3 NEURONS COMMUNICATE QUICKLY

UNIT 3 CONTENT

SCIENCE INQUIRY SKILLS

- identify, research and construct questions for investigation; propose hypotheses; and predict possible outcomes
- design investigations, including the procedure(s) to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics, including animal ethics
- conduct investigations, including the collection of data related to homeostasis and the use of models of disease transmission, safely, competently and methodically for the collection of valid and reliable data
- represent data in meaningful and useful ways, including the use of mean, median, range and probability; organise and analyse data to identify trends, patterns and relationships; discuss the ways in which measurement error, instrumental accuracy, the nature of the procedure and the sample size may influence uncertainty and limitations in data; and select, synthesise and use evidence to make and justify conclusions
- interpret a range of scientific and media texts, and evaluate models, processes, claims and conclusions by considering the quality of available evidence, and use reasoning to construct scientific arguments
- select, use and/or construct appropriate representations, including diagrams, models and flow charts, to communicate conceptual understanding, solve problems and make predictions
- communicate to specific audiences, and for specific purposes, using appropriate language, nomenclature, genres and modes, including scientific reports

SCIENCE UNDERSTANDING

Central and peripheral nervous system

- transmission of nerve impulses is via electro-chemical changes that occur at the generation of the impulse, the propagation of the impulse along the nerve fibre, and the transfer of the impulse across the synapse
- different receptors detect changes in the internal and external environments, including thermoreceptors, osmoreceptors, chemoreceptors and receptors for touch and pain
- the reflex arc is composed of specially structured neurons, including sensory, interneuron and motor neurons, to transmit information from the receptor to the effector to respond rapidly to stimuli
- the nervous and endocrine systems work together to co-ordinate functions of all body systems, but differ in terms of:
  - speed of action
  - duration of action
  - nature and transmission of the message
  - specificity of message

Source: School Curriculum and Standards Authority, Government of Western Australia

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The nervous system is one of the body's two communications systems. Along with the endocrine system studied in Chapter 2, it coordinates all our voluntary and involuntary actions. The nervous system receives and processes information from sense organs and brings about responses to the information received.

3.1 NERVE CELLS

Nerve cells, or **neurons**, are the basic structural and functional units of the whole nervous system. They are highly specialised cells perfectly designed for rapid communication of messages in the body.

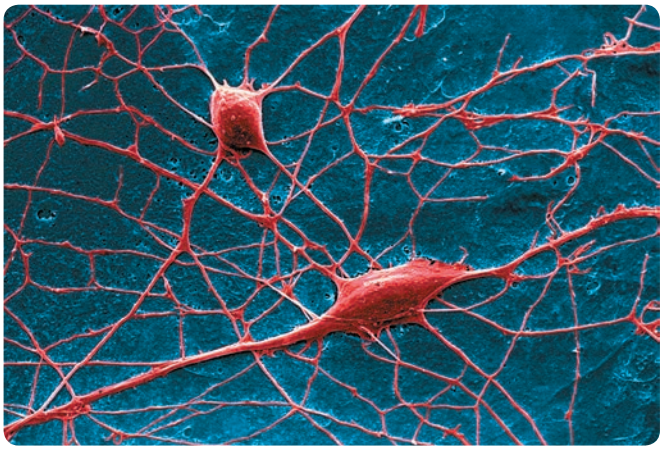

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FIGURE 3.1 A coloured scanning electron micrograph of two nerve cells from the brain

Structure of neurons

Neurons vary in size and shape, but they all consist of a cell body and two different types of extension from the cell – the dendrites and the axon.

Cell body

The **cell body** is the part of the neuron that contains the nucleus and is responsible for controlling the functioning of the cell. Around the nucleus is cytoplasm containing the organelles that are found in most cells: mitochondria, endoplasmic reticulum, ribosomes and Golgi apparatus.

Dendrites

Dendrites are usually fairly short extensions of the cytoplasm of the cell body. They are often highly branched and they carry messages, or nerve impulses, into the cell body.

Axon

The **axon** is often a single, long extension of the cytoplasm. It usually carries nerve impulses away from the cell body. Although usually longer than the dendrites, the length of axons varies enormously. Those in the brain may be only a few millimetres long, while the axons that run from the spinal cord to the foot may be a metre or so in length.

At its end, the axon divides into many small branches. Each of these branches terminates at the **axon terminal**.

Myelin sheath

Most axons are covered with a layer of fatty material called the **myelin sheath**. The term **nerve fibre** is used for any long extension of a nerve cell, but usually refers to an axon. Those that have a myelin sheath are called **myelinated fibres** and those that do not are said to be **unmyelinated**.

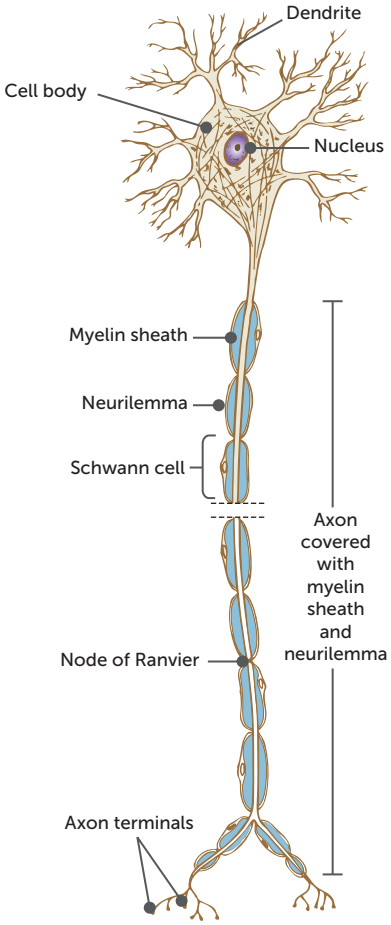

FIGURE 3.2 Structure of a typical neuron with a myelinated axon

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Outside the brain and spinal cord, the myelin sheath is formed by special cells called **Schwann cells**, which wrap around the axon. At intervals along the axon are gaps in the myelin sheath, called **nodes of Ranvier**.

The myelin sheath has three important functions:

- It acts as an insulator.
- It protects the axon from damage.
- It speeds up the movement of nerve impulses along the axon.

The outermost coil of the Schwann cell forms a structure called the **neurilemma** around the myelin sheath. This structure helps in the repair of injured fibres.

In the brain and spinal cord, the myelin sheath is produced by oligodendrocytes. The fatty nature of the myelin means that the areas containing myelinated fibres appear white and are called white matter. The areas made up of cell bodies and unmyelinated fibres are called grey matter due to their grey colour.

Activity 3.1
Creating a model of a neuron

Key concept

Nerve cells, called neurons, are composed of a cell body, axon and dendrites.

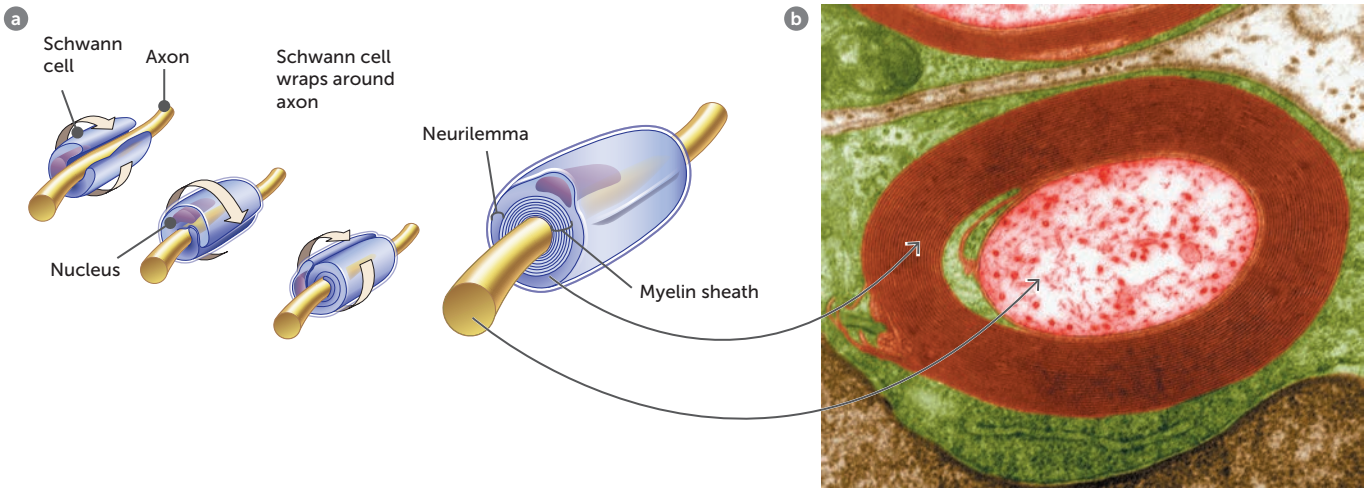

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FIGURE 3.3 a Schwann cells form the sheath of a myelinated axon by wrapping around the axon. **b** Coloured transmission electron micrograph of a transverse section of a myelinated axon. The myelin sheath (brown) is formed when Schwann cells wrap around the axon and deposit layers of myelin between each coil. The outermost layer (green) is the cytoplasm of the Schwann cell – the neurilemma

Synapses

Nerve impulses have to be passed from neuron to neuron. This usually occurs where the axon terminal of one neuron joins with a dendrite or the cell body of another. This junction is called a **synapse**.

