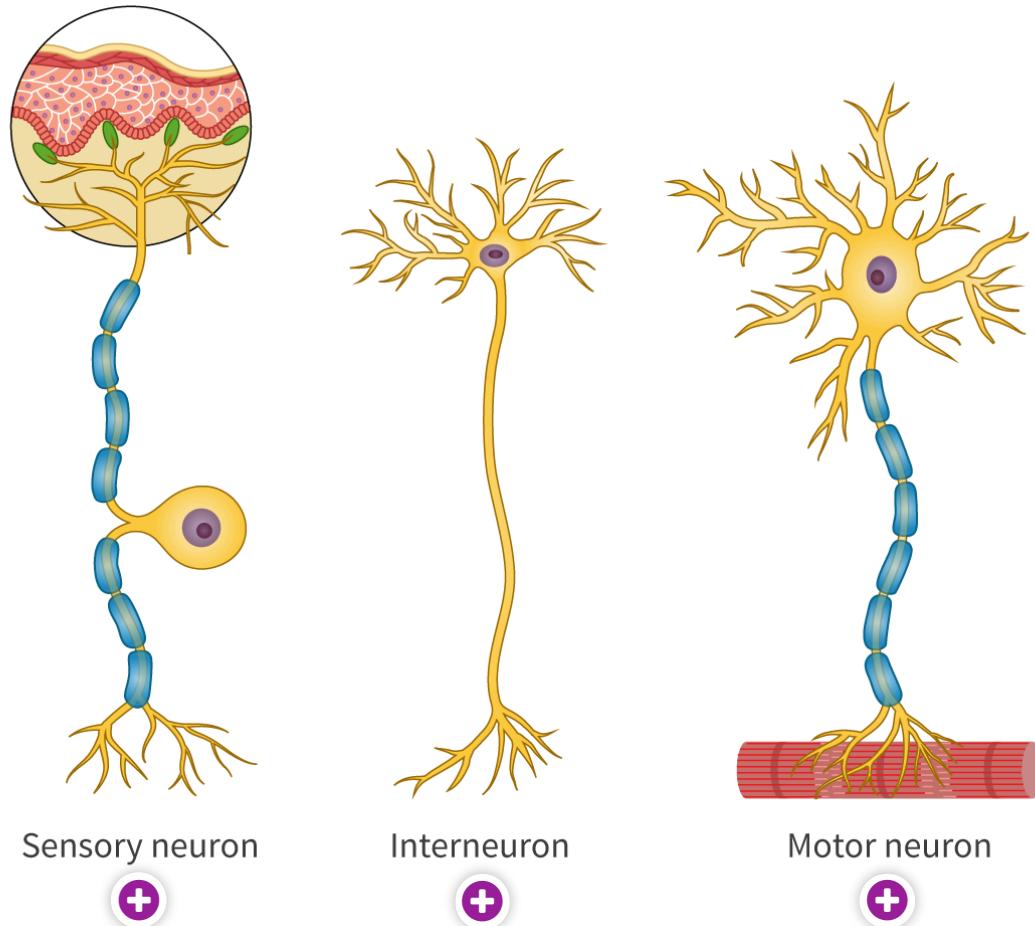
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Depending on their function, there are three types of neurons in the nervous system: sensory neurons, interneurons or relay neurons and motor neurons. **Interactive 1** shows the three types of neurons.



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Interactive 1. Structures of Different Types of Neurons.

More information for interactive 1

This interactivity illustrates the anatomy of three types of neurons: Sensory neurons, interneurons, and motor neurons.

Each type is depicted with labeled structures and hotspots explaining their role in neural communication.

The first image is of a sensory neuron. It is visualized as a single, long extension that splits into branches. The cell body is located in the dorsal root ganglion. It has a long dendrite extending from the sensory receptors to the cell body. It also contains a single axon that transmits signals to the central nervous system. The myelinated body is colored blue. These neurons detect external/internal stimuli (touch and temperature). They cause sensations like feeling pain or heat.

The second image is of an interneuron. These are short, unmyelinated axons and dendrites that have a high branching density to connect multiple neurons. These neurons integrate information (reflexes). They act as bridges within the central nervous system (CNS) for rapid signal processing.

The last image is of a motor neuron. These are multiple short dendrites and a single, long axon, which receive signals from interneurons. They are heavily myelinated as visualized by the blue color in the image. Myelination increases the speed of signal transmission. The main function of motor neurons is to carry commands from the brain and spinal cord to muscles, enabling movement.

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There are 3 Hotspots represented by plus signs at various places. Hotspot 1 is below the image of a sensory neuron. Hotspot 2 is below the image of an interneuron. Hotspot 3 is below the image of a motor neuron. Clicking on the hotspots reveals the characteristics of that specific type of neuron.

The following items are revealed at respective hotspots:

Hotspot 1: Sensory neurons: These neurons help in feeling sensations. They have an elongated dendrite running from the sensory receptors to the cell body and an axon running from the cell body.

Hotspot 2: Interneurons: These neurons are short and help in transmitting signals between the sensory and the motor neurons. The image shows an unmyelinated interneuron.

Hotspot 3: Motor neurons: These neurons make the connection between the brain and the muscles. They have many fine dendrites that bring in the impulses to the cell body from where a single long axon carries these impulses away from the cell body.

This interactivity clarifies neuron anatomy (how dendrites, axons, and myelin optimize signal transmission) and functional classification (sensory, interneuron, and motor roles in neural pathways).

Try the drag and drop activity in **Interactive 2** to label the different parts of a neuron.



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The diagram shows a myelinated neuron with its various parts labeled: Axon, Axon terminals, Myelin sheath, Schwann cells, Dendrites, Nodes of Ranvier, and Cell body. Below the diagram is a 'Check' button.

Interactive 2. The parts of a neuron.

More information for interactive 2

This is an interactive screen with a drag-and-drop activity of a neuron, a nerve cell. The diagram illustrates the basic structure of a myelinated neuron, highlighting its key components involved in transmitting nerve impulses.

On the left, there's a star-like shape, which is the cell body, or soma. It's a central, somewhat rounded structure with a darker, circular nucleus in the middle. Branching out from the cell body are numerous, short, irregular extensions that look like the twigs of a tree. These are the dendrites.

Extending from the right side of the cell body is a long, cylindrical projection called the axon. This axon is covered by a series of sausage-shaped segments that appear to be wrapped around it. These segments represent the myelin sheath, and each wrapping unit is a Schwann cell. There are small gaps between these myelin sheath segments, like constrictions along the axon. These gaps are the Nodes of Ranvier.

At the far right end of the axon, it branches out again into several smaller, irregular extensions, similar in appearance to the dendrites on the cell body, but typically smaller and at the end of the long axon. These are the axon terminals.

Below the diagram, there are seven labeled buttons: Axon, Axon terminals, Myelin sheath, Schwann cells, Dendrites, Nodes of Ranvier, and Cell body.



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These labels correspond to the different parts of the neuron shown in the diagram.

Read below for the answers.

Top row, the first one is the cell body, the second gap is the axon, then we have the nodes of Ranvier, and the last one is the axon terminals.

Below the diagram, the first gap is dendrites, then we have Schwann cells, and the last one is the myelin sheath.

Resting potential

Neurons conduct signals only when stimulated. In a neuron the sodium ions (Na^+) have a greater concentration on the outer side and the potassium ions (K^+) have a greater concentration on the inside of the cell membrane. There are also other negatively charged particles (anions) such as Cl^- ions in the extracellular fluid and some amino acids and proteins (organic anions) in the intracellular fluid. This separation of charges results in a potential difference between the inside and the outside of the neuron cell membrane. This electrical potential across the plasma membrane, when the neuron is not stimulated, is called the resting potential and is about -70 millivolts (mV) (**Figure 3**). This is disturbed for a short while when the neuron conducts signals. Once the signal passes through the neuron the resting potential is re-established.

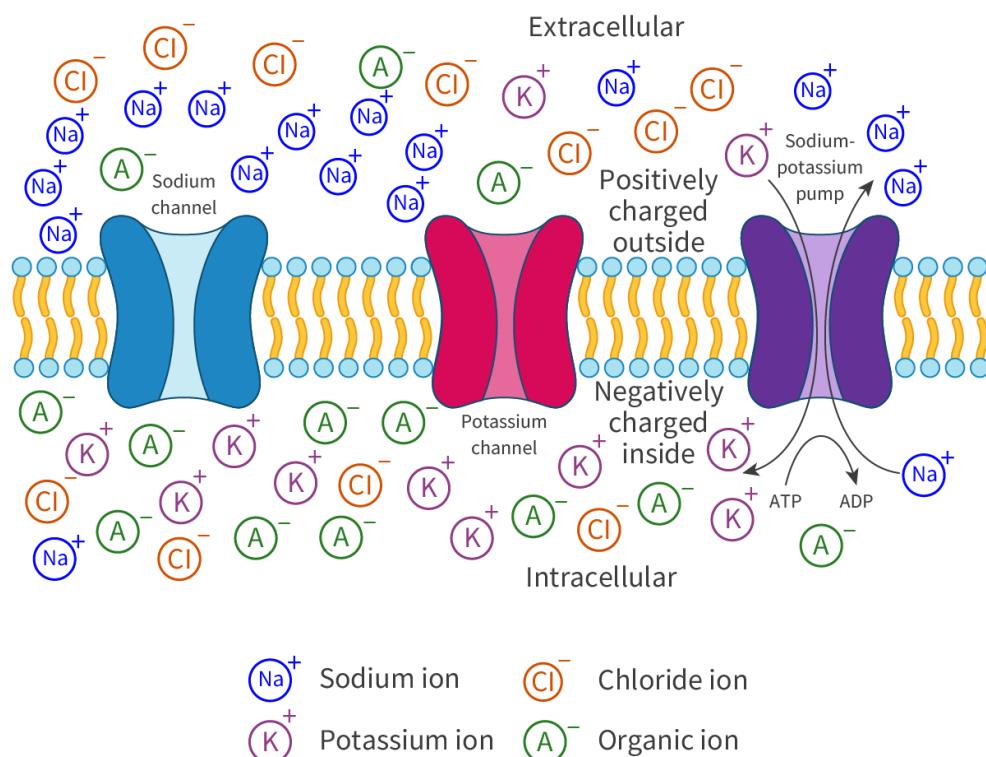


Figure 3. Resting membrane potential (RMP). The outside of the membrane is positive compared with the inside. Some sodium ions are linked to chloride ions and therefore are not free to move. Potassium ions and organic anions of amino acids and proteins make the inside of the cell negatively charged.

More information for figure 3



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The image is a diagram illustrating the resting membrane potential of a cell. It shows a cross-section of a cell membrane, detailing the distribution of ions inside and outside the cell. On the extracellular side, sodium ions (Na^+) shown in blue and chloride ions (Cl^-) shown in orange are present. The intracellular side has potassium ions (K^+) shown in purple and organic anions (A^-) shown in green.

The membrane features three main components: a blue sodium channel, a red potassium channel, and a purple sodium-potassium pump. Sodium ions flow through the sodium channel, while potassium ions move through the potassium channel. The sodium-potassium pump uses ATP (adenosine triphosphate) to exchange three sodium ions from inside the cell with two potassium ions from outside, maintaining the charge difference.

The diagram indicates that the extracellular side of the membrane is positively charged, whereas the intracellular side is negatively charged. The imbalance of ions across the membrane creates the resting membrane potential.

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Watch **Video 1** to learn about the resting membrane potential.

Neuron Resting Potential



Video 1. Resting membrane potential.



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Nerve impulses as action potentials

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Neurons help with conduction of a nerve impulse in the form of electrical signals. The temporary reversal in the electrical potential of the membrane of neurons is called a nerve impulse. This gradually builds up and travels across the entire neuron and is transmitted to another neuron or the effector cell. In **Figure 4**, you can see clearly the direction in which the nerve impulse travels (red arrows).

The stimulus is picked up by the sensory receptors and transferred to the dendrites of the sensory neuron where it travels to the cell body and further into the axon and the terminals. A nerve impulse travelling through a myelinated neuron can travel at a speed up to 120 m/s (metres per second). In a non-myelinated neuron the speed can be between 1 and 3 m/s. The presence of the myelin sheath speeds up the transmission of signals by causing the nerve impulse to jump from one node of Ranvier to another. More detail is given on this later in this section and in [section C2.2.8–11 \(/study/app/bio/sid-422-cid-755105/book/oscilloscope-and-saltatory-conduction-hl-id-46648/\)](#) (HL). Nervous coordination is a very fast-acting system with immediate responses to stimuli.

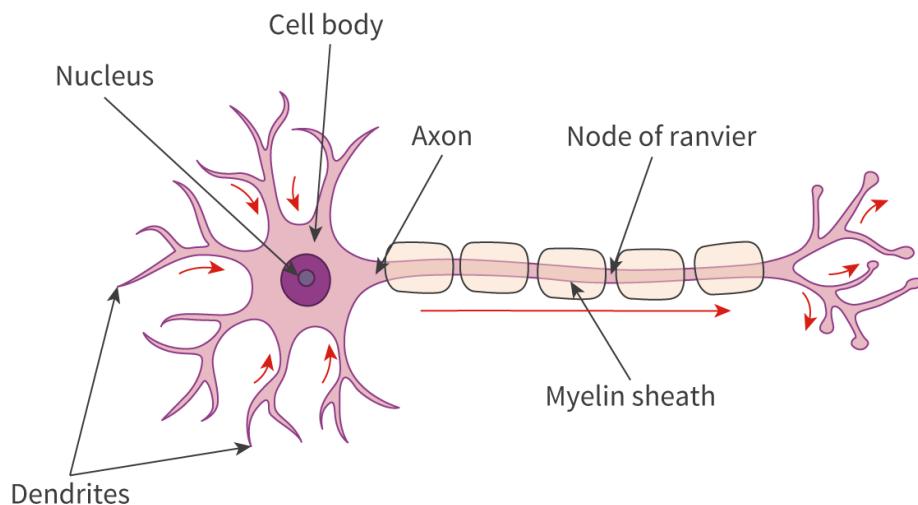


Figure 4. Direction of flow of a nerve impulse.

More information for figure 4

The image depicts a diagram of a neuron highlighting the flow of a nerve impulse. Key components are labeled, including the dendrites, cell body, axon, myelin sheath, and node of Ranvier. Arrows illustrate the direction of the nerve impulse which starts at the dendrites, travels through the cell body and axon, and moves along the axon through the myelinated sections. The myelin sheath is shown wrapping around the axon with gaps known as nodes of Ranvier, where the nerve impulse jumps, speeding up transmission. The diagram emphasizes the structural features that facilitate rapid impulse conduction.



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- 755105/o Nerve impulses are action potentials that are propagated along nerve fibres (**Figure 5**). An action potential is generated when the membrane potential of a neuron rapidly rises and falls. It is the potential difference in the membrane that occurs on excitation of the neuron.

The sodium-potassium pump in the cell membrane helps to transport the Na^+ ions out and K^+ ions inside the cell via active transport (see section B2.1.6–8 (/study/app/bio/sid-422-cid-755105/book/facilitated-diffusion-and-active-transport-in-id-44644/)) (**Figure 6**). The Na^+/K^+ pump utilises energy from ATP to perform this function. The ATPase enzyme breaks down ATP into ADP and each time this happens, three Na^+ ions are pumped out in exchange for two K^+ ions that enter into the cell against the concentration gradient. The extracellular fluid has a higher concentration of positive charges compared with the intracellular fluid. As a result of this, a negative charge is developed inside the neuron and a positive charge outside. In this condition, the neuron is polarised. This helps to stabilise the membrane potential (see section C2.1.7–9 (/study/app/bio/sid-422-cid-755105/book/signal-transduction-pathways-hl-id-46380/)), which is the difference between the charge of the inside and the outside of the neuron membrane. To understand the action of the Na^+/K^+ pump in detail, watch **Video 2**.

Sodium Potassium Pump



Video 2. How the sodium–potassium pump works.

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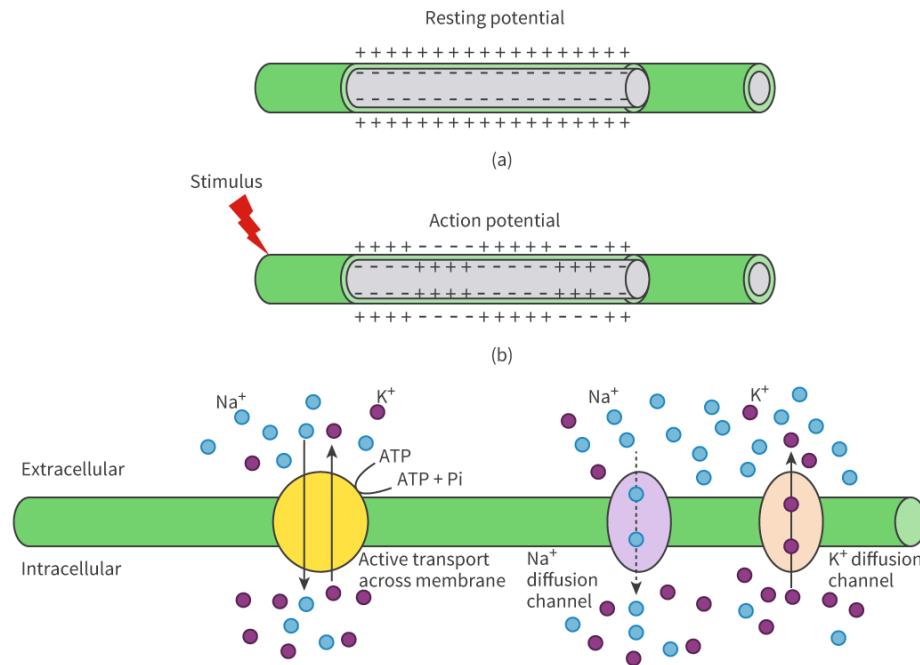


Figure 5. Membrane polarisation and depolarisation.

[More information for figure 5](#)

The image illustrates the process of membrane polarization and depolarization across different sections. At the top, two diagrams show a cross-sectional view of a membrane in two states: 'Resting potential' and 'Action potential.' The resting potential diagram shows positive charges lined up along the external side of the membrane and negative charges internally. The 'Action potential' section is indicated by a stimulus symbol, showing a reversal in polarity across the membrane region indicated by dashed lines.

Below these diagrams, there is an illustration of ion exchange across a membrane. The extracellular environment is represented above, and the intracellular environment below. Ions such as Na^+ and K^+ are shown, with Na^+ moving through an active transport channel into the cell in exchange for K^+ . This exchange process is energy-dependent, noted by an ATP molecule transforming into ATP + Pi during the process. Two diffusion channels further demonstrate the movement of Na^+ and K^+ ions.

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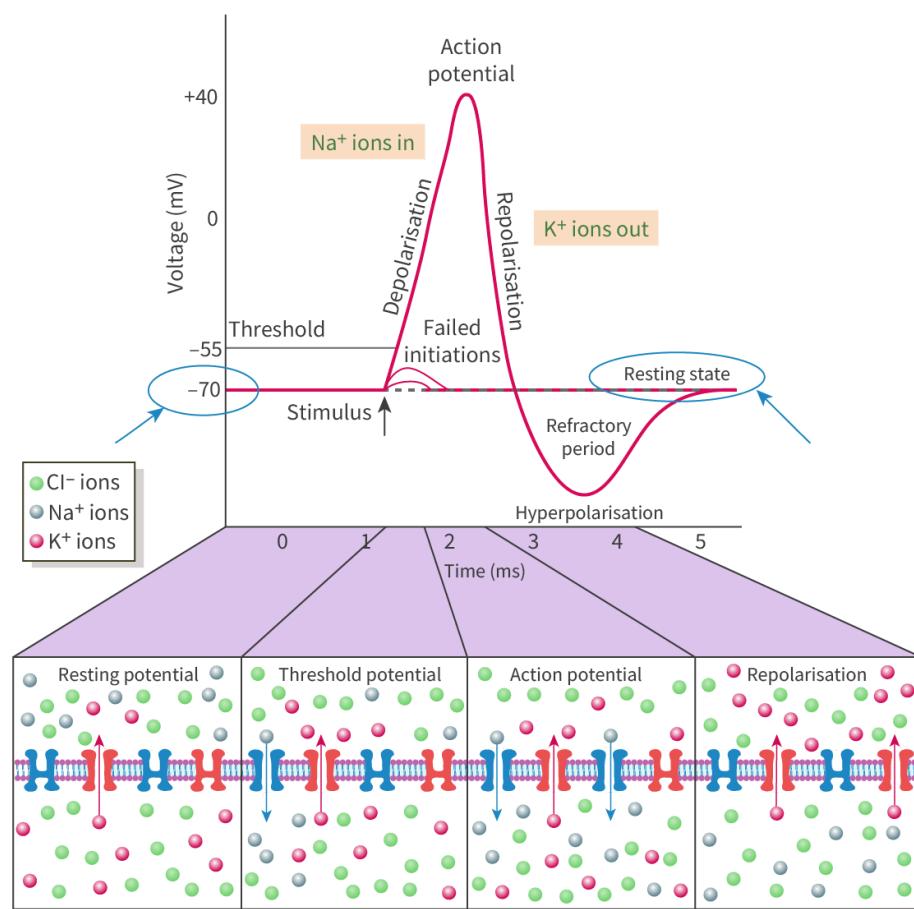


Figure 6. Transmission of nerve impulse: resting potential, threshold potential, depolarisation, action potential, repolarisation, hyperpolarisation.

[More information for figure 6](#)

This diagram illustrates the transmission of a nerve impulse, focusing on resting potential, threshold potential, depolarization, action potential, repolarization, and hyperpolarization. The upper section of the diagram includes a graph depicting voltage changes over time, from resting at -70 mV to reaching approximately +40 mV during the action potential. The X-axis represents time in milliseconds from 0 to 5 ms, while the Y-axis indicates voltage in millivolts ranging from -70 to +40 mV.

Key stages are marked, such as the threshold at -55 mV, depolarization where Na^+ ions enter the cell causing voltage to rise, and repolarization as K^+ ions exit restoring the membrane potential. Failed initiations and the refractory period are also depicted.

Below the graph, four panels illustrate ion movement across the neuron's membrane at different stages: resting potential (with more Na^+ outside and K^+ inside), threshold potential, action potential (Na^+ flows inside), and repolarization (K^+ flows outside). Each section highlights the movement of Cl^- , Na^+ , and K^+ ions, coordinated with changes in membrane potential.



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Upon receiving a stimulus, the Na^+ channels open and allow inflow of Na^+ ions into the neuron. This reverses the polarity of the axon fibre and it gets depolarised. The impulse travels as a wave through the entire length of the axon and depolarises it. Depolarisation exists merely for 2 milliseconds (ms), after which the Na^+ channels close and the K^+ channels open. K^+ ions move to the outside of the membrane. The membrane potential starts going back to -70 mV. The Na^+/K^+ pump actively transports Na^+ and K^+ to where they should be. The passage of the nerve impulse through the axon is called propagation. The nerve impulse can also be seen as a Mexican wave effect. Watch **Video 3** to see how a change begins and propagates until it reaches the end.

World record for Biggest Wave Ever !! Bristol Tenn. 130k +



Video 3. Mexican wave in a car racing track as an example of propagation of nerve impulse.

🔗 Nature of Science

Aspect: Global impact of science

Scientific knowledge, discoveries and contributions transcend national boundaries and have far-reaching implications for humanity as a whole. This emphasises the collaborative nature of scientific research and the contributions made by scientists from around the world. In the field of neuroscience some renowned scientists have made valuable contributions which have helped people on a global scale. A few scientists and their field of work are discussed below.

Santiago Ramón y Cajal from Spain along with Camillo Golgi received the Nobel prize in 1906 for developing methods that could colour and highlight the key components of the nervous system. This allowed the nervous system to be studied in greater detail.

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Thomas Südhof from Germany studied synaptic transmission, which provided insights into the calcium-dependent release of neurotransmitters in neurons.

May-Britt Moser and Edvard Moser from Norway contributed to our understanding of spatial navigation and the brain's navigation system. They discovered grid cells and place cells in the brain, which play a crucial role in our ability to navigate and create cognitive maps of our environment. Their research earned them a Nobel Prize in 2014.

Try the activity below where you will summarise your learning so far on neurotransmission by creating a timeline of an action potential.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Designing procedures and models
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual/pair activity

On a blank sheet of paper, create a timeline or sequence of events depicting the stages of an action potential. You can draw or write about each stage, such as resting potential, depolarisation, repolarisation and hyperpolarisation.

This activity will help you to understand the chronological order and key events involved in the generation and propagation of an action potential.

Speed of nerve impulse

The speed at which a nerve impulse travels down a neuron is called the nerve conduction velocity. The fastest nerve impulse achieved by various nerves of the human body was recorded in 1966, with a speed of 288 km/h. Sensory detection is by far the fastest compared with motor reactions.

The speed of transmission depends on the following factors:

- Amount of myelination: the action potential travels more rapidly along myelinated neurons compared with unmyelinated neurons.
- Diameter of the axon: the larger surface areas of axons with larger diameters are able to propagate action potentials faster than axons with smaller diameters.

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- Temperature: the cooler the temperature, the slower the transmission of nerve impulse.

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Let us look at each of these in detail.

Myelination is insulation by the wrapping of Schwann cells around the axon. As is evident from **Figure 7**, myelination is discontinuous and leaves some exposed (unmyelinated) axon called the nodes of Ranvier. The actional potential has to jump from node to node and in doing so, it covers a larger distance in a short time. This is called saltatory conduction, which is covered in more detail in [section C2.2.8–11 \(/study/app/bio/sid-422-cid-755105/book/oscilloscope-and-saltatory-conduction-hl-id-46648/\)](#).

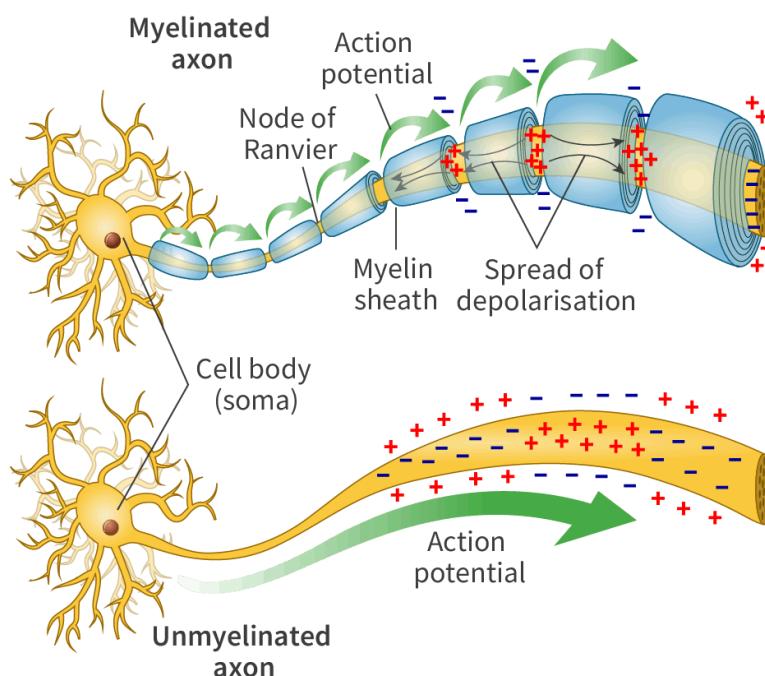


Figure 7. Myelinated versus unmyelinated axon.

More information for figure 7

The illustration compares a myelinated axon with an unmyelinated axon. At the top, the myelinated axon is depicted with Schwann cells wrapping around it, forming a myelin sheath, and leaving gaps known as nodes of Ranvier. Arrows indicate the action potential jumping from node to node, labeled as "saltatory conduction," highlighting the efficiency of this process. The bottom part shows an unmyelinated axon, with a single straight line representing the action potential traveling continuously along the axon. Surrounding text and labels include terms like "Spread of depolarisation," "Node of Ranvier," and "Action potential," providing additional insights into nerve signal transmission.

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An unmyelinated axon can be compared with a highway without any traffic lights but with speed limits. All vehicles continuously move at a steady speed. Similarly, in unmyelinated axons, the depolarisation takes place throughout the length of the axon and the action potential thus has to travel the entire length. This takes up more time than the ‘jumping signals’ in the myelinated axon.

The diameter of the axon plays a vital role in determining the speed of transmission of nerve impulse (**Figure 8**). In humans, the average diameter of an axon is $1\text{ }\mu\text{m}$, which can conduct nerve impulses at a speed of 100 m/s . Less leakage of ions from wider diameter axons results in faster generation of action potential. In axons with a smaller diameter, the ions face a lot of resistance from other molecules such as proteins and they get delayed in transmitting the impulse.

Interestingly, squids have giant axons which can measure more than $500\text{ }\mu\text{m}$ in diameter. Although their axons are unmyelinated, they can achieve quick transmission of nerve impulses due to the large diameter (**Figure 9**).

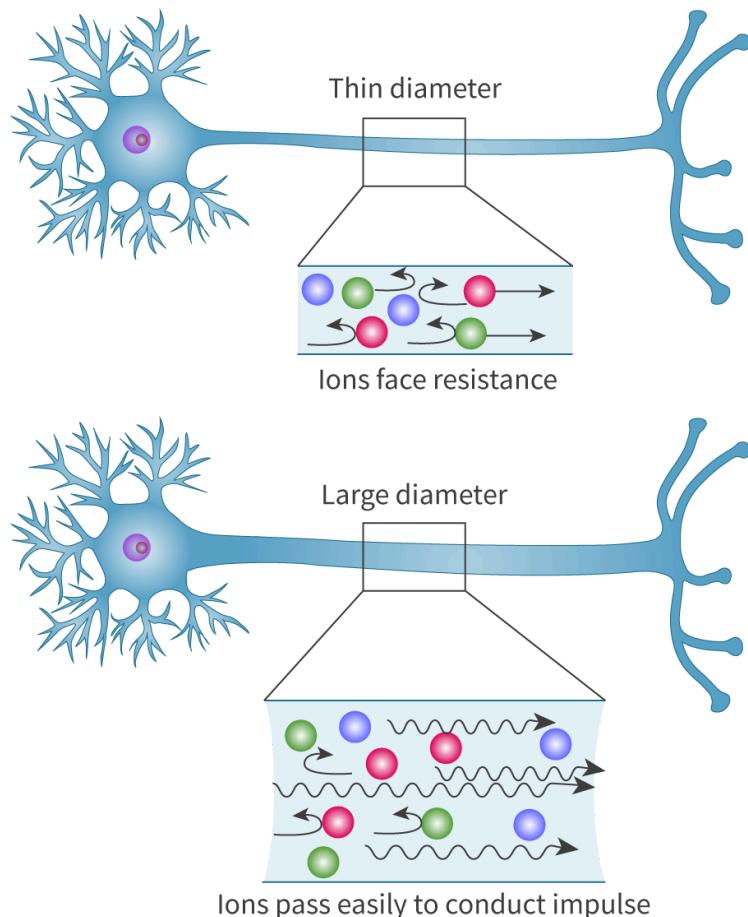


Figure 8. Comparing transmission in neurons with a smaller or larger diameter axons.

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The image is a diagram illustrating the differences in ionic flow in neurons with thin and large diameter axons. The top half of the diagram shows a neuron with a thin diameter axon. Inside the axon, there is a magnified section showing ions represented by colorful circles. The ions have arrows indicating their flow, which face resistance, as suggested by a label "Ions face resistance." The bottom half of the diagram depicts a neuron with a large diameter axon. In its magnified section, the ions similarly are shown with arrows, but they pass freely, as indicated by the label "Ions pass easily to conduct impulse." This illustrates that neurons with larger axons allow ions to pass more easily, facilitating better transmission of nerve impulses.

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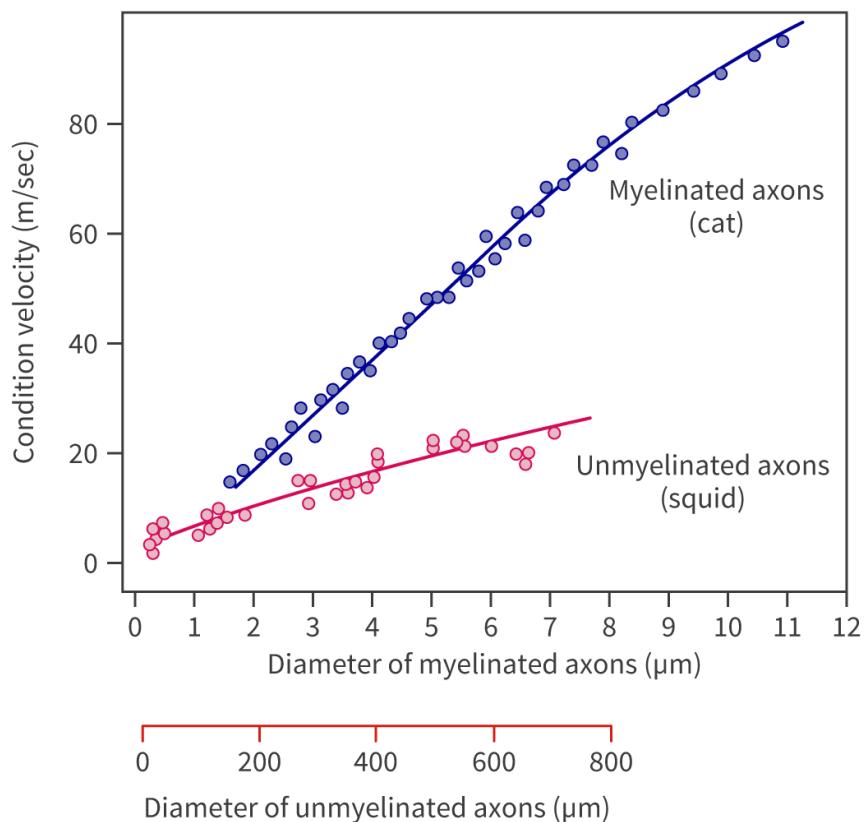


Figure 9. Speed of conduction in a myelinated versus an unmyelinated axon.