The neurons do not actually physically touch at the synapse; instead, there is a small gap between them. Messages have to be carried across this gap, which occurs by the movement of chemicals called **neurotransmitters**.

A similar synapse exists where an axon meets a skeletal muscle cell. This tiny gap is called the **neuromuscular junction**.

Synapses and neuromuscular junctions will be discussed further in Section 3.2 of this chapter.

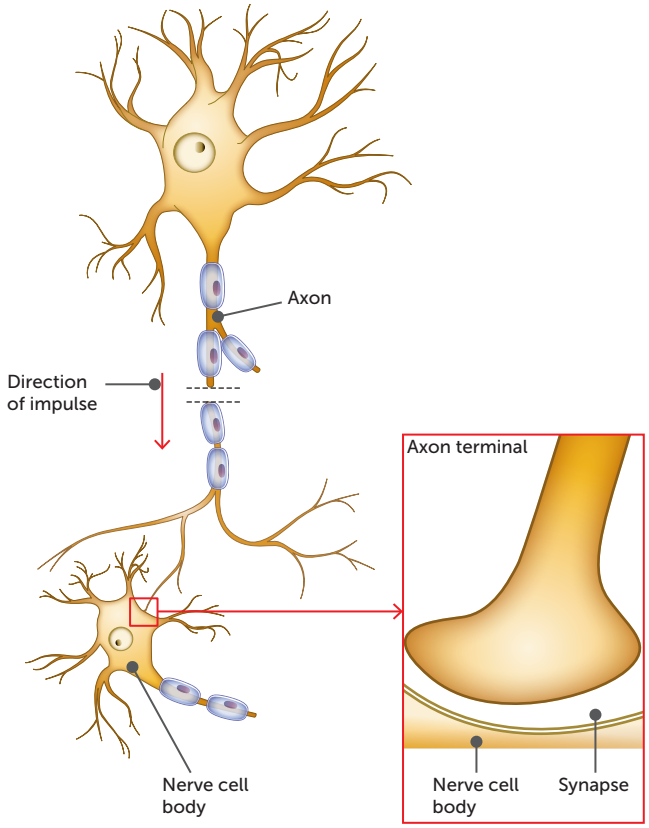

FIGURE 3.4 A synapse is a small gap between adjacent neurons

Types of neurons

Neurons can be classified based on their function or structure.

Functional types of neurons

Neurons may be classified into three types depending on the *function* each performs.

- **Sensory** (also known as **afferent** or **receptor**) **neurons** carry messages from receptors in the sense organs, or in the skin, to the central nervous system (brain and spinal cord).
- **Motor** (also known as **efferent** or **effector**) **neurons** carry messages from the central nervous system to the effectors, the muscles and glands.
- **Interneurons** are located in the central nervous system and are the link between the sensory and motor neurons. Interneurons may also be called **association neurons**, **connector neurons** or **relay neurons**.

Structural types of neurons

Another way of classifying neurons is by their *structure*. This classification is based on the number of extensions from the cell body.

- **Multipolar neurons** have one axon and multiple dendrites extending from the cell body. This type of neuron is the most common and includes most of the interneurons in the brain and spinal cord as well as the motor neurons that carry messages to the skeletal muscles.
- **Bipolar neurons** have one axon and one dendrite. Both the axon and dendrite may have many branches at their ends. Bipolar neurons occur in the eye, ear and nose, where they take impulses from the receptor cells to other neurons.
- **Unipolar neurons** have just one extension, an axon. These types of neurons are not found in humans or other vertebrates. They are found in insects.

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- **Pseudounipolar neurons** have properties of both unipolar neurons and bipolar neurons. There is a single axon from the cell body, which then separates into two extensions. One extension connects to dendrites, while the other ends in axon terminals. The arrangement of the cell body and axon means that the cell body lies to one side of the main axon. Most sensory neurons that carry messages to the spinal cord are of this type.

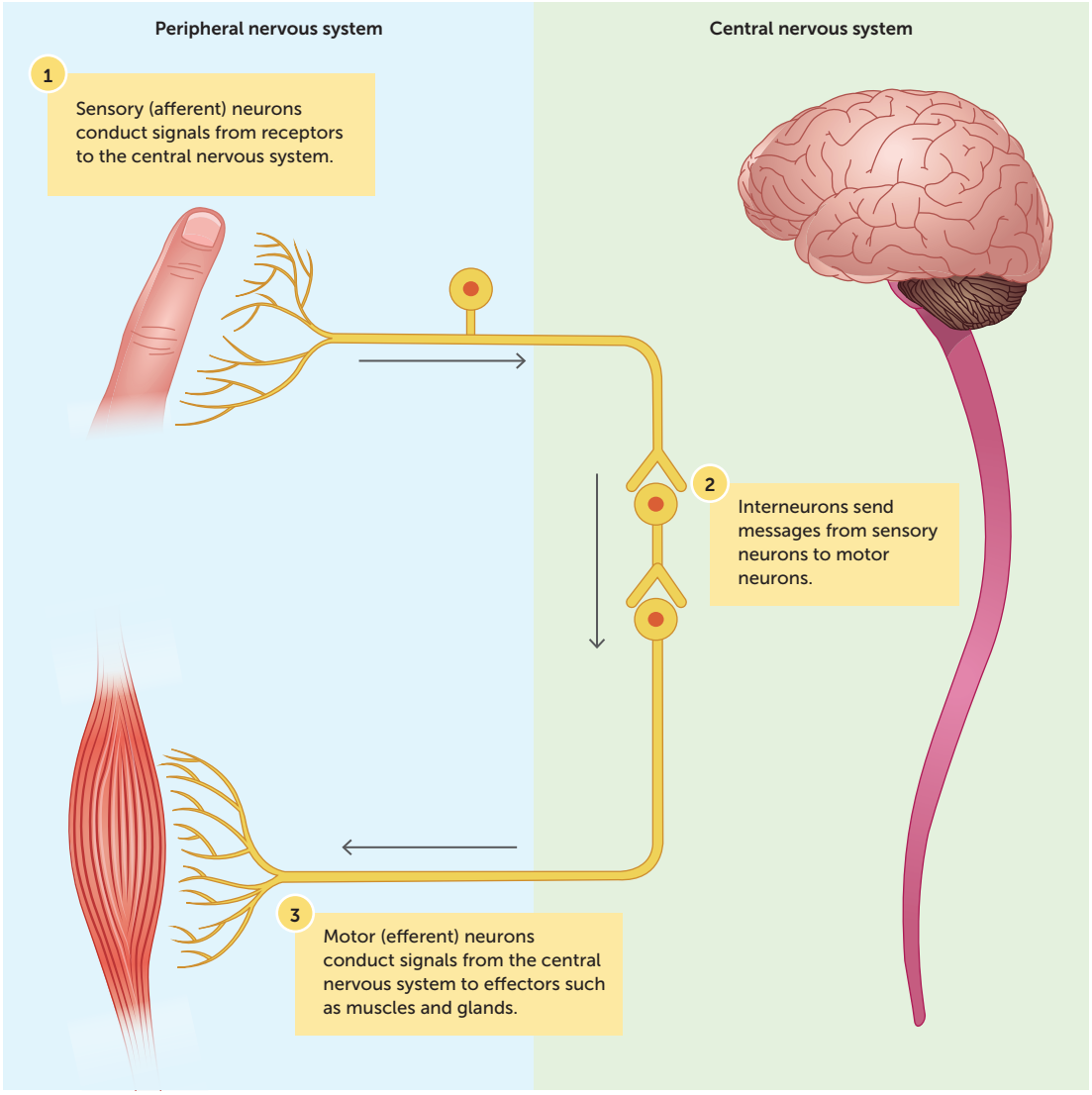

FIGURE 3.5 The direction of nerve impulses through sensory neurons, interneurons and motor neurons

TABLE 3.1 Summary of structural neurons

TYPE OF NEURON	NUMBER OF AXONS	NUMBER OF DENDRITES CONNECTING WITH THE CELL BODY	EXAMPLES OF NEURONS
Multipolar neurons	one	many	Motor neuron Interneuron
Bipolar neurons	one	one	Neurons in eye, ear and nose
Unipolar neurons	one	nil	Not found in humans
Pseudounipolar	one that divides into two	nil	Sensory neuron

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3.1 Neurons

Key concept

Neurons can be classified based on either their structure or their function.

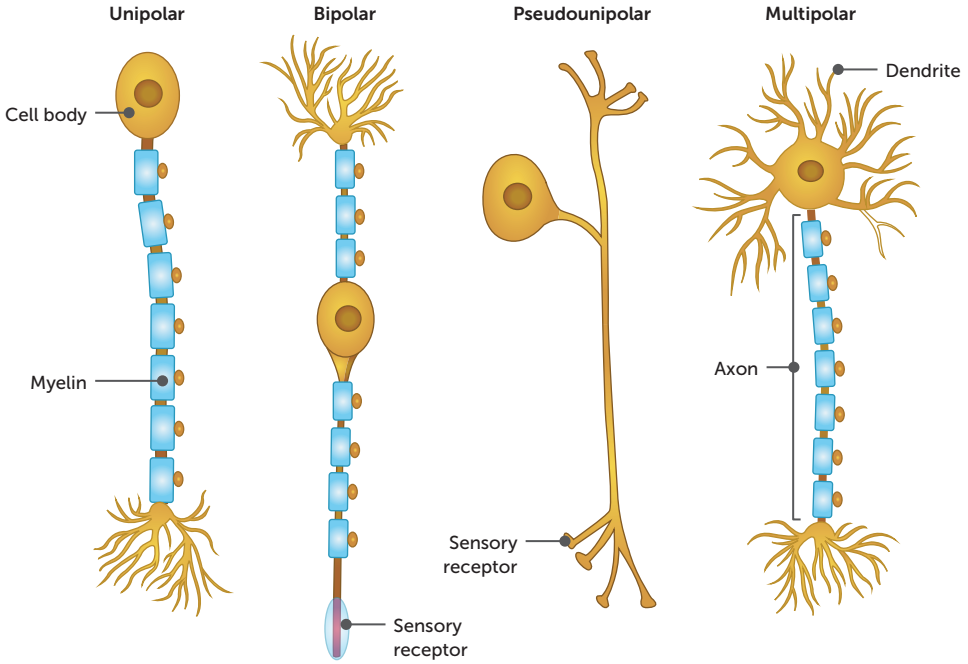

FIGURE 3.6 Types of neurons based on their structure

Nerve fibres

As previously mentioned, the axons and dendrites of nerve cells are known as nerve fibres. Outside the brain and spinal cord, nerve fibres are grouped together to form a **nerve**. Nerve fibres are arranged into bundles held together by connective tissue, with multiple bundles joining together to form a nerve.

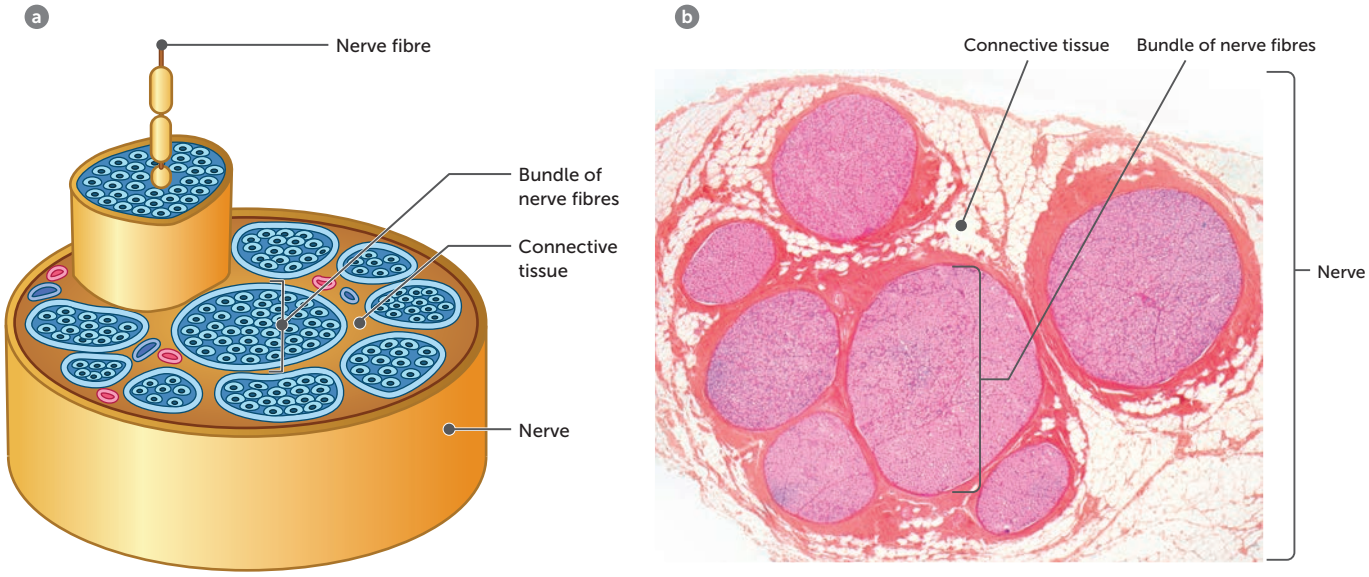

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FIGURE 3.7 a Cross-section of a nerve; **b** Cross-section of a nerve viewed under a microscope

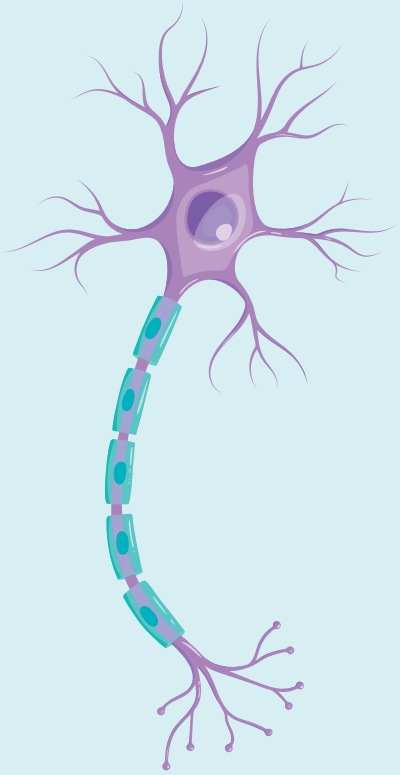
TABLE 3.2 The difference between neurons, nerve fibres and nerves

NEURON	A nerve cell
NERVE FIBRE	Any long extension of cytoplasm of a nerve cell body, although the term usually refers to an axon
NERVE	Bundles of nerve fibres held together by connective tissue

Questions 3.1

RECALL KNOWLEDGE

1 Label the diagram below to identify the axon, cell body, myelin sheath, dendrite, nucleus, axon terminal, cytoplasm, node of Ranvier and Schwann cell.



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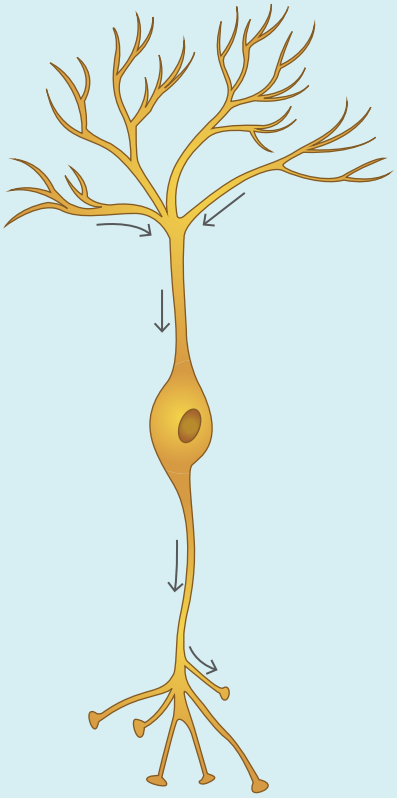
2 Complete the table to state the function of the parts of a neuron.

STRUCTURE	FUNCTION
Mitochondria	
Axon	
Dendrite	
Myelin sheath	
Neurilemma	

3 State the function of:

- **a** motor neurons
- **b** interneurons
- **c** sensory neurons.

4 Classify the neuron shown below and justify your choice.



5 Describe the arrangement of nerve fibres in a nerve.

6 Define 'synapse' and state its function.

APPLY KNOWLEDGE

7 Explain why the white matter in the brain is white in colour.

8 Compare and contrast a synapse and a neuromuscular junction.

9 Suggest why interneurons are multipolar in structure.

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3.2 NERVE IMPULSES

The message that travels along a nerve fibre is called a **nerve impulse**. Nerve impulses are transmitted very quickly, making it possible for the body to respond rapidly to any change in the internal or external environment.

Conduction of a nerve impulse

A nerve impulse is an **electrochemical change** that travels along a nerve fibre. It is described as electrochemical because it involves:

- a change in *electrical* voltage
- that is brought about by changes in *chemicals* (specifically, the concentration of ions inside and outside the cell membrane of the neuron).

Electrical charge and potential difference

There are two types of electrical charges: positive and negative. Two positive or two negative charges *repel* each other. A positive and a negative charge *attract* each other. That is, like charges repel and opposite charges attract.