More information for figure 9

The graph compares the conduction velocity (in m/sec) of nerve impulses along axons of different diameters, displayed on the X-axis. The Y-axis represents conduction velocity, labeled from 0 to 80 m/sec. Two sets of data are shown:

Myelinated axons (cat): Represented by blue data points, this line shows an upward trend with increasing diameters from 0 to about 11. Axon diameters range from 0 to 12 μm , indicating that as the diameter of myelinated axons increases, the conduction velocity increases sharply, reaching around 80 m/sec at the largest diameter.

Unmyelinated axons (squid): Depicted with pink data points, showing a more modest increase in conduction velocity with axon diameters, ranging from



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0 to about 800 μm . The conduction velocities here remain below 25 m/sec, with only a slight increase as the diameter approaches the largest values. \nThe overall trend reveals that myelinated axons show a more significant increase in conduction velocity with diameter compared to unmyelinated axons.

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Temperature is also a key factor in determining the speed of nerve conduction. In research conducted by Dr K. Todnem in 1989, the median sensory and median motor nerves were studied in 20 neurologically healthy individuals. The study was carried out after cooling and heating the skin of the arm using cooling and heating pads. It is important to note that the response duration of sensory neurons increased in a linear fashion with a decline in temperature. The amplitude of response did not show any significant relation to temperature both in sensory and motor neurons. The tools of mathematics can be employed to understand the correlation in this case.

⊕ Study skills

The Pearson correlation coefficient (r) and coefficient of determination (R^2)

Karl Pearson suggested a way to calculate the strength of relationship between two given variables. It is called the Pearson's correlation coefficient. Correlations can have negative or positive values ranging from -1 to 1 .

Worked example

How does the diameter of axon affect the speed of conduction of a nerve impulse?

To find out the correlation between the diameter of an axon and the speed of conduction of a nerve impulse, we will follow the steps given below:

1. Record the data for the diameter of different axons and the speed of conduction of nerve impulse in a table in Google sheets.
2. The table should look something like Table 1.

Table 1. Sample data.



Student
view

Diameter of axon (X) μm	X^2	Speed of conduction of nerve impulse (Y) (m/s)	Y^2	XY
8	64	50	2500	400
7	49	40	1600	280
3	9	15	225	45
2	4	12	144	24
1	1	1.6	2.56	1.6
0.8	0.64	1.5	2.25	1.2
$\Sigma X = 21.8$	$\Sigma X^2 = 127.68$	$\Sigma Y = 120.1$	$\Sigma Y^2 = 4473.81$	$\Sigma XY = 751.8$

3. Fill in the calculated values in the formula to get the value of R.

$$R = \frac{\Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{n}}{\sqrt{\left[\left(\Sigma X^2 - \frac{(\Sigma X)^2}{n_x} \right) \left(\Sigma Y^2 - \frac{(\Sigma Y)^2}{n_y} \right) \right]}}$$

- ΣX This simply tells you to add up all the X scores
- ΣY This tells you to add up all the Y scores
- ΣX^2 This tells you to square each X score and then add them up
- ΣY^2 This tells you to square each Y score and then add them up
- ΣXY This tells you to multiply each X score by its associated Y score and then add the resulting products together (this is called a ‘cross product’)
- n This refers to the number of ‘pairs’ of data you have.

4. $R = 0.9957$.

5. Simply square the value of R to get $R^2 = 0.99$.

6. If the R value is between 0 and 1, then there is a positive correlation.

7. If the R value is between 0 and -1, then there is a negative correlation.

8. If the R value is closer to 1, then there is a strong correlation.

9. If the R value is closer to 0, then there is a weak correlation.



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You can use this [free online simulator](https://ilearn.med.monash.edu.au/physiology/action-potentials/stim-strength#simulation) (<https://ilearn.med.monash.edu.au/physiology/action-potentials/stim-strength#simulation>) provided by Monash University to collect data to study the effect of axon diameter on the speed of transmission of nerve impulse in myelinated and unmyelinated axons.

- Read the theory of the experiment given in the first tab on the webpage.
- Collect the data for myelinated and then unmyelinated axons.
- Record your findings in a data table (preferably Excel) spreadsheet.
- Plot a graph for both the myelinated axon and unmyelinated axon.
- For further processing of data you may draw a line of best fit.

Try the next activity in which you will investigate the effects of different variations on the speed of a relay race to model variations in speed of neurotransmission.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Social skills — Working collaboratively to achieve a common goal
- **Time required to complete activity:** 30 minutes
- **Activity type:** Group activity

Activity: Action Potential Relay Race

Objective: To help you understand the process of action potentials and the variation in speed of nerve impulses.

Materials

- stopwatch or timer
- cones or markers
- paper and markers
- whiteboard/chart paper
- bean bags
- basketball
- tennis ball
- marble.

Procedure

- Divide into teams of four to five students each.



Student view

- Set up a relay course in the classroom or outdoor area using cones or markers. The course should be long enough to allow for running and passing of objects.
- Your team should choose a name team name and write this on a piece of paper to be displayed on the whiteboard.
- You will be participating in a relay race, but instead of passing a baton, you will be passing a bean bag or other small object to represent an action potential.
- The first student of each team should stand at the starting line. When the race begins, the student will run to the first cone or marker and pass the bean bag to the next student.
- The next student will run to the next cone or marker, and so on, until all students have completed the course.
- Before the race begins, your team will be randomly assigned a ‘variation’ to be incorporated into the race. The variations could include running the course blindfolded, running the course backwards, running the course while holding a book or running the course while wearing oven mitts.
- After your team has completed the race, gather around the whiteboard or chalkboard and write down your time, the variation you were assigned and any observations they made during the race.
- Using observations from all teams, discuss with your class how different variations can affect the speed of the race, just as different factors can affect the speed of nerve impulses.

5 section questions ▾

C2. Interaction and interdependence: Cells / C2.2 Neural signalling

Synapses and neurotransmitters

C2.2.5: Synapses C2.2.6: Release of neurotransmitters from a presynaptic membrane

C2.2.7: Generation of an excitatory postsynaptic potential

Learning outcomes

By the end of this section you should be able to:

- Explain the role of synapses in communication between neurons.
- Compare and contrast the mechanisms of neurotransmitter release in different types of synapses.

- Analyse the factors that affect the magnitude and duration of EPSPs.

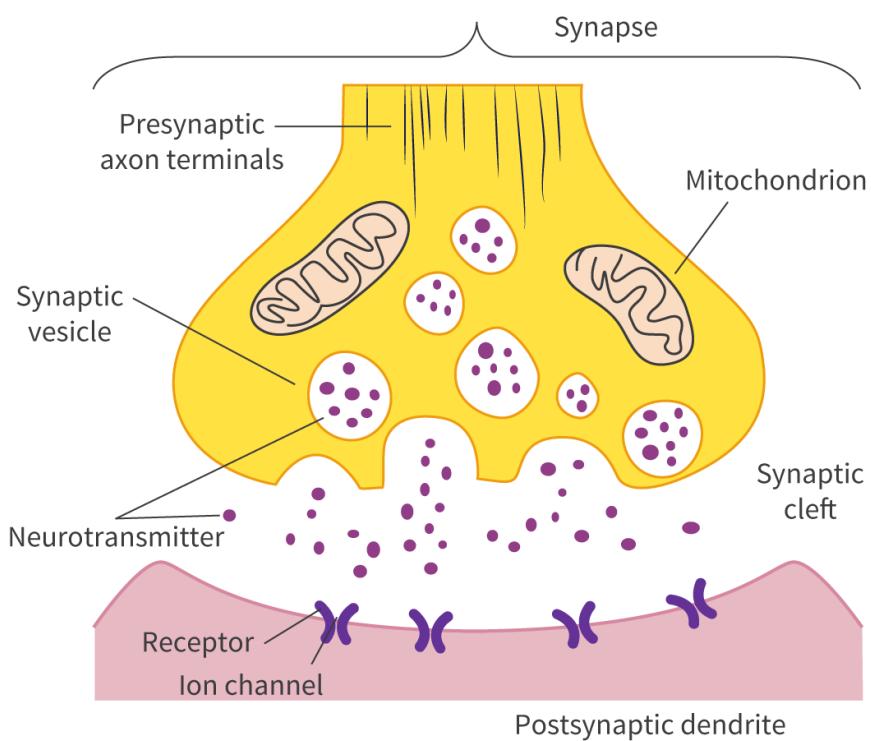
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Have you ever wondered how you are able to learn and what drives your cognitive processes? The neurons in your body work in coordination to pass on the stimuli from the point of reception to the brain and then back again from the brain to the effector organ. In doing so the signals have to be passed from one neuron to the other. How does this happen?

Synapses as junctions

Signals can pass only in one direction along a neuron. This unidirectional flow is essential for the proper functioning of the nervous system and is primarily achieved through the presence of specialised structures called synapses.

There are several junctions between neurons that help to quickly transmit signals. These specialised junctions are called synapses (**Figure 1**). They can occur between two neurons and between a neuron and an effector cell. It consists of the synaptic knob (the end part of the axon terminal) of the presynaptic neuron (before the synaptic cleft) and the dendrite of the postsynaptic neuron (after the synaptic cleft). The knob is bulb-like and has many vesicles containing neurotransmitters. The pre- and postsynaptic neurons do not touch each other, instead there is a small space between them which is called the synaptic cleft. This cleft is around 12–20 nm in size. The neurotransmitters are released in this space.



Student
view

Figure 1. A synapse between two neurons. The presynaptic neuron contains neurotransmitter held inside vesicles. The space between the presynaptic neuron and postsynaptic neuron is the synaptic cleft.

 More information for figure 1

The diagram illustrates the structure of a synapse between two neurons. At the top, there's the presynaptic axon terminal, which is shown as a large yellow bulb. Within this bulb are synaptic vesicles and mitochondria. The synaptic vesicles contain neurotransmitters, represented by small dots. Below the presynaptic bulb is the synaptic cleft, a small space where neurotransmitters are released. At the bottom of the diagram is the postsynaptic dendrite, shown in pink, which contains receptors and ion channels to receive the neurotransmitters. The labeled parts clearly show the interaction zones and the transfer of neurotransmitters across the synaptic cleft.

[Generated by AI]

Synapses exist between neurons and can also occur between neurons and effector cells (**Figure 2**).

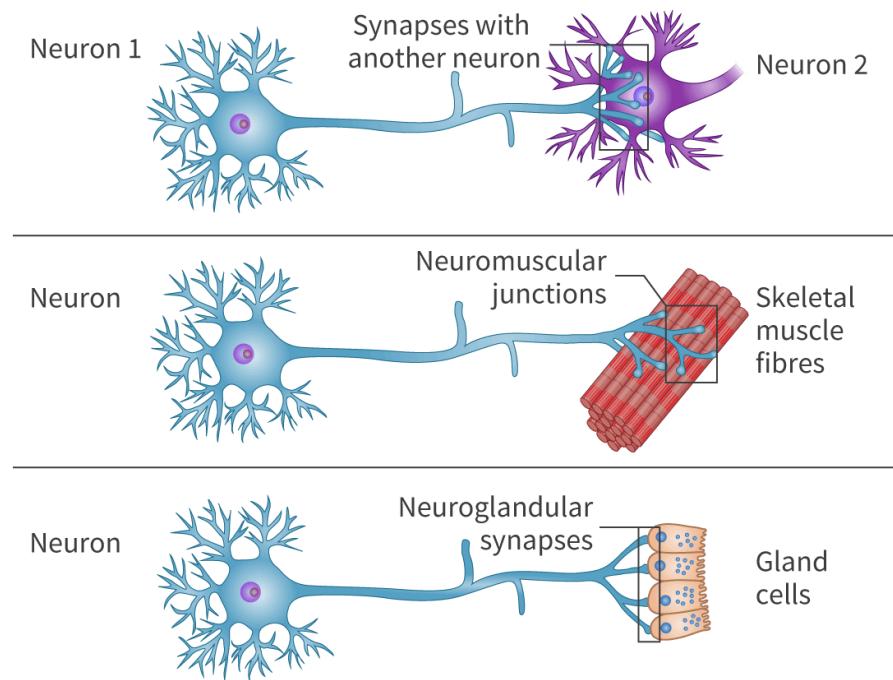


Figure 2. Three different types of synapses. Synapses can occur between neurons (top diagram), or between neurons and effector cells such as skeletal muscle fibres (centre) or gland cells (lower).

 More information for figure 2

The image is a diagram showing three types of synapses.

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At the top, there is a synapse between two neurons labeled as "Neuron 1" and "Neuron 2." The neurons are shown with dendritic trees extending from cell bodies, and a synapse connecting them.

In the middle, a "Neuromuscular junction" is illustrated between a neuron and skeletal muscle fibers. The neuron connects to the muscle fibers, which are depicted as bundled fibers extending horizontally.

At the bottom, a "Neuroglandular synapse" is shown. The neuron connects to gland cells, which are depicted with small, rounded structures. The synapses are labeled, and each type is visually connected, showing the distinct structure and arrangement.

[Generated by AI]

Neuronal synapses

Neuronal synapses occur between two neurons. They involve the release of neurotransmitters from the presynaptic neuron and the binding of these neurotransmitters to receptors on the postsynaptic neuron.

Examples include synapses in the brain, spinal cord and peripheral nerves.

Neuromuscular junction

The neuromuscular junction (see [section B3.3.2–4 \(/study/app/bio/sid-422-cid-755105/book/muscle-contraction-h1-id-44815/\)](#)) is a specialised synapse between a motor neuron and a muscle fibre (**Figure 3**). It is responsible for transmitting signals from the motor neuron to the muscle, leading to muscle contraction. When the motor neuron releases the neurotransmitter acetylcholine, it binds to receptors on the plasma membrane of the muscle fibre (sarcolemma), initiating the muscle contraction. This is achieved by depolarisation of the muscle membrane (sarcolemma) and release of calcium ions by the sarcoplasmic reticulum. This junction plays a crucial role in motor control and movement. Watch **Video 1** to understand the functioning of the neuromuscular junction.



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2-Minute Neuroscience: Neuromuscular Junction



Video 1. Neuromuscular junction.

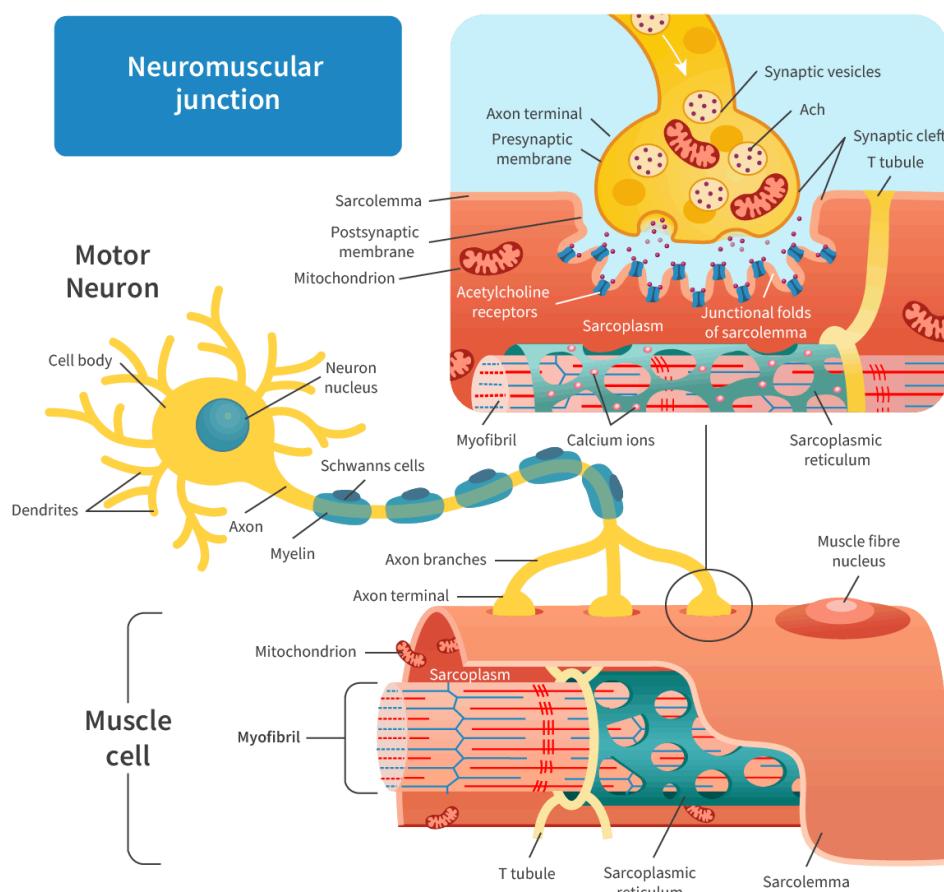


Figure 3. Neuromuscular junction

More information for figure 3

The diagram illustrates a neuromuscular junction highlighting the interaction between a motor neuron and muscle cell. In the top section, an inset shows the axon terminal connecting to muscle cell structures including the presynaptic membrane, synaptic cleft, and postsynaptic membrane, with labels pointing to synaptic vesicles, acetylcholine receptors,

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and junctional folds of the sarcolemma. The main section shows the motor neuron on the left with labeled parts such as the cell body, dendrites, axon, Schwann cells, and axon branches, leading to the axon terminal. The right side shows the muscle cell featuring mitochondrion, myofibril, T-tubule, sarcoplasmic reticulum, and sarcolemma, with arrows indicating calcium ions flowing into the muscle cell. This diagram provides a detailed view of the neuromuscular interface and key components involved in muscle activation.