When opposite charges are separated, an electrical force tends to pull them together. The force that pulls unlike charges together can be measured, and its strength increases as the charges get closer or larger. When positive and negative charges come together, energy is released. If a group of positive and negative charges are separated, they have the potential to come together and release energy. The potential, or **potential difference**, between two places can be measured. It is called the voltage and is measured in volts (V) or millivolts (mV), where there are 1000 mV in 1 V.

Potential difference across a cell membrane

When some chemical substances are dissolved in water, they break up into electrically charged particles called **ions**. This happens to some of the substances dissolved in the fluid around and inside cells.

- The fluid outside the cell, the **extracellular fluid**, contains a high concentration of sodium chloride, and so most of its charged particles are positive sodium ions (Na^+) and negative chloride ions (Cl^-).
- The fluid inside the cell, the **intracellular fluid**, has a low concentration of sodium ions and chloride ions. Its main positive ions are potassium (K^+), and the negative ions come from a variety of organic substances made by the cell.

Differences in the concentration of ions mean that there is a potential between the inside and the outside of the cell membrane. This potential difference is called the **membrane potential**. It occurs in all body cells, but is particularly large in nerve and muscle cells. The membrane potential of unstimulated nerve cells, known as the **resting membrane potential**, can be measured and is about −70 mV. This means that the potential of the inside of the membrane is 70 mV less than that of the outside.

Key concept

The resting membrane potential of an unstimulated neuron is approximately −70 mV due to the fluid inside the cell being more negatively charged than the fluid outside of the cell.

Ions are unable to diffuse through the phospholipid bilayers of the cell membrane directly. Instead, they move through protein channels. Some channels, called **leakage channels**, are open all the time; others, called **voltage-gated channels**, only open when the nerve is stimulated.

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The resting membrane potential of neurons is due mainly to differences in the distribution of potassium ions (K^+) and sodium ions (Na^+) on either side of the cell membrane, making the extracellular fluid more positively charged than the intracellular fluid.

- The concentration of sodium ions is about 10 times higher outside the neuron than inside. The cell membrane is only slightly permeable to sodium ions due to the limited number of sodium leakage channels. This limits the facilitated diffusion of sodium ions.
- The concentration of potassium ions is about 30 times greater inside the neuron than outside. The cell is highly permeable to potassium due to the larger number of potassium leakage channels. Therefore, more potassium ions are able to diffuse than sodium ions.
- The concentration of chloride ions is higher outside the neuron than inside. The cell membrane is highly permeable to chloride ions, allowing their diffusion through protein channels.
- The concentration of large, negatively charged organic ions is higher inside the neuron than outside. The cell membrane is impermeable to these ions; therefore, they stay inside the cell.

In addition to protein channels, sodium and potassium ions move across the cell membrane through a carrier protein known as the **sodium–potassium pump**. The pump moves two potassium ions into the cell for every three sodium ions that are removed. Therefore, there is a net reduction of positive ions inside the cell. This movement is against the concentration gradient and, therefore, is active transport and uses adenosine triphosphate (ATP).

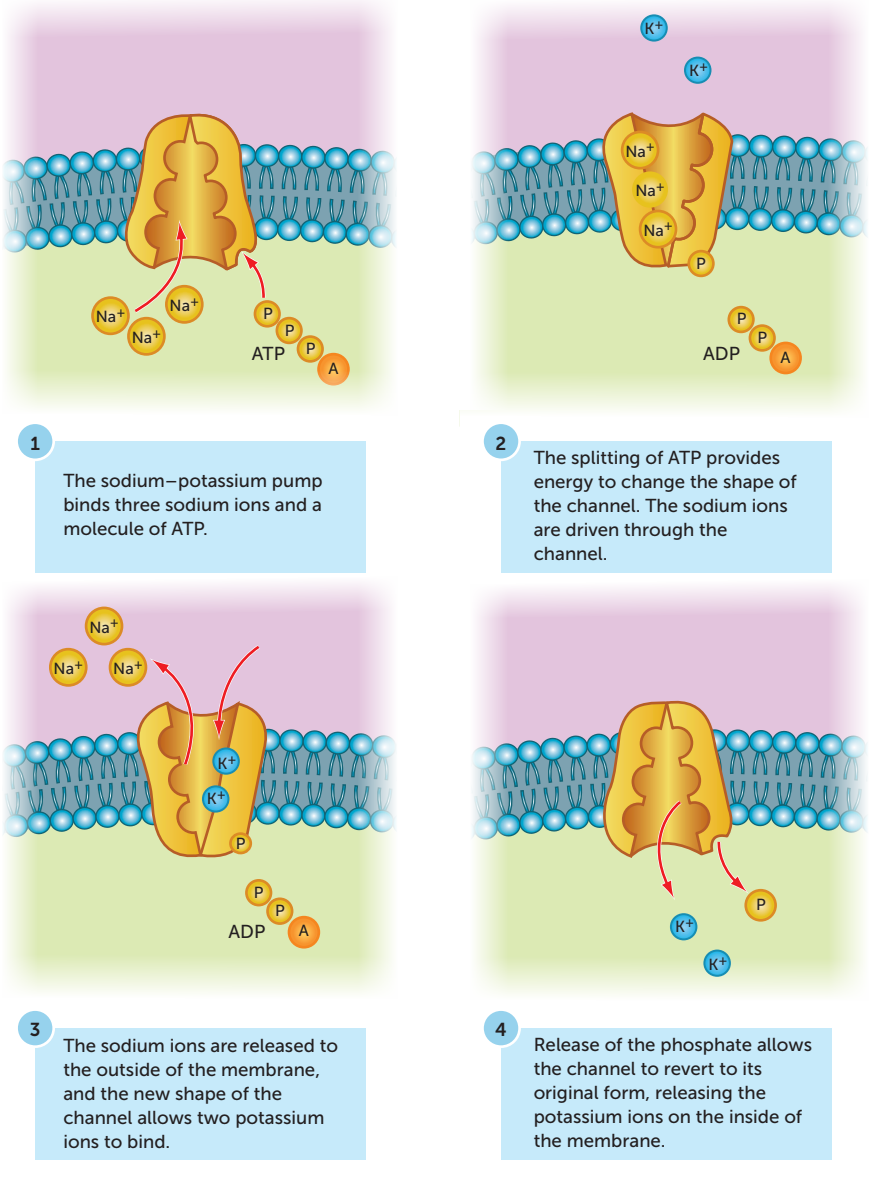

FIGURE 3.8 The sodium–potassium pump uses active transport to move three sodium ions out of the cell for every two potassium ions that move into the cell

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The combination of the location of the ions, the permeability of the cell membrane and the sodium–potassium pump means that there is a net flow of positive ions out of the cell because more potassium ions are diffusing out of the cell than there are sodium ions diffusing into the cell. This, in addition to the negative organic ions inside the cell, results in the inside of the cell being more negative than the outside. This produces a negative resting membrane potential, and the membrane is said to be **polarised**.

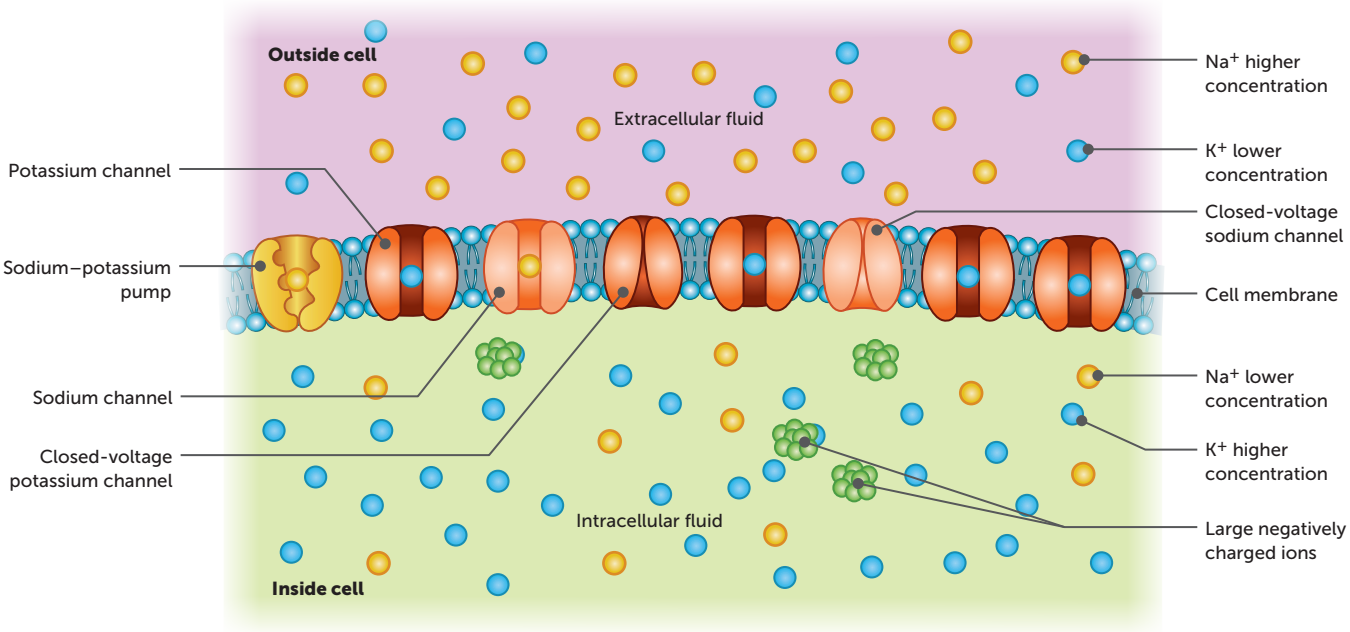

FIGURE 3.9 Relative concentrations of ions creating the resting membrane potential

Key concept

The resting membrane potential is maintained by a difference in the number of leakage channels for sodium and potassium ions, the membrane being impermeable to large organic negative ions and the sodium–potassium pump. This results in the intracellular fluid being less positively charged than the extracellular fluid.

Action potential

If the stimulus to a neuron is sufficient, the signal will be passed along the neuron. This happens due to the opening and closing of voltage-gated channels, which causes the rapid depolarisation and repolarisation of the membrane. This lasts approximately 1 millisecond and is called an **action potential**.

1 Depolarisation

Depolarisation is the sudden increase in membrane potential. This occurs if the level of stimulation exceeds about 15 mV, or the **threshold**.

When a neuron is stimulated by a neurotransmitter or a sensory receptor, some sodium channels are opened. These channels are known as ligand-gated or mechanical-gated channels. Once they are open, more sodium ions move into the cell. This makes the intracellular fluid less negative, increasing the potential difference.

If the stimulus is strong enough to increase the potential to −55 mV, then voltage-gated sodium channels open. This produces a movement of sodium ions into the cells that proceeds independently of the stimulus. That is, the size of the response is not related to the strength of the stimulus. This is known as an **all-or-none response**.

This inward movement of sodium ions is too great to be balanced by an outward movement of potassium ions, making the inside of the membrane more positive than the outside. The original polarity of the membrane increases, reaching approximately +40 mV. The membrane is then said to be **depolarised**.

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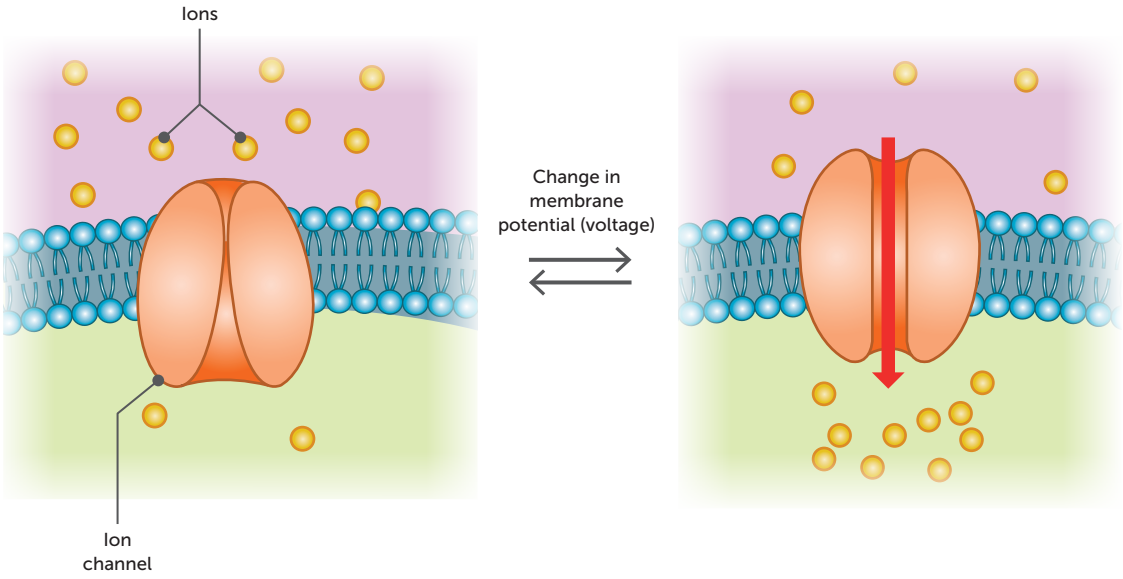


FIGURE 3.10 The opening of voltage-gated sodium ion channels leads to the movement of sodium ions into the cell, increasing the membrane potential

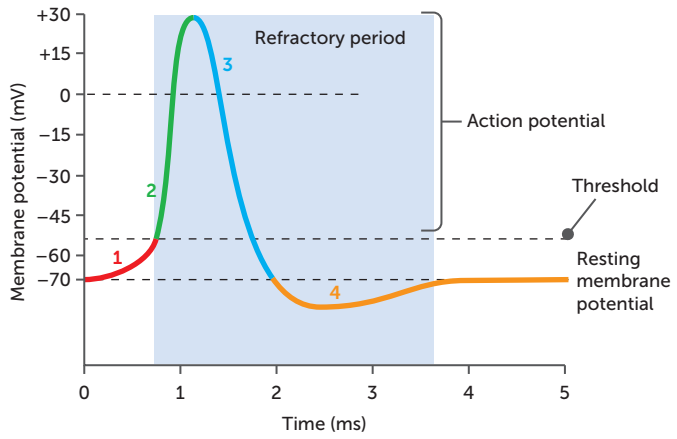
2 Repolarisation

After a short period, **repolarisation** occurs. The sodium channels close, which stops the influx of sodium ions. At the same time, voltage-gated potassium channels open, increasing the flow of potassium ions out of the cell. This makes the inside of the membrane more negative than the outside and decreases the membrane potential. The membrane is **repolarised**.

The potassium channels remain open longer than what is needed. This results in the membrane potential dropping lower than the resting membrane potential, and the membrane is **hyperpolarised**. This process is called **hyperpolarisation**.

3 Refractory period

Once the sodium channels have opened, they quickly become inactivated. This means that they are unresponsive to stimulus. Therefore, for a brief period after being stimulated, the membrane will not undergo another action potential. This period, called the **refractory period**, lasts from when the membrane reaches the threshold of −55mV until it returns to the resting membrane potential of −70mV.



1 Slow depolarisation of the membrane brings the potential to the threshold.

2 Sodium channels in the membrane open; sodium ions flood into the cell; membrane becomes depolarised; membrane voltage rises.

3 Sodium channels close and membrane becomes repolarised.

4 Membrane is hyperpolarised and then returns to resting state.

FIGURE 3.11 Development of an action potential on a nerve cell membrane

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3.2 Nerve impulses

Action potential
Watch a simulation of the changes in potential during an action potential.

Activity 3.2
Storyboarding an action potential

Key concept

An action potential is the rapid depolarisation and repolarisation of the membrane. A refractory period means that there is a period of time before another action potential can occur at the same location.

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Transmission of the nerve impulse

A single action potential occurs in one section of a membrane. However, it triggers an action potential in the adjacent membrane. This process continues along the length of the neuron and is called a nerve impulse.

Thus, an action potential does not travel along the nerve fibre; it is the message, or nerve impulse, that travels along the fibre. The situation has been likened to a line of dominoes. When the first domino falls it pushes over the second, which in falling pushes over the third, and so on. No one domino travels along the line, but the energy that triggers the fall is transmitted from the first domino to the last.

Conduction along unmyelinated fibres

In an unmyelinated nerve fibre, depolarisation of one area of the membrane causes a movement of sodium ions into the adjacent areas. This movement stimulates the opening of the voltage-gated sodium channels in the next part of the membrane, which initiates an action potential in that area of the membrane. The process repeats itself along the whole length of the membrane so that the action potential moves along the membrane away from the point of stimulation.

If the stimulus should occur in the middle of a fibre, impulses will travel in both directions along the fibre, away from the point of stimulation. However, in the body this would be unusual as stimulation normally occurs at the end of a fibre.

The nerve impulse is prevented from going backwards along the fibre by the refractory period. During the refractory period of an action potential, another action potential cannot be generated at that point on the fibre and so the nerve impulse is unable to travel in that direction.