[Generated by AI]

Neuroglandular junction

Neuroglandular junctions are synapses between neurons and glandular cells. They allow for the transmission of signals from neurons to glands, regulating their secretory activities. An example is the synapse between neurons in the hypothalamus and the cells of the pituitary gland, which controls the release of hormones.

Release of neurotransmitters from a presynaptic membrane

Neurotransmitters

Our brain and nervous system are able to communicate with such precision because of chemicals called neurotransmitters. Neurotransmitters are of two types: small molecules and large peptide molecules. The small molecules are synthesised locally in the axon terminal and stored in membrane-bound vesicles. The large peptide molecules are synthesised by ribosomes in the cell body and transported to the axon terminal in vesicles. These neurotransmitters are released from the presynaptic membrane into the synaptic cleft. It is a critical process that allows neurons to transmit signals to other neurons or effector cells, enabling our brains to process information, control our movements and regulate various bodily functions.

Acetylcholine (ACh) is the most common neurotransmitter found in our nervous systems. It is a small molecule neurotransmitter. Neurons that release ACh are called cholinergic neurons, whereas those that release norepinephrine (noradrenaline) are called adrenergic neurons. The main neurotransmitters in the body are acetylcholine, norepinephrine, GABA, serotonin, glutamate, glycine and dopamine.





Release of neurotransmitters

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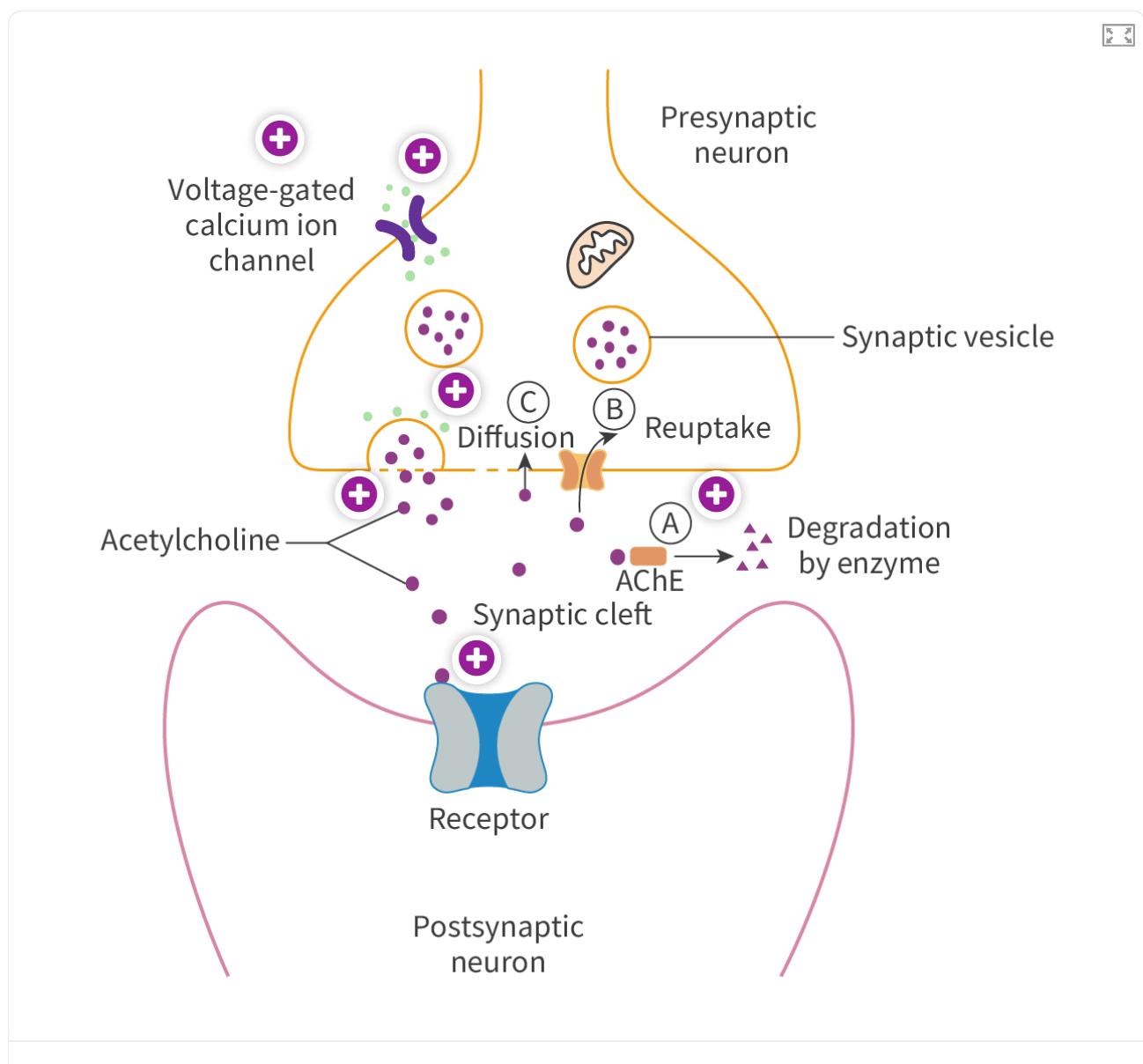
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An action potential travels down the axon of the presynaptic neuron and reaches the presynaptic terminal. The terminals are bulbs with neurotransmitters stored in the vesicles. The action potential causes the voltage-gated calcium ion channels to open and calcium ions flow into the presynaptic neuron from high to low concentration. The calcium ions induce exocytosis in the vesicles and they fuse with the presynaptic membrane to release the neurotransmitters into the synaptic cleft. The released neurotransmitters diffuse across the synaptic cleft. Neurotransmitters bind to receptors on the postsynaptic neuron or effector cell. Postsynaptic response is initiated, either excitatory or inhibitory.

Neurotransmitters are cleared from the synaptic cleft through reuptake, enzymatic degradation or diffusion (see **Interactive 1**).



Interactive 1. Release of Neurotransmitter from the Presynaptic Membrane and its Diffusion Across the Synapse.



Student view

This interactive diagram illustrates the step-by-step process of neurotransmitter release from a presynaptic neuron, synaptic transmission, and signal termination, with a focus on acetylcholine (ACh) as a key neurotransmitter. The visualization highlights the roles of voltage-gated calcium channels, vesicle fusion, and postsynaptic receptor activation, along with mechanisms for neurotransmitter clearance. The diagram uses labeled structures and dynamic hotspots to enhance understanding of synaptic communication.

The presynaptic neuron is placed at the top. An electrical signal (action potential) travels down the axon to the presynaptic terminal. The membrane potential change opens voltage-gated calcium ion channels.

Calcium ions flow into the neuron (down its concentration gradient). When an electrical signal reaches the presynaptic terminal, it depolarises the membrane. This opens voltage-gated calcium ion channels allowing calcium ions to flow into the neuron. With calcium ions influx, synaptic vesicles fuse with the membrane, releasing neurotransmitters into the synaptic cleft via diffusion.

ACh binding induces ion flow, propagating or inhibiting the signal. Lastly, termination of the signal involves enzymatic degradation, where acetylcholinesterase breaks down acetylcholine, and choline is recycled into the presynaptic neuron for ACh resynthesis and diffuses away from the cleft.

There are 6 Hotspots represented by plus signs at various places. Hotspot 1 near the voltage-gated ion-channel. Hotspot 2 is next to hotspot 1. Hotspot 3 near to the label diffusion. Hotspot 4 is next to the acetylcholine. Hotspot 5 next to the label degradation by enzyme. Hotspot 6 is near the receptor. Clicking on the hotspots reveals the process that takes place on the specific place.

The following items are revealed at respective hotspots:

Hotspot 1: An action potential arriving at the presynaptic terminal causes depolarisation of the membrane which causes voltage-gated calcium ion channels to open in the presynaptic terminal.

Hotspot 2: Calcium ions diffuse down their concentration gradient into the presynaptic terminal as the membrane is depolarized.

Hotspot 3: The influx of calcium triggers vesicles containing neurotransmitter (ACh) to move towards the presynaptic membrane.

Hotspot 4: Vesicles fuse with the presynaptic membrane, releasing their acetylcholine contents into the synaptic cleft.

Hotspot 5: Acetylcholine is removed from the synapse by three methods: (A) it is broken down by acetylcholine esterase in the synaptic cleft, (B) it is taken back into the presynaptic neuron through reuptake receptors and (C) it diffuses back into the presynaptic neuron.

This interactive clarifies: Signal initiation (How action potentials trigger calcium ions dependent ACh release), Synaptic transmission (Receptor binding and postsynaptic effects) and Signal termination (Enzymes and reuptake maintaining signaling precision).





Generation of an excitatory postsynaptic potential

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The neurotransmitters diffuse into the synaptic cleft from high concentration to low concentration. There are several receptors present on the postsynaptic membrane which readily receive the neurotransmitters. This binding allows sodium ion channels to open and there is an inflow of Na^+ into the postsynaptic neuron. This causes an imbalance of charge and the resting membrane potential is disturbed, causing depolarisation. This results in the generation of an excitatory postsynaptic potential (EPSP).

Hyperpolarisation leads to an inhibitory postsynaptic potential (IPSP) because the membrane potential becomes more negative and insufficient to generate an action potential. This is discussed in more detail in section C2.2.12–14 ([\(/study/app/bio/sid-422-cid-755105/book/inhibitory-and-excitatory-synaptic-transmission-hl-id-46649\)](#)).

Watch **Video 2** for an explanation of postsynaptic potentials.

Postsynaptic Potentials



Video 2. Postsynaptic potentials.

❖ Theory of Knowledge

How do we know that our current understanding of synaptic transmission, the release of neurotransmitters, and excitatory postsynaptic potential accurately represents the complex reality of neural communication, considering the limitations of human observation, interpretation and the ever-evolving nature of scientific knowledge?

Possible explorations for the above question may include:



Student view

- examining the role of empirical evidence makes it possible to analyse studies, experiments and research findings that contribute to our current understanding of

synaptic processes. Discussions may be based on the methodologies used, the validity of the data collected, and the reliability of the conclusions drawn

- investigating the influence of interpretation
- exploring the dynamic nature of scientific progress
- reflecting on the limitations of human observation
- considering the influence of cognitive biases and cultural perspectives.

Make some flashcards to improve your understanding of neurotransmission, in the activity below.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Thinking skills — Designing procedures and models
- **Time required to complete activity:** 45 minutes
- **Activity type:** Individual/pair activity

Your task

Working individually or in pairs you will make digital or paper **neurotransmitter flashcards** to review and reinforce your knowledge of the following concepts:

- synapses,
- neurotransmitters
- excitatory postsynaptic potentials.

Create flashcards following the example below:

- Write the concept on one side of the flashcard followed by a term that falls under the concept. For example:





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SYNAPSES

Presynaptic terminal

- On the flip side of the flash card, write the description/explanation of the term. For example:

SYNAPSES

The presynaptic terminal is at the end of the presynaptic neuron. It is the place where action potential (electrical signal) is converted into chemical signal (neurotransmitter release).

- After completion, share your flashcards with each other and use them for revising these concepts.

5 section questions ▼



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C2. Interaction and interdependence: Cells / C2.2 Neural signalling

Propagation of nerve impulses (HL)

C2.2.8: Depolarisation and repolarisation during action potentials (HL) C2.2.9: Propagation of an action potential along a nerve fibre (HL)

C2.2.10: Oscilloscope traces showing resting potentials and action potentials (HL) C2.2.11: Saltatory conduction in myelinated fibres (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Describe the process of depolarisation and repolarisation during an action potential.
- Evaluate the importance of action potential propagation in neural communication and information processing.
- Interpret and analyse oscilloscope traces of resting potentials and action potentials.
- Describe the process of saltatory conduction in myelinated fibres.

Nerve impulses power our every thought, movement and sensation. Have you ever wondered what mechanism drives some of our actions which are as quick as the blink of an eye? In this section you will discover the underlying mechanisms behind every action in our body.

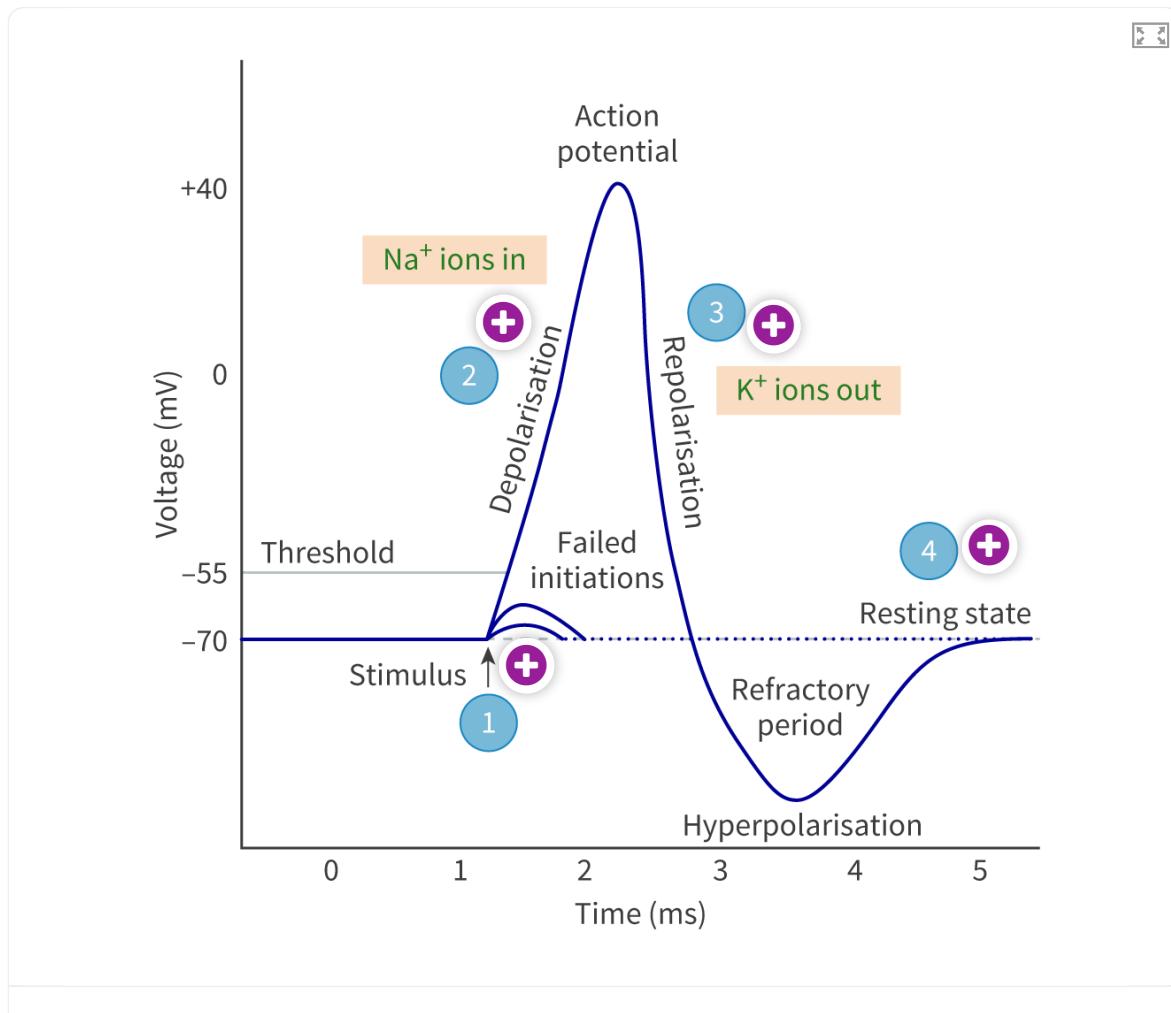
Depolarisation and repolarisation during action potentials

Changes in the membrane potential cause the opening of Na^+ ion channels which cause depolarisation due to influx of Na^+ ions. The resting membrane potential of -70 mV is disturbed and when it reaches approximately -50 mV , the voltage-gated sodium channels start to open. This potential is called the threshold potential. These voltage-gated sodium channels open only at the point where the threshold potential is reached. A flood of Na^+ ions is pushed inside the cell through the channel from high concentration to lower concentration. These Na^+ ions now freely move in the axon disturbing the membrane potential along their way. As a result many more Na^+ channels open up and more Na^+ ions enter the axon. This works as a positive feedback loop causing the resting membrane potential to drastically shift from -50 to $+40\text{ mV}$. This is called the depolarisation phase. The sodium channels remain open for about 1–2

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ms after which they close. Some Na^+ are also able to sneak out during this time through the leak channels. Leak channels, also referred to as leakage or passive channels, represent the most basic type of ion channel found in cells, essential for shaping the membrane's potential difference. Unlike other ion channels, leak channels are non-gated and remain continuously open, regardless of external stimuli. The perpetual openness enables ions to move across the membrane according to their respective electrochemical gradients, ensuring a steady flow of ions.

Click on the hotspots in **Interactive 1** to view the events of an action potential.



Interactive 1. Depolarisation and Repolarisation During Action Potential.

More information for interactive 1

An interactive graph illustrates the electrical changes in a neuron's membrane during an action potential, depicting the key phases of depolarization, repolarization, and hyperpolarization. The visualization highlights ion movements (Na^+ and K^+) and their role in generating and terminating neural signals. The graph uses labeled phases and hotspots to link electrical changes to underlying ion dynamics.

The Y-axis represents membrane potential (mV) from -80 mV to +40 mV. The resting potential is -70 mV (baseline), the threshold potential (minimum depolarization needed to trigger an action potential) is -55 mV, and the peak potential is +40 mV. The X-axis represents time (ms), showing the duration of each phase. The action potential is represented with a blue line that traces its rise and fall. The graph also marks two failed initiations.

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The phases of action potential are labeled 1 to 4 on the graph. Phase 1 is the stimulus phase, the voltage is -70 mV, and the neuron is polarized and stable (maintained by the Na^+/K^+ pump and leak channels) and ready to respond to stimuli. The hotspot reads, Any stimulus is received — sight, smell, sound, heat, cold.

Phase 2 is Depolarization (Na^+ influx). A stimulus opens voltage-gated Na^+ channels, allowing Na^+ influx. When the threshold potential -55 mV is reached, a rapid rise to +40 mV occurs. If the threshold is reached, a positive feedback loop triggers rapid depolarization. The hotspot reads, Depolarization — sodium channels open allowing inflow of sodium ions.

Phase 3 is repolarization (K^+ efflux). Voltage declines from +40 mV back toward resting potential, and K^+ flows out of the cell. Membrane potential returns toward a resting state. The hotspot reads, Repolarization — potassium channels open allowing potassium ions to move out.

Then, it undergoes hyperpolarization. K^+ channels close slowly, causing the voltage to briefly dip below resting potential (-80 mV), labeled Refractory period. Hyperpolarization prevents signal backflow, ensuring one-way transmission.

Phase 4 is the return to the Resting state. The hotspot reads, Resting membrane potential — sodium—potassium pump actively transports three sodium ions out and two potassium ions inside the cell. The voltage stabilizes and returns to -70 mV, and the cell returns to a resting state.

This interactivity clarifies how neurons generate signals via Na^+ -driven depolarization, terminate signals via K^+ -driven repolarization, and maintain precision through refractory periods and active ion transport.

The membrane immediately tries to restore the resting potential. In doing so, the voltage-gated K^+ channels are opened and K^+ ions flow out of the cell to maintain the balance. The K^+ ion channels also remain open for 1–2 ms allowing K^+ ions to move in and out freely. This causes rapid repolarisation of the membrane. Soon the Na^+/K^+ pump, which is activated by ATP, comes into action and starts active transport of Na^+ and K^+ across the membrane to restore the resting potential of -70 mV. Resting potential is reached and the Na^+/K^+ pump acts to swap the Na^+ and K^+ ions to their proper side of the cell membrane.

Watch **Video 1** for an explanation of depolarisation and repolarisation of the membrane.

Nerve Impulse Molecular Mechanism [3D Animation]



Student
view



Video 1. Depolarisation and repolarisation of neuron.

Causes of electrochemical gradient

The electrochemical gradient is caused due to the charge on the ions and their concentration in the extracellular and intracellular fluid. The charge on sodium and potassium ions is the same but, as discussed in the previous section, their movement through the Na^+/K^+ pump is unequal. For every three sodium ions that leave the cell, two potassium ions are taken in. These ions also move freely through the leak channels from high to low concentration. The concentration of sodium and potassium ions in the extracellular and intracellular fluid is given in **Table 1**. It is easy to note the direction of flow of these ions based on their concentrations.

Table 1. Concentration of sodium and potassium ions in the extracellular and intracellular fluid.

Symbol of ion	Extracellular conc (mM)	Intracellular conc (mM)
Na^+	145	15
K^+	4	150

Steps of an action potential

- Resting state: neuron at its resting membrane potential of -70 mV.
- Depolarisation: stimulus causes a brief influx of sodium ions, leading to depolarisation of the cell membrane.
- Threshold: membrane potential reaches a critical threshold, triggering an action potential.
- Rising phase: voltage-gated sodium channels open, allowing a rapid influx of sodium ions, further depolarising the cell.
- Falling phase: voltage-gated sodium channels close and voltage-gated potassium channels open, allowing potassium ions to exit the cell, repolarising the membrane.
- Hyperpolarisation: membrane potential briefly hyperpolarises as potassium channels continue to close.
- Resting potential: sodium and potassium ions return to their resting distribution through the action of the Na^+/K^+ pump, restoring the cell to its resting membrane potential.
- Refractory period: brief period where the neuron is unresponsive to another stimulus, ensuring one-way propagation of the action potential.





Propagation of an action potential

The propagation of an action potential is an interesting phenomenon to study. As discussed in [section C2.2.1–4 \(/study/app/bio/sid-422-cid-755105/book/neurons-and-nerve-impulses-id-46646/\)](#), the action potential travels as a wave from the axon hillock to the end terminals. It propagates in a sequential manner along the axon, with depolarisation and repolarisation occurring in each segment. At the site where the action potential begins, voltage-gated sodium channels open in response to the depolarisation of the membrane. This influx of sodium ions generates a local current that depolarises the adjacent region of the axon membrane. The diffusion of sodium ions both inside and outside an axon can cause the threshold potential to be reached. As the depolarisation spreads, adjacent voltage-gated sodium channels open in a domino-like fashion, creating a wave of depolarisation that travels along the axon. This process is often described as a ‘domino effect’ or a ‘wave of excitation’. The local currents generated by the influx of sodium ions in one region of the axon trigger the opening of voltage-gated sodium channels in the next region, propagating the action potential forward.

Meanwhile, behind the advancing wave of depolarisation, the previously depolarised regions undergo repolarisation and enter a refractory period during which they are temporarily unable to generate another action potential. This refractory period ensures that the action potential moves in a unidirectional manner along the axon.

In a myelinated neuron, the action potential jumps from one node of Ranvier to the next, increasing the speed of conduction (**Figure 1**). However, in an unmyelinated neuron, the action potential propagates continuously along the entire length of the axon.

The action potential continues to propagate along the entire length of the axon, ensuring the signal reaches its target destination.



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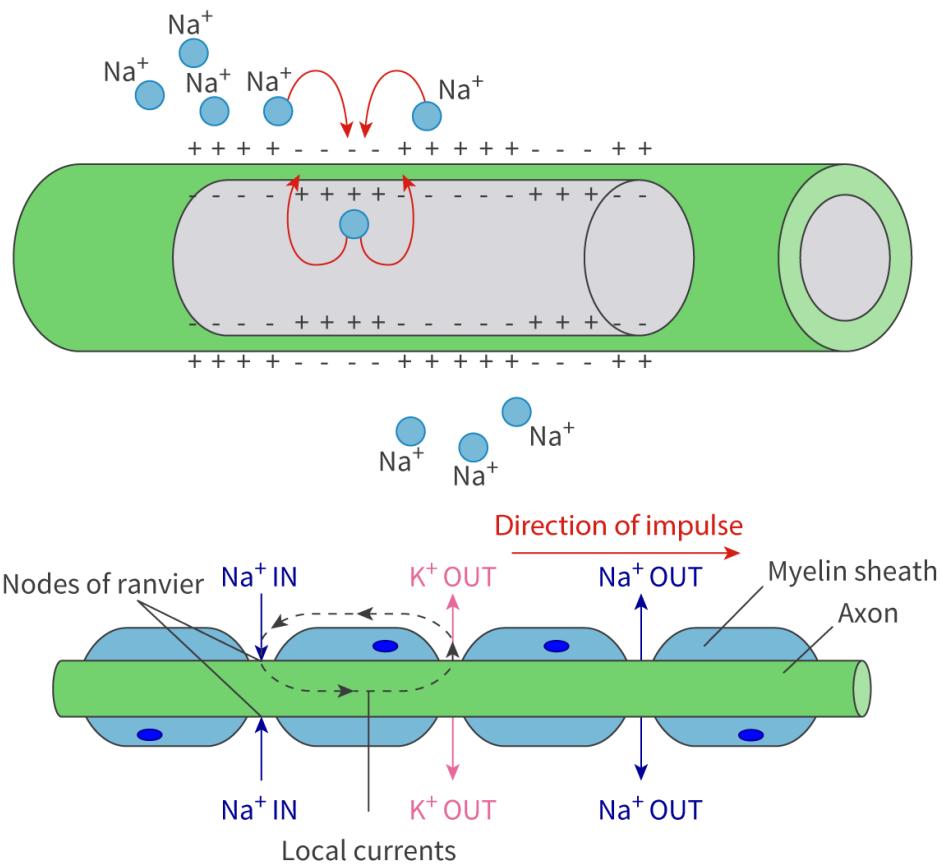


Figure 1. Generation of local currents at the nodes of Ranvier.

More information for figure 1

The image is a diagram showing the movement of ions across a myelinated axon, focusing on the nodes of Ranvier. The top section of the diagram includes sodium ions (Na^+) moving across a membrane with an indication of local currents, depicted by red arrows looping inside the membrane, and sodium ions moving in and out. The middle section labels the areas of interest: Nodes of Ranvier, myelin sheath, and axon.

In the lower section, the diagram illustrates the sequence of ion exchange during an action potential: sodium ions (Na^+) flow in, potassium ions (K^+) flow out, and the direction of the impulse is shown with a red arrow moving left to right. Blue and pink arrows and text show the movements of Na^+ and K^+ ions, respectively. This illustrates how action potentials are propagated along the axon via local currents at the nodes of Ranvier, allowing the nerve impulse to leap from node to node, a process known as saltatory conduction.

[Generated by AI]

Oscilloscope

An oscilloscope is a graph-displaying device that draws a graph of an electrical signal. This is a scientific instrument that can be used to measure the membrane potential across an axon membrane. It can be employed to record and display the voltage changes that occur during neuronal activity. The electrodes are placed on either side of the membrane and an oscilloscope trace is recorded. The graph shows how signals change over time. The horizontal axis represents time in milliseconds and the vertical axis represents membrane potential in millivolts.

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Figure 2 shows an oscilloscope trace depicting a stable resting potential, indicating a negative voltage (-70 mV) at rest. It also shows the difference of schematic versus real oscilloscope trace. The oscilloscope trace is in the form of a wave. The repeating patterns of the nerve impulse generate these waves. Mostly these are triangle waves. The number of times a cycle or pattern is repeated in a second is called the frequency. Voltage is the signal strength between two points of the conducting neuron.

A typical action potential lasts for approximately 3–5 ms and consists of four stages:

1. resting potential — resting phase
2. depolarisation — rising phase
3. repolarisation — falling phase
4. refractory period — recovery phase.

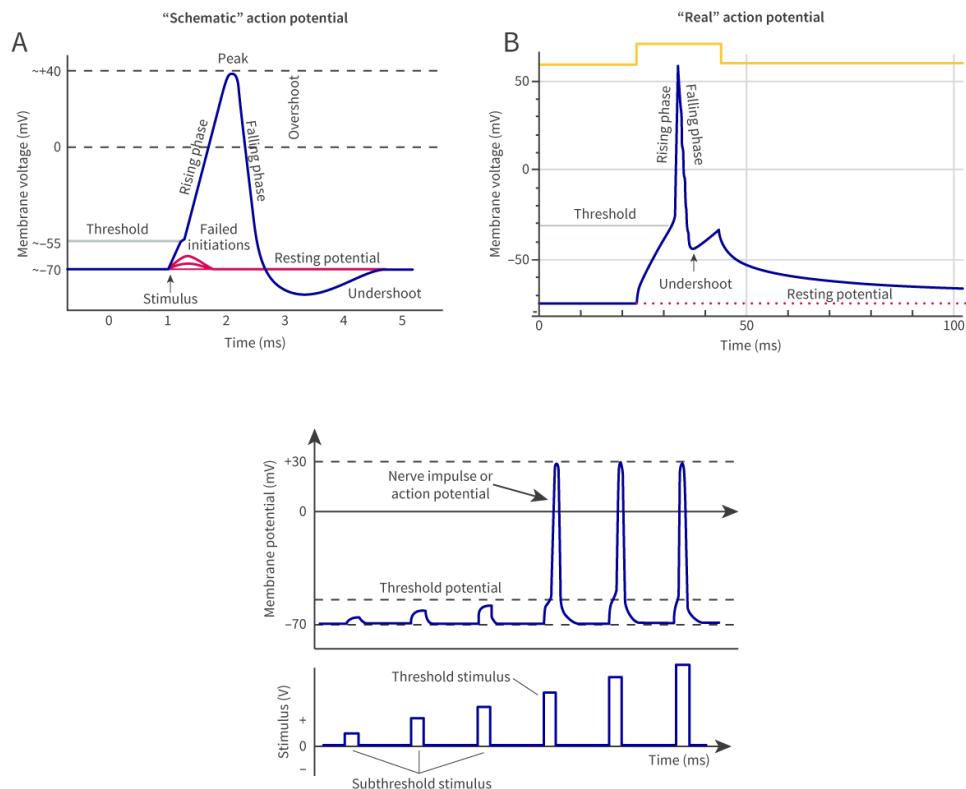


Figure 2. Oscilloscope trace.

🔗 More information for figure 2

The image contains multiple graphs illustrating action potentials seen on an oscilloscope trace.

1. Top Left (Graph A - Schematic Action Potential):
2. X-Axis: Time (ms), ranging from 0 to 5 ms.
3. Y-Axis: Membrane voltage (mV), ranging from -70 to +40 mV.
4. Key features: Rising phase due to stimulus, peak representing full depolarization, falling phase indicating repolarization, undershoot below the resting potential, which eventually returns to the resting level.
5. Labels indicate: Threshold, stimulus, rising/falling phases, resting potential, peak, and undershoot.

✖
 Student view



6. Top Right (Graph B - Real Action Potential):

7. X-Axis: Time (ms), ranging from 0 to 100 ms.
 8. Y-Axis: Membrane voltage (mV), showing values of -70, 0, and above.
 9. Key features: Indicate natural oscillation in membrane voltage, including repeated spikes.
 10. Includes labels such as resting potential, undershoot, and threshold.
11. Bottom Section:
12. Top Graph: Similar to Graph A, indicates multiple nerve impulses over time.
 13. Bottom Graph: Stimulus intensity over time (Y-axis: Stimulus, ranging from subthreshold to above-threshold levels)
 14. Both indicate correlation between stimulus provided and membrane voltage responses, emphasizing repetitive spike pattern relevant to action potential.

[Generated by AI]

During the resting phase the oscilloscope shows a straight line depicting the resting potential at -70 mV. If a stimulus triggers an action potential and it depolarises the membrane, then a spike is seen. The rising phase indicates depolarisation due to opening of the sodium channels while the falling phase indicates repolarisation when the sodium channels close and potassium channels open. Multiple oscilloscope traces can be observed, which shows the repetitive nature of action potentials.

Saltatory conduction

The conduction of nerve impulses in a neuron depends on the structure of the neuron. Essentially, the structure of a neuron is simple and it facilitates the propagation of nerve impulses. As discussed in [section C2.2.1–4 \(/study/app/bio/sid-422-cid-755105/book/neurons-and-nerve-impulses-id-46646/\)](#), axons with wider diameter and myelin sheath allow impulses to travel with greater speed compared with thinner and unmyelinated axons.