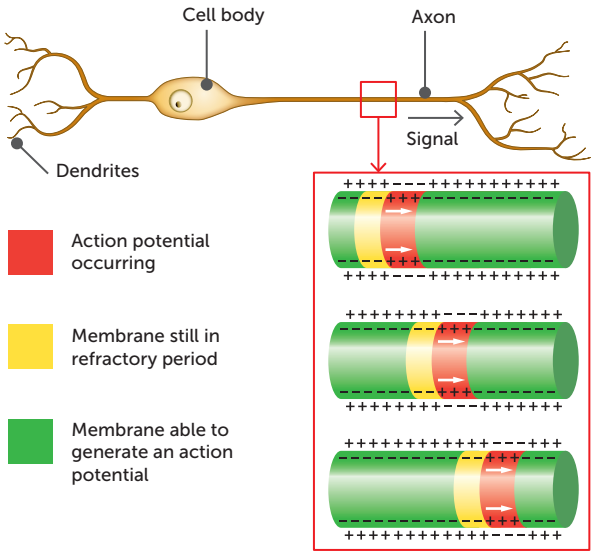

FIGURE 3.12 Transmission of a nerve impulse along an unmyelinated fibre. Successive action potentials are generated along the membrane of the nerve fibre

Transmission along myelinated fibres

In a myelinated fibre, the myelin sheath insulates the nerve fibre from the extracellular fluid. This does not occur at the nodes of Ranvier because the myelin sheath is absent from the nodes. Therefore, where the nerve fibre is surrounded by myelin, ions cannot flow between the inside and outside of the membrane and an action potential cannot form. Instead, the action potential jumps from one node of Ranvier to the next. This 'jumping conduction', known as **saltatory conduction**, allows the nerve impulse to travel much faster along myelinated fibres than along unmyelinated ones. A large myelinated fibre can conduct impulses at a speed of up to 140 metres per second (m/s); in an unmyelinated fibre the maximum speed of transmission is 2 m/s.

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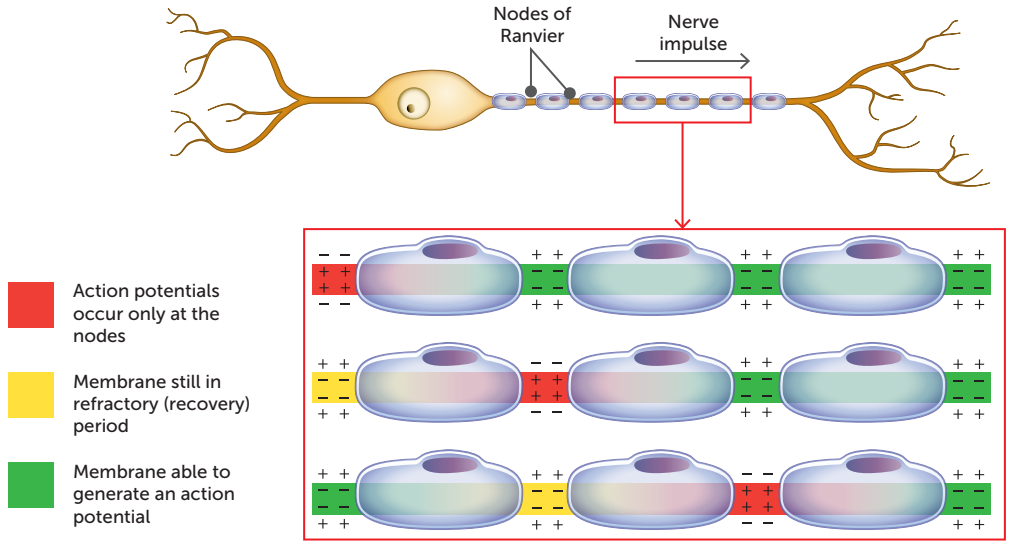

FIGURE 3.13
Saltatory conduction along a myelinated fibre. The nerve impulse jumps from node to node

Key concept

Nerve impulses travel much faster along a myelinated fibre due to saltatory conduction.

Size of the nerve impulse

A nerve impulse that travels along a fibre is always the same size, regardless of the size of the stimulus. A weak stimulus, provided it exceeds the threshold, produces the same action potential as a strong one. As mentioned before, this is called an all-or-none response – a stimulus is either strong enough to trigger an impulse, or it is not. The magnitude of the impulse is always the same. If you stub your toe, nerve impulses will be generated that travel along an axon all the way up to your spinal cord. The voltage of the impulses arriving at the spinal cord will be the same as the voltage of those generated at the toe. This situation has been likened to a burning fuse. When the fuse is lit, the heat generated ignites the next part of the fuse, which then produces enough heat to light the next part, and so on. The end of the fuse burns with the same amount of heat as the beginning. Like the heat in a burning fuse, a nerve impulse does not become weaker with distance.

How is it, then, that we are able to distinguish stimuli of different intensities? For example, how do we tell a light tap on the shoulder from a heavy slap on the back? Two things enable us to determine the strength of a stimulus: a strong stimulus causes depolarisation of more nerve fibres than a weak stimulus; and a strong stimulus produces more nerve impulses in a given time than a weak stimulus.

Transmission across a synapse

The synapse is the very small gap between adjacent neurons. We have seen how the nerve impulse is transmitted along the membrane of a neuron by a change in the ion concentration on each side of the membrane, but at the synapse there is no membrane and so some other method of transmission must be involved. The process is as follows:

1. When the nerve impulse reaches the axon terminal, it activates voltage-gated calcium ion channels.
2. As there is a higher concentration of calcium ions in the extracellular fluid, they flow into the cell at the pre-synaptic axon terminal.

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Activity 3.3
Examining the discovery of neurotransmitters

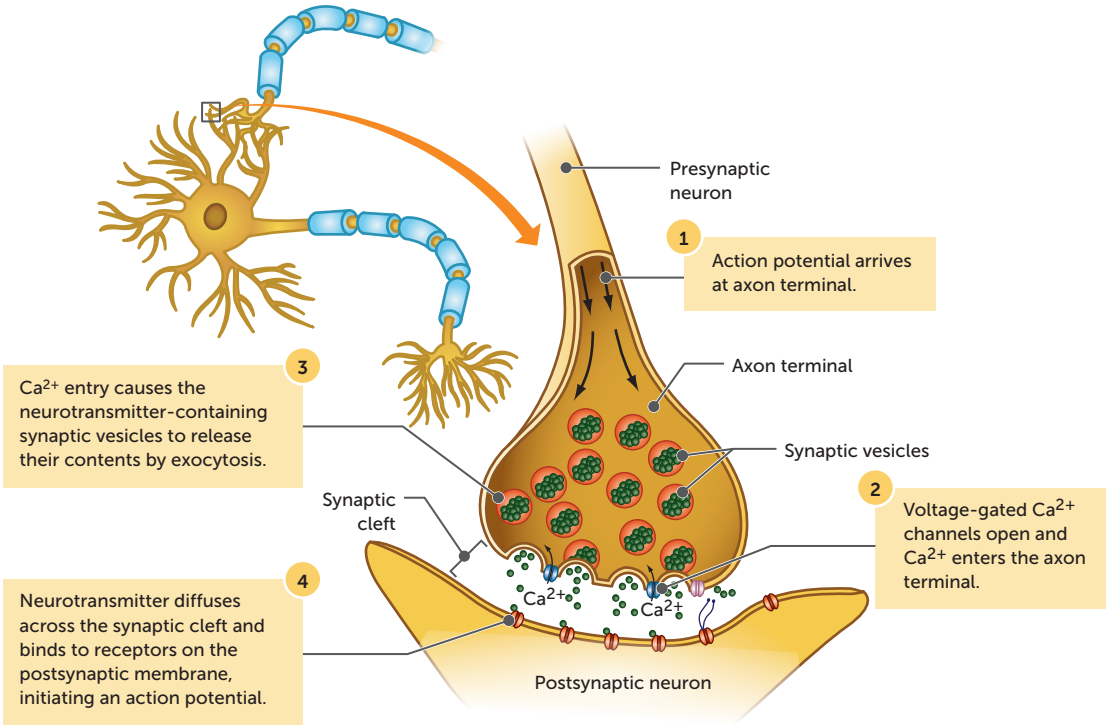
3 This causes synaptic vesicles to fuse with the membrane, releasing special chemicals called neurotransmitters by exocytosis.
4 The neurotransmitters diffuse across the gap and attach to receptors on the membrane of the next neuron.
5 This stimulates ligand-gated protein channels to open, which allows the influx of sodium ions and initiates an action potential in the post-synaptic membrane.

Neurotransmitters are removed from the synapse by being reabsorbed by the presynaptic membrane, by being degraded by enzymes or by moving away through diffusion.

More than 100 different substances are either confirmed as or suspected of being neurotransmitters, including acetylcholine, adrenaline, dopamine and histamine.

The transmission of nerve impulses across a synapse occurs in only one direction – from axon to dendrite or from axon to cell body.

FIGURE 3.14
Transmission of a nerve impulse across a synapse



Chocolate and neurotransmitters
Do you like chocolate? This website explores how chocolate may have an effect on neurotransmitters in the brain.

Nerve agents
This website provides more information about nerve agents.

Key concept

Nerve impulses travel from one neuron to the next by neurotransmitters diffusing across the synapse.

Effect of chemicals on the transmission of nerve impulses

There are many chemicals, both natural and synthetic, that influence the transmission of nerve impulses, mostly at the synapse or at the neuromuscular junction. Stimulants such as caffeine and benzedrine stimulate transmission at the synapse. Other drugs, such as anaesthetics or hypnotics, depress the transmission. Venom from certain species of snakes and spiders also affects the neuromuscular junction.