Sodium–potassium pumps and sodium and potassium channels are clustered at nodes of Ranvier. These exposed surfaces allow sodium and potassium ions to move across the membrane through the pumps and channels.

The covering of the myelin sheath provides electrical resistance to leakage of ions and prevents depolarisation of the membrane. Therefore, an action potential is propagated from node to node. The jumping of an impulse from node to node bypassing the myelinated regions until it reaches the axon terminal, is called [saltatory conduction](#). This occurs only in myelinated neurons. It is one of the main reasons for the high speed transmission of nerve impulse as the impulse does not have to travel along each part of the entire length of the axon.



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The depolarisation at one node of Ranvier generates local currents that quickly depolarise the next node, aiding in the rapid propagation of the action potential. Saltatory conduction helps in the conservation of energy of the neuron as fewer sodium and potassium ions need to be transported across the membrane to re-establish the resting membrane potential.

Watch **Video 2** to summarise the process of saltatory conduction.

Saltatory conduction - Conduction through Myelinated nerve fiber : P...



Video 2. Saltatory conduction.

❖ Theory of Knowledge

The oscilloscope as a technological tool has expanded our understanding of electrical signalling in neurons and other systems. Today, artificial intelligence is providing even greater scope of diagnosis and therapeutics in the field of neuroscience.

What are the benefits and limitations of using technology in scientific inquiry, and what is the potential impact of relying on technology for our knowledge acquisition?

Create a mindmap in the activity below to summarise your learning on action potentials.

Section

Student... (0/0)

Feedback



Print (/study/app/bio/sid-422-cid-

Assign



Activity

755105/book/synapse-neurotransmitters-and-propagation-of-nerve-impulses-id-46647/print/)



Student view

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Communication skills — Using digital media for communicating information

Section

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Mind Map

- 1. Use the website given below or an A4 size blank sheet to design a mindmap:
<https://www.biointeractive.org/classroom-resources/model-builder>
(<https://www.biointeractive.org/classroom-resources/model-builder>)
- 2. Write the main concept in the centre and use boxes, arrows and connectors to make links.
- 3. Ensure you include all the following terms you have come across in this subtopic:

Neurons
Action potentials
Synapses
Neurotransmitters
Membrane potential
Resting potential
Depolarisation
Repolarisation
Hyperpolarisation
Nerve impulses
Myelination
Saltatory conduction
Receptors
Excitatory neurotransmitters
Inhibitory neurotransmitters
Threshold potential
Nervous system

5 section questions

C2. Interaction and interdependence: Cells / C2.2 Neural signalling

Inhibitory and excitatory synaptic transmission (HL)

C2.2.12: Effects of exogenous chemicals on synaptic transmission (HL)

C2.2.13: Inhibitory neurotransmitters and generation of inhibitory postsynaptic potentials (HL)

C2.2.14: Excitatory and inhibitory neurotransmitters in a postsynaptic neuron (HL)

Student view



Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Describe the effects of exogenous chemicals on synaptic transmission, including drugs and toxins.
- Analyse the factors that affect the magnitude and duration of inhibitory postsynaptic potentials.
- Describe how multiple presynaptic neurons interact with all-or-nothing consequences in terms of postsynaptic depolarisation.

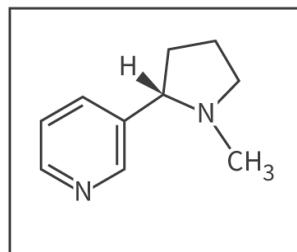
Have you noticed how many smokers often are addicted to smoking? This addiction is partly due to exogenous compounds, such as nicotine, present in tobacco smoke and e-cigarettes, which can interfere with neurotransmission in the brain. These compounds act as agonists for certain receptors, mimicking the effects of endogenous neurotransmitters and disrupting the normal balance of excitatory and inhibitory signals. As a result, neural communication pathways are altered, leading to addiction and physiological changes associated with smoking.

Understanding the impact of exogenous compounds on neurotransmission provides insights into addiction mechanisms and highlights the intricate interplay between chemicals and the nervous system.

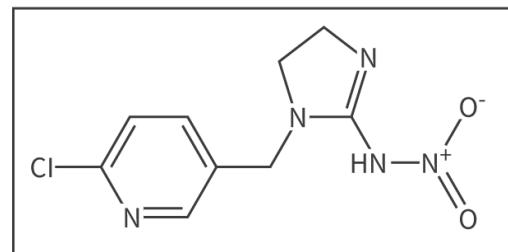
Exogenous chemicals and their effects on synaptic transmission

Around the world, bees and other pollinators are dying due to the harsh pesticides used by farmers. Many of these pesticides contain neonicotinoids (**Figure 1**).

Nicotine



Imidacloprid



**Figure 1.** Structural similarities of nicotine and neonicotinoids.

More information for figure 1

The image displays the chemical structures of nicotine and imidicloprid side by side. On the left is the structure of nicotine, which includes a pyridine ring connected to a pyrrolidine ring. The pyridine ring has a nitrogen atom and the pyrrolidine ring has nitrogen with an attached methyl group (CH_3) and a hydrogen atom. On the right is the structure of imidicloprid, which also contains a pyridine ring but with a chlorine atom attached. Imidicloprid's structure features additional complexity with an imidazole ring and a nitroimino group ($\text{N}-\text{HN}-\text{NO}_2$) attached, reflecting its classification as a neonicotinoid pesticide.

[Generated by AI]

Neonicotinoids are a class of chemicals that are similar to nicotine. They completely block synaptic transmission by binding to the acetylcholine receptors present in the cholinergic synapses of the CNS of insects. The binding is irreversible and the receptors remain blocked. Therefore, the acetylcholine molecules are unable to bind to their receptors and synaptic transmission is prevented. This causes the death of insects as a result of paralysis.

Neonicotinoids are widely used as pesticides. One of the most widely used neonicotinoids is imidacloprid. They are also found in insect sprays, seed treatments, soil drenches, tree injections and veterinary ointments to control fleas in dogs and cats. The widespread use of this toxic chemical causes harmful effects on non-pest species such as bees. However, its effects on humans is not prominent. This may be due to the presence of fewer cholinergic receptors in humans compared with insects.

You can learn more about how insects are endangered by pesticides [here](https://www.unr.edu/nevada-today/news/2022/noxious-nectar) (<https://www.unr.edu/nevada-today/news/2022/noxious-nectar>).

Action of cocaine on humans

The reward pathway of the brain is stimulated by certain types of foods, sex and many drugs of abuse such as cocaine. This pathway uses dopamine as the neurotransmitter. Cocaine is known to exhibit its effects by blocking removal of dopamine from the synapse by binding to the dopamine reuptake transporters (**Figure 2**). Dopamine continues to build up in the synaptic cleft causing the postsynaptic neuron to receive amplified signals. Cocaine has psychoactive and addictive effects on the brain as a result of these amplified signals. It causes dependency, that is, a desire to take the drug again. Continuous consumption of this exogenous drug causes the brain to create more dopamine receptors leading to more drug use. If consumption of cocaine is stopped or reduced at this point, this leads to excessive craving and depression.



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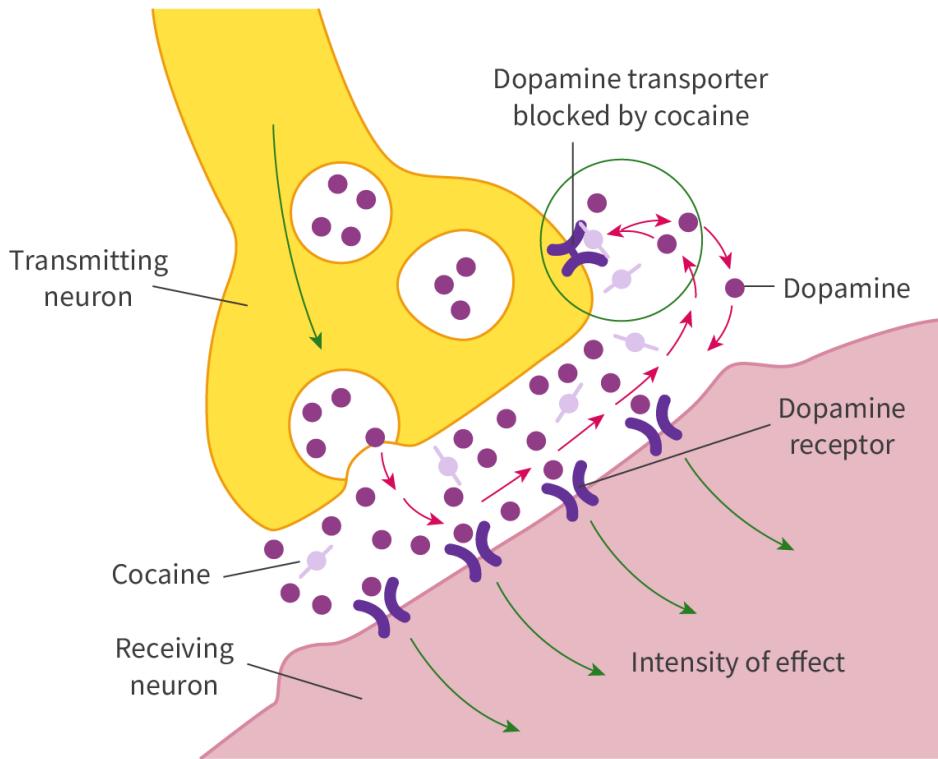


Figure 2. Effect of cocaine.

More information for figure 2

The diagram represents the effect of cocaine on a synaptic cleft between neurons. The image shows a transmitting neuron and a receiving neuron. Dopamine is released from the transmitting neuron into the synapse. Cocaine molecules block the dopamine transporters, preventing dopamine from being reabsorbed into the transmitting neuron. This results in an accumulation of dopamine in the synapse, leading to increased activation of dopamine receptors on the receiving neuron, which enhances the intensity of the effect.

[Generated by AI]

⌚ Creativity, activity, service

Strands: Creativity and Service

Learning outcomes:

- Demonstrate how to initiate and plan a CAS experience
- Demonstrate engagement with issues of global significance
- Recognise and consider the ethics of choices and action

One possible CAS activity could be to create an awareness campaign in your school against drug use by teenagers. This could be done by working in groups or pairs to create posters and slogans regarding the psychoactive and

addictive effects of cocaine on the nervous system, as described in the sections above.

Hyperpolarisation leading to inhibitory postsynaptic potentials

Not all neurotransmitters excite the postsynaptic neurons. Some neurotransmitters bind to the postsynaptic membrane and cause a more negative membrane potential. This makes it difficult for the postsynaptic action potential to reach the threshold.

Once a depolarisation wave is complete, the neuron has to reset itself in preparation to receive the next stimuli. Sometimes, the repolarisation is so strong that it even crosses the resting membrane potential and goes into a more negative value. Hyperpolarisation is a change in the membrane potential of a neuron, causing it to become more negative than its resting potential. It is typically associated with inhibitory potentials in neural signalling. It is caused by the opening of specific ion channels or the closing of others, leading to an efflux of positively charged ions (such as K^+) or an influx of negatively charged ions (such as Cl^-). This results in an increased polarisation of the cell membrane, making it more difficult for the neuron to generate an action potential and reducing its excitability.

Among other mechanisms that lead to hyperpolarisation, one involves activation of inhibitory neurotransmitters like GABA, which bind to receptors on the cell membrane and activate ion channels, allowing negatively charged ions to enter.

It is noteworthy that hyperpolarisation can also be influenced by the activation of ion pumps responsible for actively transporting ions out of the cell. For instance, the Na^+/K^+ ATPase pump operates by extruding three positively charged sodium ions for every two positively charged potassium ions it transports inward. This mechanism aids in establishing a more negative membrane potential.

Watch **Video 1** to learn more about the the effects of GABA and glutamate on the transmission of a nerve impulse.



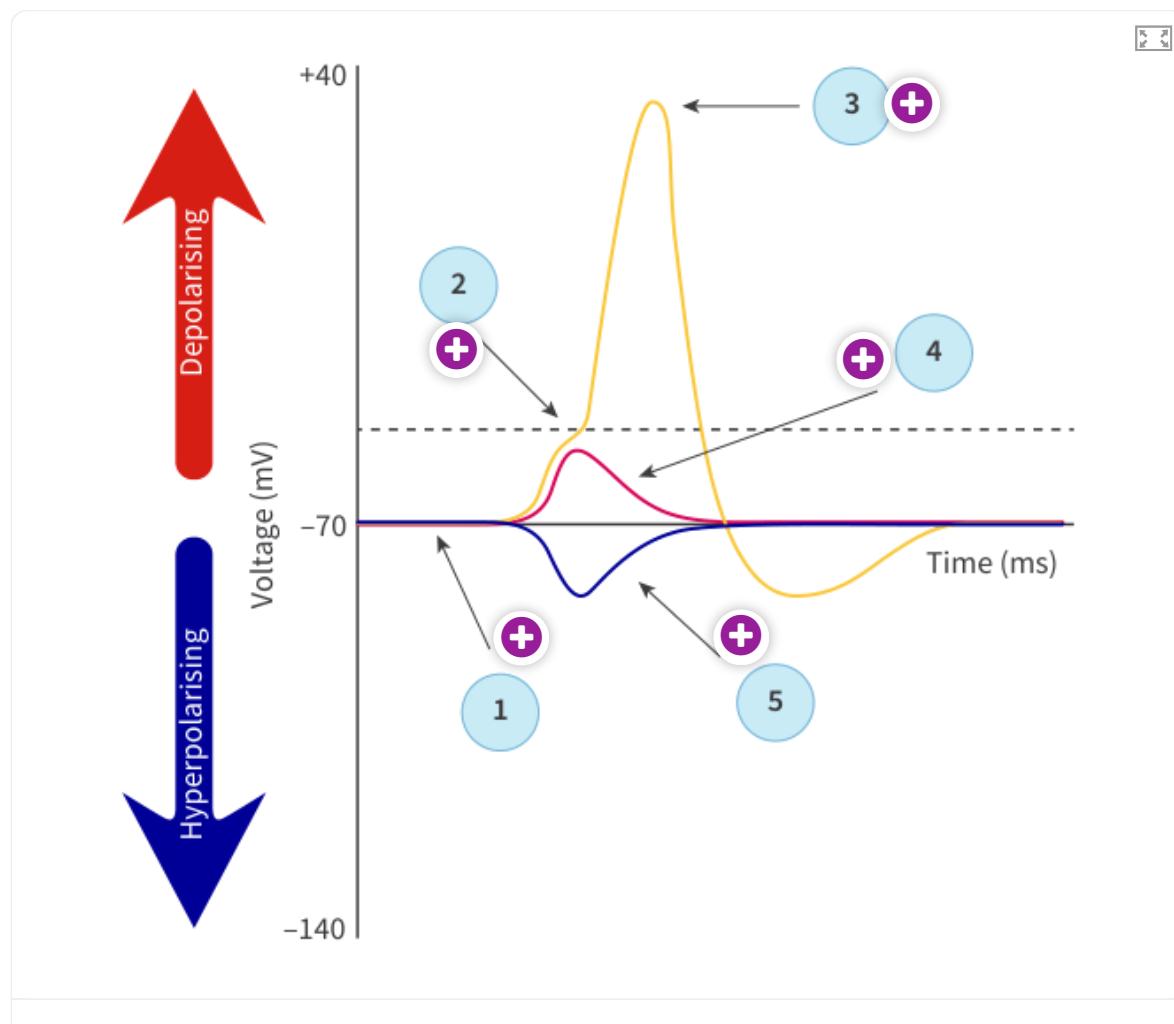
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Neuroscience Basics: GABA and Glutamate, Animation



Video 1. Effects of GABA and glutamate on neurotransmission.

Use **Interactive 1** to see how an inhibitory postsynaptic potential is shown on a graph.



Interactive 1. Inhibitory Postsynaptic Potential.

More information for interactive 1



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An interactive graph compares excitatory (depolarizing) and inhibitory (hyperpolarizing) changes in neuronal membrane potential, illustrating how inhibitory neurotransmitters like GABA suppress action potentials by increasing membrane potential. The graph uses numbered phases and hotspots to explain electrical changes to ion movements and neurotransmitter actions.

The Y-axis represents voltage (mV) with ranges from -140 mV (hyperpolarized) to +40 mV (depolarized). The rating potential baseline is at -70 mV and the threshold potential is -55 mV (which is the minimum depolarization needed to trigger an action potential). The X-axis represents time (ms) and tracks the duration of the action potential phases. Depolarising is represented with a red upward arrow and hyperpolarizing is depicted with a blue arrow pointing downward. Yellow/red lines depict depolarization (Excitatory postsynaptic potential or EPSP) and the blue line depicts hyperpolarizing (Inhibitory Postsynaptic potential or IPSP).