Nerve agents (also called nerve gases) contain organophosphates, which cause the build-up of acetylcholine at the neuromuscular junction. All muscles in the body then try to contract and the loss of muscle control prevents breathing. Organophosphates are also used in some insecticides.

Activity 3.4
Investigating synapse response in *Daphnia*

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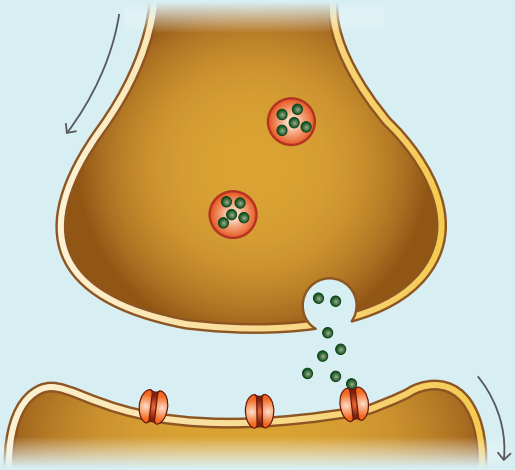
Questions 3.2

RECALL KNOWLEDGE

1 Describe the difference between an action potential and a nerve impulse.
2 Are there more sodium leakage channels or potassium leakage channels in the membrane of a neuron?
3 Explain the role of large organic ions in establishing the resting membrane potential.
4 Use a flow chart to describe the events that happen during an action potential.
5 Describe the concept of an all-or-none response in relation to an action potential and the relevance of the threshold.
6 Describe how a nerve impulse travels along a nerve fibre.
7 Draw, and label, a graph representing the membrane potential before, during and after an action potential.
8 List the ways in which a large stimulus is able to be recognised as different from a weak stimulus.
9 Add labels and additional structures to the diagram below to show how a nerve impulse travels from one neuron to the next.
10 Describe the process of saltatory conduction.

APPLY KNOWLEDGE

11 Explain the difference between a membrane potential of –70 mV and +40 mV.
12 Suggest how the resting membrane potential would be different if the sodium–potassium pump did not work.
13 Compare and contrast the progression of a nerve impulse along a myelinated fibre and along an unmyelinated fibre.
14 Explain why organophosphate poisoning results in continual muscle contractions.



3.3 RECEPTORS AND REFLEXES

A **receptor** is a structure that is able to detect a change in the body's internal or external environment. Sometimes receptor cells of a particular type are grouped together in a **sense organ**, such as the light receptors in the eye or the receptors sensitive to sound vibrations in the ear. Other receptors are simple nerve endings and may be spread through parts of the body or even the whole body, such as pain receptors or the temperature receptors in the skin. When a receptor is stimulated, the body is able to respond to the change. In some cases, this is via an automatic reflex; in other cases the response is more complex.

Types of receptors

Changes in the environment may come from different sources. Therefore, there are different types of receptors to be able to detect the different types of **stimuli**.

Thermoreceptors

Thermoreceptors are able to respond to heat and cold. Skin thermoreceptors inform the brain (the hypothalamus and the cerebrum) of changes in the temperature outside the body. In this way, we are consciously aware of the temperature of our surroundings. Peripheral thermoreceptors in the skin are nerve endings that are sensitive to either heat or cold, but not both. If the skin is tested with hot and cold probes, it is found that there are definite hot spots and cold spots, depending on the type of thermoreceptors present.

The temperature inside the body, the **core temperature**, is monitored by thermoreceptors in the hypothalamus, which detect the temperature of the blood that is flowing through the brain. Using information received from the skin and from its own thermoreceptors, the hypothalamus can regulate body temperature. This process will be discussed further in Chapter 5.

Osmoreceptors

Osmotic pressure is determined by the concentration of substances dissolved in the water of the blood plasma. The higher the concentration, the greater the osmotic pressure. **Osmoreceptors** are located in the hypothalamus and are sensitive to even very small changes in osmotic pressure. They can stimulate the hypothalamus so that the body's water content is maintained within very narrow limits. This process will be discussed further in Chapter 6.

Chemoreceptors

Chemoreceptors are stimulated by particular chemicals. They are present in the nose, making us sensitive to odours, and in the mouth, giving us sensitivity to tastes. There are also internal chemoreceptors that are sensitive to the composition of body fluids. Of particular importance are chemoreceptors in certain blood vessels that are sensitive to the pH of the blood and to the concentrations of oxygen and carbon dioxide. These chemoreceptors are involved in the regulation of the heartbeat and of breathing, which will be discussed in Chapter 6.

Touch receptors

Touch receptors (also known as mechanoreceptors or pressure receptors) are found mainly in the skin. There are a number of different types of touch receptors. Some are close to the surface of the skin and are sensitive to very light touch. These occur in greater concentrations in areas such as the lips, fingertips, eyelids and external genital organs.

Nerve endings are also associated with the base of each hair follicle. These respond to any light touch that bends the hair. Touch receptors close to the skin surface and those attached to the hairs adapt rapidly, and so after a short time we are no longer aware of the touch. For example, when first putting on clothing we are aware of it touching the skin, but that sensation disappears very quickly.

Other touch receptors are located deeper in the skin and are sensitive to pressure and vibrations.

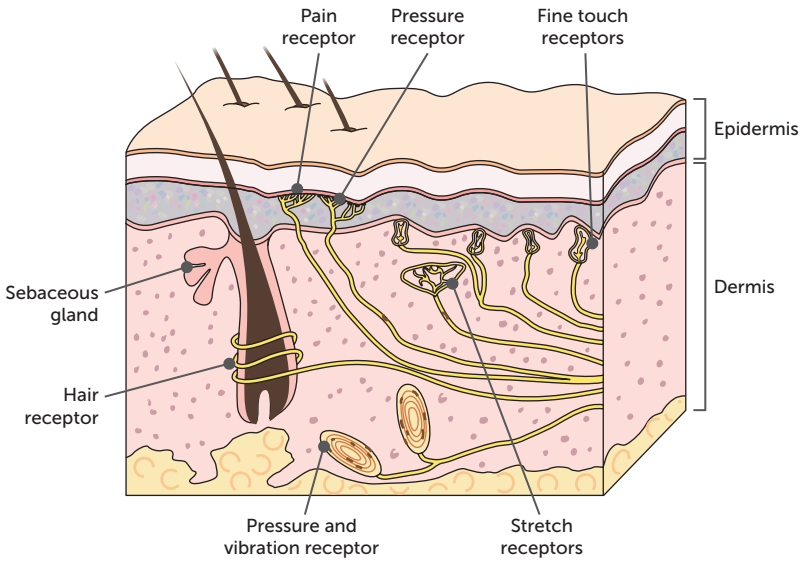


FIGURE 3.15 Section of the skin showing receptors

Pain receptors

Pain receptors (also called nociceptors) are stimulated by damage to the tissues, such as from a cut or a heavy bump, by poor blood flow to a tissue, or by excessive stimulation from stimuli such as heat or chemicals. The receptors for pain are especially concentrated in the skin and the mucous membranes. They occur in most organs, but not in the brain.

Pain is uncomfortable, but it is essential for our wellbeing. Pain warns us that damage to tissues is occurring, and we can therefore take evasive action or seek medical help so that damage is minimised.

Unlike many other receptors, pain receptors adapt little or not at all, so that pain continues for as long as the stimulus is present. In some cases, prolonged stimulation of pain receptors makes the pain worse. The failure of pain receptors to adapt keeps the person aware that a tissue-damaging situation exists.

Reflexes

A **reflex** is a rapid, automatic response to a change in the external or internal environment. All reflexes have four important properties.

- A *stimulus* is required to trigger a reflex – the reflex is not spontaneous.
- A reflex is *involuntary* – it occurs without any conscious thought.
- A reflex response is *rapid* – only a small number of neurons are involved.
- A reflex response is *stereotyped* – it occurs in the same way each time it happens.

Some reflexes involve the unconscious parts of the brain, but most are coordinated by the spinal cord. When a nerve impulse comes into the spinal cord from a receptor, the message is not necessarily carried up to the brain. The impulse may be passed to motor neurons at the same level in the cord, or it may travel a few segments up or down the cord before travelling out through a motor neuron. In these cases, the reflex is carried out by the spinal cord alone and is known as a **spinal reflex**. The pathway a nerve impulse follows in travelling from a receptor to an effector is known as a **reflex arc** or, in the case of a spinal reflex, a **spinal reflex arc**.

Even though contraction of skeletal muscles may occur in a spinal reflex, it does not involve the brain and therefore is involuntary. Impulses may be sent to the brain, and so we become aware of what is happening, but this awareness does not occur until after the response has been initiated. For example, if you step on something sharp with bare feet, the reflex response is to withdraw your foot from the painful stimulus. By the time your brain becomes consciously aware of the painful stimulus, your foot has already been withdrawn.