Numbered points 1-5 mark key stages. Point 1 is the Resting state (-70 mV). The neuron is polarized and ready to respond. The hotspot reads "Resting membrane potential".

A stimulus opens voltage-gated Na^+ channels, initiating depolarization. The hotspot at point 2 reads "Threshold of excitation".

Point 3 represents depolarization (peak at +40 mV). Na^+ influx reverses membrane polarity and results in Excitatory Postsynaptic Potential (EPSP). The hotspot reads "Action potential".

The hotspot at point 4 reads "Excitatory postsynaptic potential".

Inhibitory postsynaptic potential (IPSP) is reached when GABA or glycine opens Cl^- channels (influx) or K^+ channels (efflux). Membrane potential drops below resting state (e.g. -90 mV). The hotspot of 5 reads "Inhibitory postsynaptic potential".

The last phase is a return to resting potential as the Na^+/K^+ pump restores ion balance.

This interactive demonstrates Excitation vs. Inhibition (by contrasts between EPSPs (Na^+) and IPSPs (Cl^-/K^+)), Dynamic balance (how neurons integrate opposing signals for precise communication), and Therapeutic targets (Drugs modulating inhibition (e.g. anxiolytics, anticonvulsants)).

The full screen icon at the top right allows the users to view the illustration in zoomed-in version.

Summation

There can be more than one presynaptic neuron that forms a synapse with a single postsynaptic neuron. In most cases the impulse received from one excitatory presynaptic neuron is insufficient to generate an action potential. Summation is a combined effect of the excitatory and inhibitory stimuli that are received from a number of presynaptic neurons and transmitted to the axon hillock (a specialized part of the cell body (soma) of a neuron that connects to the axon) of the postsynaptic neuron. If it reaches the threshold potential then an action potential is generated which will be sufficient to depolarise the postsynaptic neuron. Use **Figure 3** to explore the process of summation.



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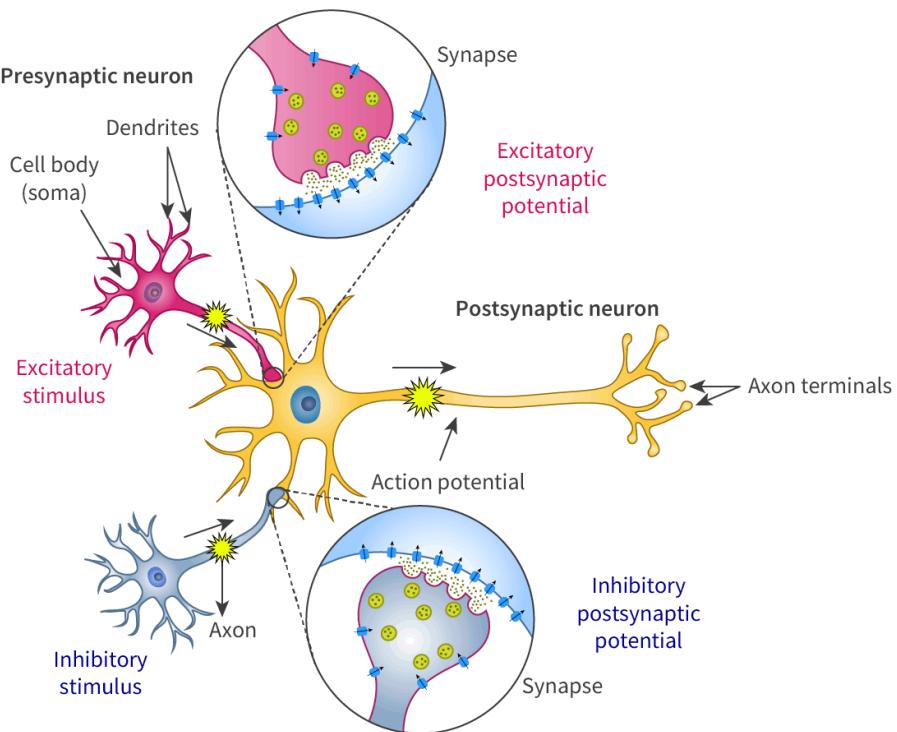


Figure 3. Summation effect of EPSP and IPSP.

More information for figure 3

The diagram illustrates the interaction between presynaptic and postsynaptic neurons focusing on excitatory and inhibitory stimuli. It contains labeled parts showing how signals are sent and received between different neurons. At the top left, a presynaptic neuron is shown with dendrites leading to a synapse in a small magnified circle, representing excitatory postsynaptic potential, labeled in pink. The central neuron, labeled as the postsynaptic neuron, indicates where action potential occurs. Arrows show the direction of the signal transmission from the excitation site through the axon to axon terminals. Below, an inhibitory stimulus is shown from another presynaptic neuron, leading to another synapse also magnified in a small circle, demonstrating the inhibitory postsynaptic potential, labeled in blue. The diagram highlights the summation process at the postsynaptic neuron, integrating signals to potentially generate an action potential.

[Generated by AI]

Neurons either transmit a signal from one end to the other or they do not transmit any signal at all. The all-or-nothing principle states that when the stimulus is generated, either all of it is transmitted in the form of action potential or nothing is transmitted at all (**Figure 4**). The stimulus is collected through various dendrites and all of this reaches the axon hillock. If the stimulus is strong enough, an action potential is generated. If the stimulus is weak, no further action is taken.



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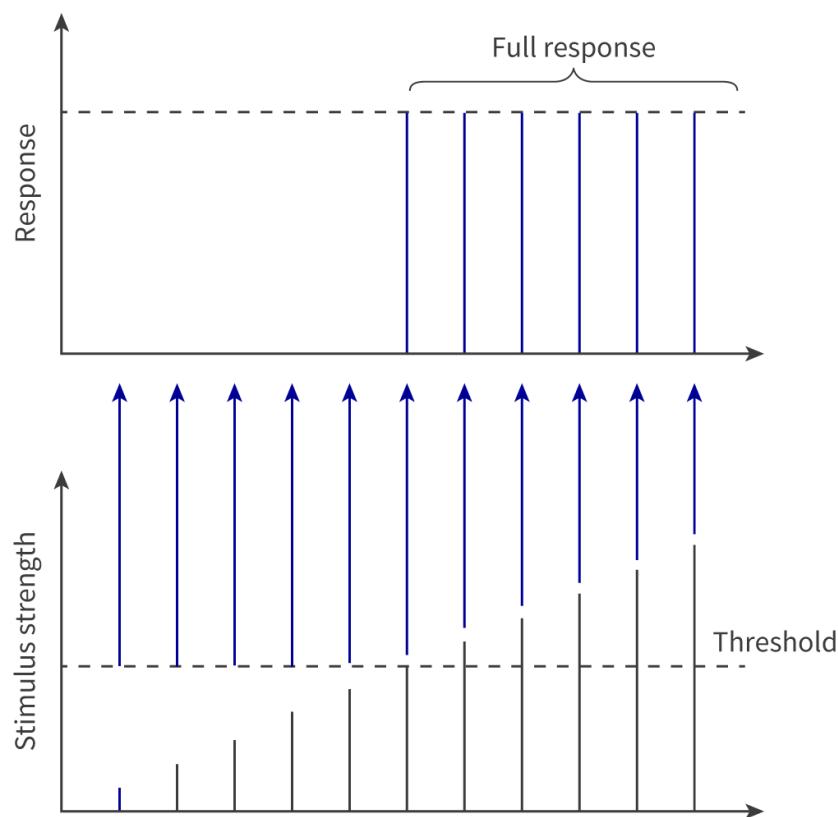


Figure 4. The all-or-nothing principle.

[More information for figure 4](#)

The image is a graph with two main sections representing the all-or-nothing principle in neurons. The top section shows the response of a neuron, while the bottom section illustrates stimulus strength. On the left, the Y-axis is labeled "Response" for the top graph and "Stimulus strength" for the bottom graph. The X-axis represents time or stimulus intensity for both sections.

In the bottom graph, several upward arrows of varying heights represent different stimulus strengths, with a dashed line labeled "Threshold" indicating the minimum stimulus strength required to generate an action potential. The arrows below this line do not trigger a response, while those above it result in a full response.

In the top graph, once the threshold is surpassed, a full response is triggered regardless of further increases in stimulus strength. This is symbolized by a series of consistent vertical lines above the dashed line, labeled "Full response." This demonstrates the principle that a neuron either completely responds or does not respond at all, depending on whether the stimulus surpasses the required threshold.

[Generated by AI]

Video 2 describes how the action potential is generated from the many stimuli that are received at the axon hillock.



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008 The All-or-None Action Potential



Video 2. The all-or-nothing action potential.

Try the activity to summarise your learning about the effects of exogenous chemicals on neurotransmission.

Activity

- **IB learner profile attribute:** Communicator
- **Approaches to learning:** Communication skills — Reflecting on the needs of the audience when creating engaging presentations
- **Time required to complete activity:** 45–50 minutes
- **Activity type:** Group activity

Your task

In small groups, research and create a brief presentation on a specific exogenous chemical (e.g. caffeine, alcohol, nicotine) known to affect synaptic transmission.

Your presentation should include details of how the chemical influences synaptic transmission, focusing on its effects on neurotransmitter release, receptor activation, or reuptake. Include real-life examples, such as the impact of caffeine on alertness or alcohol on coordination.

Present your findings to the other groups.



Student
view

5 section questions

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C2. Interaction and interdependence: Cells / C2.2 Neural signalling

Pain and consciousness (HL)

C2.2.15: Pain perception by neurons with free nerve endings in the skin (HL) C2.2.16: Consciousness as an emergent property (HL)

Higher level (HL)

Learning outcomes

Section

By the end of this section you should be able to:

Student... (0/0)

Feedback

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Assign

- Describe perception of pain.
755105/book/oscilloscope-and-saltatory-conduction-hl-id-46648/print/
- Explain that consciousness is another example of the consequences of interaction.

Have you ever wondered how our perception of pain varies from person to person, influenced by factors such as genetics, past experiences and psychological state? Our individual experiences shape the way we interpret and respond to pain, highlighting the complex nature of pain perception and its subjective nature. Why do some people feel more/less pain and why do some rare individuals feel no pain at all?

Ashlyn Blocker from Georgia feels no pain. How has this changed her life and what does it mean to feel pain? This video (<http://youtu.be/n6iOUW523BE>) presents a short case study of Ashlyn Blocker and her inability to feel any pain. Watch the video to understand why it is important for us to sense pain.

The skin is the largest organ of the human body and consists of three primary layers: the epidermis, dermis and hypodermis (**Figure 1**).

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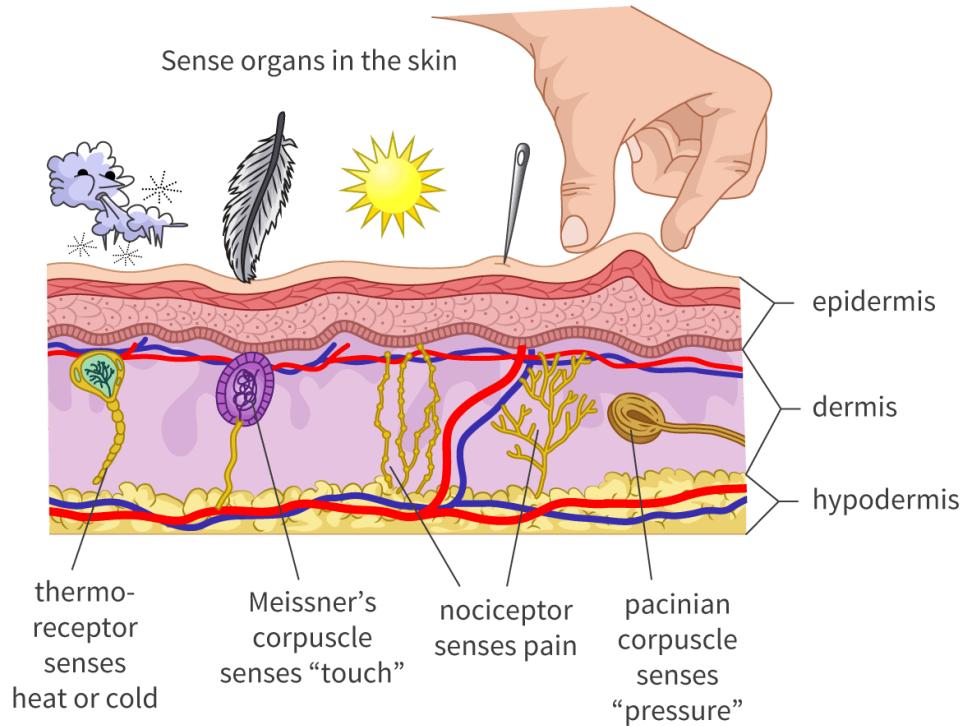


Figure 1. Skin longitudinal section showing different types of receptors.

More information for figure 1

The diagram illustrates a cross-section of human skin with three main layers labeled: epidermis, dermis, and hypodermis. Within these layers, various sensory receptors are shown, each linked to a specific stimulus. From left to right, thermoreceptors, Meissner's corpuscles, nociceptors, and Pacinian corpuscles are depicted. Thermoreceptors sense temperature changes such as heat or cold. Meissner's corpuscles are responsible for sensing light touch, displayed with a feather. Nociceptors are pain receptors, illustrated with a needle pricking the skin. Pacinian corpuscles sense pressure, shown with a symbol representing compression. The diagram highlights the intricate network of nerves and vascular structures within the dermal and hypodermal regions, vital for the sensory functions of the skin.

[Generated by AI]

The epidermis is the outermost layer and provides a protective barrier against external factors. It is composed of several layers of cells, including the stratum corneum, stratum granulosum, stratum spinosum and stratum basale. Within the epidermis, specialised cells called keratinocytes produce the protein keratin, which contributes to the skin's strength and waterproofing properties. Beneath the epidermis lies the dermis, which contains various structures, including blood vessels, hair follicles, sweat glands and sensory receptors. The dermis is rich in collagen and elastin fibres, giving the skin its elasticity and strength. It also houses different types of sensory receptors that detect various stimuli.



Student
view



Within the dermis, there are several types of receptors responsible for sensing different sensory information. These include:

- thermoreceptors: found in the dermis, they are responsible for detecting the change in temperature (hot and cold).
- Meissner's corpuscles: found in the superficial layers of the dermis, Meissner's corpuscles are responsible for detecting light touch and low-frequency vibrations.
- nociceptors: these nerve endings are responsible for detecting pain. 'Noci' in Latin means 'hurt'.
- Pacinian corpuscles: located in the deeper layers of the dermis, Pacinian corpuscles detect deep pressure and high-frequency vibrations.
- Ruffini endings: found throughout the dermis, Ruffini endings are involved in detecting skin stretch and contribute to the perception of continuous pressure.
- free nerve endings: these sensory receptors are spread throughout the skin and are responsible for detecting various sensations, including pain, temperature and itching.

These receptors play a crucial role in our ability to perceive and respond to different sensory stimuli, allowing us to experience touch, pressure, temperature and pain. Their distribution and sensitivity vary across different areas of the body, enabling us to have a diverse range of sensory experiences.

The perception of pain is influenced by various factors, including the individual's past experiences and emotional state. Pain can be subjective and varies from person to person. Additionally, chronic pain conditions may involve changes in the nervous system, leading to heightened sensitivity and altered pain perception.

The neurons with free nerve endings in the skin have specific ion channels that respond to various stimuli. These channels, such as those for positively charged ions, can be triggered by factors like high temperature, acid or certain chemicals like capsaicin (**Figure 2**). When these channels open, positively charged ions flow into the neuron, reaching the threshold potential necessary for generating nerve impulses. These impulses then propagate along the nerve fibres to the brain, where pain is perceived and processed. This mechanism allows our body to detect and respond to potentially harmful or painful stimuli, enabling us to take appropriate protective actions.



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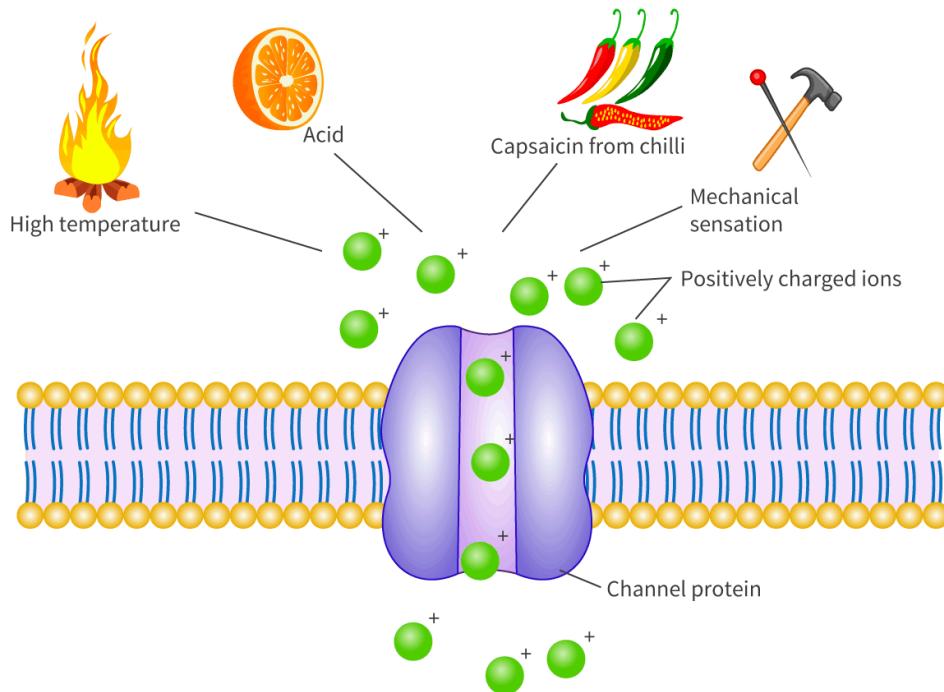


Figure 2. Positively charged ions associated with nerve endings in the skin.

More information for figure 2

This diagram illustrates how a channel protein in a cell membrane allows positively charged ions to flow into the cell. The membrane is depicted with a bilayer structure, represented by yellow and blue lines. A purple channel protein spans the membrane, with green spheres labeled as positively charged ions entering the channel. Various stimuli that trigger this ion flow are represented around the channel: high temperature (illustrated with a flame), acid (depicted with an orange slice), capsaicin from chilli (shown with chilli peppers), mechanical sensation (symbolized by a hammer), and positively charged ions themselves. Each of these stimuli has an arrow pointing towards the channel, indicating its role in activating the ion flow. This process represents how nerve endings in the skin respond to different stimuli by initiating a nerve impulse.

[Generated by AI]

Capsaicin is a compound found in chillies. The receptors that can respond to capsaicin are called TRPV1 (transmembrane receptor protein V1), and these also respond to temperatures greater than 43 °C. While eating jalapenos or other chillies, the capsaicin molecules bind to the TRPV1 receptors in our mouth which sends neural signals to our brain and immediately we come to know that we are eating something very spicy.

You may wonder why animals and humans are affected by capsaicin in chilli peppers but birds such as parrots love to eat them. This is because of the variant of the TRPV1 protein present in the birds, which responds to high temperature but not to capsaicin.



Student
view



Consciousness

Imagine a realm of our mind where thoughts, perceptions, and self-awareness are intertwined. Consciousness is everything that we experience. It brings awareness about ourselves and our surroundings. It is possible to be aware of many things at the same time. While the precise nature of consciousness remains a mystery, it is widely accepted that it arises from the collective activity and connectivity of countless neurons throughout the brain.

The brain is composed of the cerebrum, cerebellum and brainstem. The cerebrum is the largest part of the brain consisting of right and left hemispheres (see section C3.1.6–8 ([\(/study/app/bio/sid-422-cid-755105/book/sensory-and-motor-neuronsome-id-44822/\)](#))). Each hemisphere controls the opposite side of the body. The cerebrum is connected to the spinal cord by the brainstem. It contains a system of nerve cells and fibres (called the reticular activating system) located deep within the upper part of the brainstem. This system controls levels of consciousness and alertness.

Conscious awareness is associated with the cerebral cortex of the brain. Each experience that we have corresponds to a neural activity in the posterior part of the brain comprising the parietal, occipital and temporal lobes.

Watch **Video 1** to understand more about consciousness.

What is consciousness? - Michael S. A. Graziano



Video 1. The origin of consciousness.

The brain's neural networks, composed of densely interconnected neurons, engage in complex electrical and chemical signalling that underlies various cognitive processes, sensory perceptions, emotions and self-reflection. Consciousness is not attributed to any singular neuron or localised region; rather, it is a complex emergent property arising from the collective interplay of these interconnected neural networks.

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We can have different levels of consciousness at different times of the day. Sleep is a form of partial consciousness. Some sedatives, psychedelic drugs and anaesthetics reduce our consciousness (**Figure 3**). If taken in high doses they cause unconsciousness.

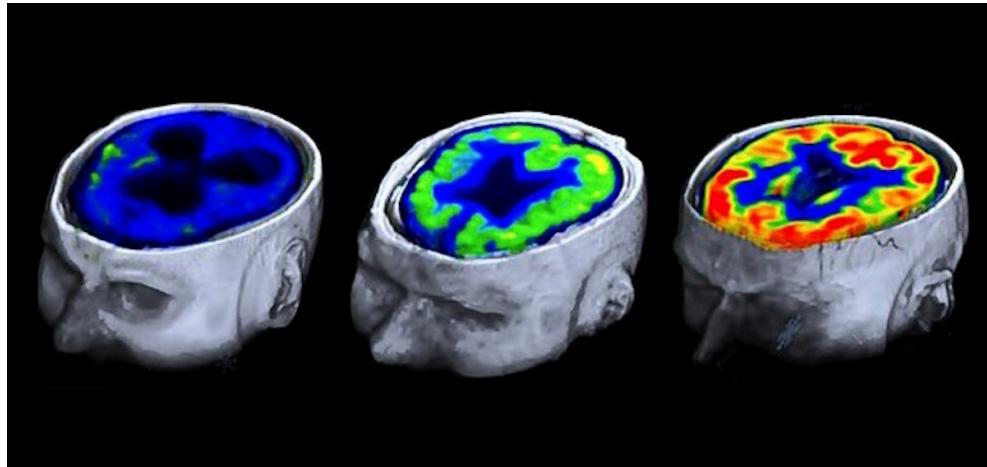


Figure 3. Fluorodeoxyglucose-PET images obtained from study subjects at different levels of consciousness induced by anaesthesia. The cerebral glucose consumption maps are shown as a colour map with red being the highest rate and blue the lowest. The rate of cerebral glucose consumption is observed to drop near uniformly across the cortex from awake to moderate and deep anaesthesia.

Source: "PET-SCAN BrainDeath - Coma" https://commons.wikimedia.org/wiki/File:PET-SCAN_BrainDeath_-_Coma.jpg" by Ericneuro is licensed under CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0/deed.en>

More information for figure 3

The image shows three distinct PET brain scans lined up horizontally, representing different levels of cerebral glucose consumption as indicated by a color map. Each brain is presented in a top-down view, highlighting activity. The brain on the left shows mostly blue areas, representing low activity, suggesting deep anesthesia. The middle image shows more green and slightly blue areas, indicating moderate activity, corresponding to moderate anesthesia. The rightmost image is filled with red and yellow hues, suggesting the highest level of brain activity, correlating with an awake state. The color gradient from blue to red represents increasing rates of glucose consumption: blue (lowest) to red (highest).

[Generated by AI]

Through technologies like fMRI (functional magnetic resonance imaging) and PET (positron emission tomography), we gain invaluable glimpses into the neural underpinnings of consciousness, unravelling the intricate workings of the brain and shedding light on the complex nature of our conscious experience. However, it is difficult to pinpoint the exact location in the brain from where consciousness is controlled. It can be said that it emerges from the interaction of neurons in the brain.

Student view



Thus, it is an emergent property because it is not governed by an individual component alone. It exists due to the contribution of many components which work at different degrees.

⊕ International Mindedness

Ability to understand different cultural contexts and viewpoints.

Cross-cultural studies of consciousness provide a rich opportunity to explore how different cultures have developed unique techniques and perspectives to understand and alter their conscious experiences. For instance, when exploring the realm of meditation, we come across many practices that have originated from diverse cultural and spiritual traditions worldwide. In India, the ancient techniques of Vipassana and Transcendental Meditation have stood the test of time, with practitioners diligently pursuing these methods for centuries in their quest for elevated levels of awareness and profound inner tranquillity. These practices reflect the profound wisdom and heritage embedded within the cultural fabric of India, where the pursuit of heightened consciousness is regarded as a pathway to deep personal growth and serenity. Similarly, Zen meditation from Japan emphasises mindfulness and deep concentration to achieve clarity of mind.

Certain cultures and societies practice extraordinary rituals or feats where individuals appear to transcend the experience of pain. Some examples are given below.

- Firewalking: this is a traditional practice found in various cultures, including parts of South Asia, Africa and Polynesia. Participants walk barefoot over hot coals or burning embers without apparent injury. This practice is often associated with religious or spiritual ceremonies and is believed to symbolise purification, strength or the testing of faith.
- Ritual piercing and body suspension: some cultures, such as certain indigenous tribes and communities, engage in ritual piercings and body suspensions as part of religious or cultural practices. Participants undergo body piercings, sometimes with large hooks or skewers, and are suspended by those hooks from elevated structures. Despite the apparent physical trauma, participants often report altered states of consciousness and diminished perception of pain.

♀ Creativity, activity, service

Strands: Creativity, Activity and Service



Learning outcomes:



- Identify own strengths and develop areas for growth
- Demonstrate how to initiate and plan a CAS experience
- Show commitment to, and perseverance in CAS experiences
- Demonstrate the skills and recognise the benefits of working collaboratively
- Demonstrate engagement with issues of global significance

Mental wellbeing is of prime importance for every individual. Consider some ways to positively impact your own mental health and wellbeing and that of others. For example:

- Engage in creative pursuits such as art, music, writing or other forms of self-expression that can promote self-awareness, emotional expression and personal growth. These creative activities will allow you to explore your thoughts and emotions, channel your energy and find outlets for self-discovery.
- Take the 30-day yoga challenge. View the poster for the different 'asanas' (poses).



More information

The image displays a 'Yoga: 30 day challenge' chart with different poses outlined for various days. Each pose is labeled with a number and name, and the chart includes instructions and day indicators when certain poses are off. The instructions specify holding each pose for 30 seconds on specific days. Poses are categorized with color codes for different skill levels:

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blue for beginners, pink for beginners and pregnant women, and yellow for intermediate practitioners. The chart includes images of each yoga pose with their names and a brief description, such as 'Sukhasana (easy)' or 'Vrksasana (tree).' There are pauses indicated on specific days to allow rest or different activities like walking or biking.

[Generated by AI]

- Collaboratively organise a mental wellbeing workshop for the students and teachers of your school. You may wish to use some of the following ideas:
 - Conduct a yoga and meditation session.
 - Arrange an expert talk on the importance of mental wellbeing.
 - Use painting/colouring for stress relief.

Try the activity to research pain perception in different cultures.

Activity

Section

Student... (0/0)

 Feedback

 Print (/study/app/bio/sid-422-cid-

755105/book/inhibitory-and-excitatory-synaptic-transmission-hl-id-46649/print/) 

- **IB learner profile attribute: Inquirer**
- **Approaches to learning:** Research skills — Comparing, contrasting and validating information
- **Time required to complete activity:** 45—50 minutes
- **Activity type:** Pair activity

Using ideas about pain perception in different cultural contexts touched on in the International Mindedness box above, work in pairs to research a cultural practice associated with pain perception. Share your findings with the class.

5 section questions

C2. Interaction and interdependence: Cells / C2.2 Neural signalling

Summary and key terms



Student view

- Neurons are cells within the nervous system that carry electrical impulses.

- Resting potential is established through ion pumping to maintain concentration gradients of sodium and potassium ions across the plasma membrane.
- Nerve impulses, known as action potentials, propagate along nerve fibres for rapid communication and their speed can vary based on factors like axon diameter and myelination.
- Synapses serve as junctions between neurons and effector cells, enabling communication through neurotransmitters.
- Calcium ions increase the permeability of the presynaptic membrane causing neurotransmitters to be released in the synaptic cleft.
- Excitatory postsynaptic potentials (EPSPs) result from the binding of neurotransmitters, leading to depolarisation of the postsynaptic membrane.

Higher level (HL)

- Action potentials involve depolarisation and repolarisation, enabling the transmission of signals.
- Propagation of action potentials along nerve fibres occurs through local currents generated by the diffusion of Na^+ ions in and out of the axon, resulting in saltatory conduction in myelinated fibres for faster impulse transmission.
- Oscilloscope records impulse transmission and oscilloscope traces visualise resting potentials and action potentials, aiding in their analysis.
- Perception of pain involves neurons with free nerve endings in the skin.
- Consciousness emerges from the interaction of individual neurons in the brain, influencing our self-awareness and subjective experiences.





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Key terms

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. The rapid electrical signal that travels along a nerve fibre is an
2. A is a junction between neurons or between a neuron and an effector cell.
3. Chemical messengers that transmit signals between neurons are called
4. Something that stimulates or enhances the likelihood of an action potential is , whereas something that reduces or inhibits the likelihood of an action potential is
5. The difference in electrical charge between the inside and outside of a neuron's membrane is known as the
6. [HL] is a shift in membrane potential toward a more positive state, whereas is the return of the membrane potential to its resting state after depolarisation.
7. [HL] The rapid conduction of an action potential in myelinated nerve fibres is known as
8. [HL] is the process by which an action potential travels along a nerve fibre or axon.

neurotransmitters saltatory conduction inhibitory synapse
 depolarisation nerve impulse propagation membrane potential
 action potential excitatory repolarisation

Check

Interactive 1. Neural Communication and Action Potential.

C2. Interaction and interdependence: Cells / C2.2 Neural signalling

Checklist

Student view

Section

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What you should know

After studying this subtopic you should be able to:

- Describe the structure of a neuron having a cell body with elongated nerve fibres of varying length projecting from it.
- Describe the axon as a long single fibre helping in the conduction of electrical impulse and dendrites as multiple shorter fibres receiving and processing incoming signals.
- Describe how energy from ATP drives the sodium-potassium pump during resting potential.
- Explain the concept of membrane polarisation and membrane potential and the reasons for resting potential being negative.
- Compare the speed in myelinated and non-myelinated fibres.
- Explain the role of synapses in communication between neurons.
- Compare and contrast the mechanisms of neurotransmitter release in different types of synapses.
- Analyse the factors that affect the magnitude and duration of EPSPs.

Higher level (HL)

Section

- Describe the process of depolarisation and repolarisation during an action potential.
- Evaluate the importance of action potential propagation in neural communication and information processing.
- Interpret and analyse oscilloscope traces of resting potentials and action potentials.

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Assign

755105/book/summary-and-key-terms-id-46643/print/

- Describe the process of saltatory conduction in myelinated fibres.
- Describe the effects of exogenous chemicals on synaptic transmission, including drugs and toxins.
- Analyse the factors that affect the magnitude and duration of inhibitory postsynaptic potentials.
- Describe how multiple presynaptic neurons interact with all-or-nothing consequences in terms of postsynaptic depolarisation.
- Describe perception of pain.
- Explain that consciousness is another example of the consequences of interaction.



Student
view

C2. Interaction and interdependence: Cells / C2.2 Neural signalling

Investigation

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Section

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Assign

- **IB learner profile attribute:** Balanced
- **Approaches to learning:** Thinking skills – Providing a reasoned argument to support conclusions
- **Tool 3:** Mathematics – Processing uncertainties
- **Time required to complete activity:** 45–50 minutes
- **Activity type:** Individual activity

Your task

You have studied the effect of axon diameter on the speed of propagation. Use a variety of sources to gather information regarding axon diameter, myelination and speed of propagation in humans, squids, dogs and cats. Compare the data to understand the reason for the difference of speed of propagation in different animals.

Instructions

- Use a spreadsheet to create data tables and record your findings.
- Process the data by applying the correlation coefficient and coefficient of determination (R^2) to evaluate the degree to which variation in the independent variable explains the variation in the dependent variable. Refer back to the worked example in [section C2.2.1–4](#) (/study/app/bio/sid-422-cid-755105/book/neurons-and-nerve-impulses-id-46646/) and watch **Video 1** to understand how to calculate correlation coefficient and coefficient of determination.
- Make a correlation between:
 - the conduction speed of nerve impulse and the size of animal
 - the conduction speed of nerve impulse and the diameter of axon
 - the conduction speed of nerve impulse and myelination.
- Plot the data using appropriate graphs.
- Analyse and evaluate the observations.
- Present a valid conclusion.
- Suggest further areas of improvement/research.



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The Correlation Coefficient - Explained in Three Steps



Video 1. The correlation coefficient.

C2. Interaction and interdependence: Cells / C2.2 Neural signalling

Reflection

Section

Student... (0/0)

Feedback



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755105/book/reflection-id-46885/print/)

Assign

ⓘ Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.



Reflection

Now that you've completed this subtopic, let's come back to the guiding questions introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43541/):

- How are electrical signals generated and moved within neurons?
- How can neurons interact with other cells?

✖
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With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

⚠ Once you submit your response, you won't be able to edit it.

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Rate subtopic C2.2 Neural signalling

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