A reflex arc has the following basic components.

- The *receptor* reacts to a change in the internal or external environment by initiating a nerve impulse in the sensory neuron.
- A *sensory neuron* carries impulses from the receptor to the spinal cord or brain.
- There is at least one *synapse*; the nerve impulse may be passed directly to a motor neuron, or there may be one or more interneurons that direct the impulse to the correct motor neuron.
- A *motor neuron* carries the nerve impulse to an effector.
- An *effector* receives the nerve impulse and carries out the appropriate response. Effectors are muscle cells or secretory cells.

Figure 3.16 shows the components in a simple spinal reflex involving three neurons. The response would occur in a fraction of a second; while it was occurring, impulses would travel up the spinal cord to the brain. Only after the response had been made would the person become consciously aware of the situation. Many reflexes, such as withdrawing the hand from a painful stimulus, protect the body from injury. Blinking when something touches the cornea of the eye, sneezing or coughing when something irritates the nose or trachea, and constriction of the pupil in response to intense light are other protective reflexes.

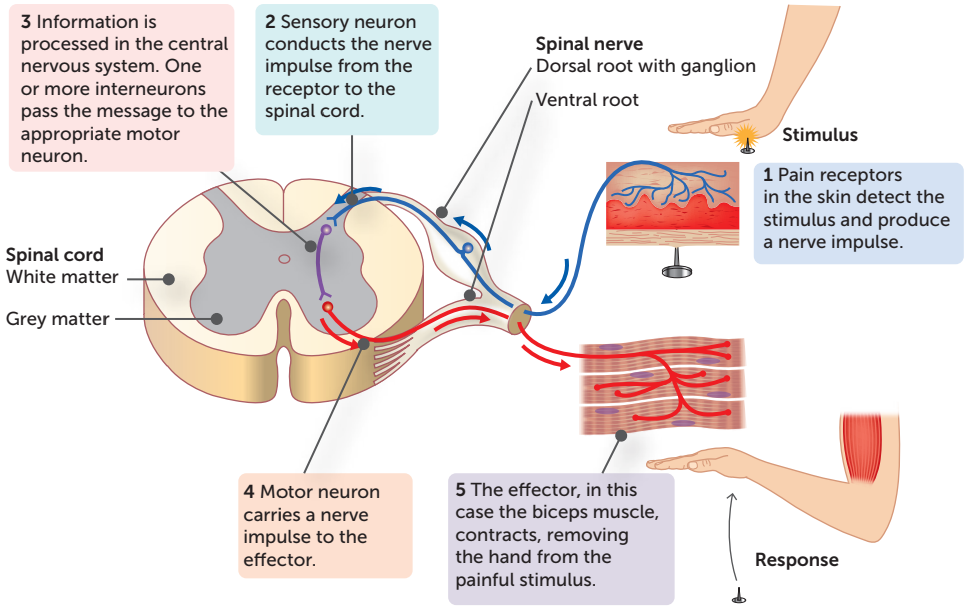


FIGURE 3.16 The neurons involved and the pathway followed by the nerve impulses in a spinal reflex. In this example, the impulses enter and leave the spinal cord by the same spinal nerve. This is not always the case

Simple reflexes and reflex arcs
This website provides more information about simple reflexes and reflex arcs and an animation of the latter.

Other reflexes include secretion of saliva in response to the sight, smell or taste of food, the ejaculation of semen during sexual intercourse, and the responses brought about by the autonomic nervous system.

Learnt reflexes

The protective reflexes mentioned above are present from birth. More complex motor patterns appear during a baby's development, including reflexes such as suckling, chewing or following movements with the eyes. These **innate reflexes** are determined genetically.

Some complex motor patterns are learnt and are called **acquired reflexes**. Muscular adjustments required to maintain balance while riding a bike, jamming on the brakes of a car to avoid a dangerous situation, or catching a ball are all acquired reflexes. They are learnt through constant repetition.

Activity 3.5
Investigating reflexes

Activity 3.6
Investigating reaction time

Activity 3.7
Testing more reaction times

Questions 3.3

RECALL KNOWLEDGE

1. List the different types of receptors and state the relevant stimulus for each.
2. List the properties of all reflexes.
3. Draw a labelled diagram to represent a spinal reflex arc.

APPLY KNOWLEDGE

4. Compare and contrast pain and touch receptors.
5. Explain how a gag reflex protects the body.
6. Describe the steps involved in the reflex initiated by touching a hot object.

3.4 COMPARISON OF HORMONAL AND NERVOUS COORDINATION

Both the endocrine system and the nervous system are involved in communication within the body. However, they do not duplicate each other's roles; rather, they complement and reinforce each other.

The differences between the actions of nerves and hormones are as follows.

- Nervous responses are more rapid than hormonal ones, because nerve impulses travel rapidly along nerve fibres, while hormones are transported in the bloodstream. The nervous system

responds to a stimulus in milliseconds, while the release of hormones may take from several seconds to several days.

- When a stimulus ceases, the nervous system stops generating nerve impulses and the response ceases almost immediately. Thus, nerve impulses bring about an immediate response, which lasts for only a short time. Hormones are typically slower acting, and responses can last a considerable time (even for years).
- Nervous messages are an electrochemical change that travels along the membrane of a neuron. Endocrine messages are chemicals (hormones) that are usually transported by the blood.
- Nerve impulses travel along a nerve fibre to a specific part of the body and often influence just one effector; hormones travel to all parts of the body, are carried by the blood and often affect a number of different organs.

It should be stressed that these differences are only generalisations. There are exceptions to each of them. For example, response to the hormone adrenaline can be quite rapid, and some chemical messengers are not carried by the blood because their site of action is adjacent to the cells in which they are produced.

Despite these differences there are important overlaps between the two systems.

- Some substances function as both hormones and neurotransmitters. Examples are noradrenaline, antidiuretic hormone and dopamine.
- Some hormones such as oxytocin and adrenaline are secreted by neurons into the extracellular fluid.
- Some hormones and neurotransmitters have the same effect on the same target cells. For example, noradrenaline and the hormone glucagon both act on liver cells to cause glycogen to be broken down into glucose.

Table 3.3 compares the nervous and endocrine systems.

TABLE 3.3 A comparison of the nervous and endocrine systems

CHARACTERISTIC	NERVOUS SYSTEM	ENDOCRINE SYSTEM
Nature of message	Electrical impulses and neurotransmitters	Hormones
Transport of message	Along the membrane of neurons	By the bloodstream
Cells affected	Muscle and gland cells; other neurons	All body cells
Type of response	Usually local and specific	May be very general and widespread
Time taken to respond	Rapid – within milliseconds	Slower – from seconds to days
Duration of response	Brief – stops quickly when the stimulus stops	Longer lasting – may continue long after the stimulus has stopped

Questions 3.4

RECALL KNOWLEDGE

1 For each property listed below, state whether it describes the nervous system or the endocrine system.
   - **a** Has a specific target.
   - **b** Produces a long-lasting effect.
   - **c** Message is carried through the bloodstream.
   - **d** Is slow to respond to a stimulus.
   - **e** Messages travel due to an electrochemical change.
   - **f** Affects muscles, glands and other neurons.
   - **g** Is quick to respond.
   - **h** Affects all body cells.
   - **i** Effects last a short time.

2 State two ways in which the nervous system is similar to the endocrine system.

APPLY KNOWLEDGE

3 Explain why the body needs both the endocrine and nervous systems.

4 Suggest which system (nervous or endocrine) would have the biggest effect on heart rate. Justify your answer.

CHAPTER 3 ACTIVITIES

ACTIVITY 3.1 Creating a model of a neuron

Models are a useful way to represent information. In this activity, you will create a model of a multipolar neuron with a myelinated axon.

1. In groups of two or three, brainstorm the various components that you will need to show in your model and the materials you will represent them with. For example, you might use play dough, plasticine, lollies and pipe cleaners.
2. Create your model.
3. Take a photo of your model.
4. Annotate or label all the structures that make up your model of a neuron.
5. Make a video of your model by using your photo and adding a voice-over to explain the structures and their functions.

ACTIVITY 3.2 Storyboarding an action potential

Imagine that you are a sodium ion in the extracellular fluid around a neuron. Tell the story of your life during times when the neuron is unstimulated as well as when the neuron is sending a message in the body.

To make your story as accurate as possible, brainstorm the following:

1. What will be the setting of your story?
2. What will you (the ion) be doing during each of the different situations?
3. What other characters will be in your story?
4. What is the plot of the story?

Write your story using clear explanations. Include relevant scientific terms to ensure the accuracy of the information.

ACTIVITY 3.3 Examining the discovery of neurotransmitters

Neurotransmitters are chemicals released from a neuron that cause a response in an adjacent neuron, muscle or organ. A German pharmacologist, Otto Loewi, was the first person to demonstrate that nerve impulses exert their effect on muscles through the secretion of a neurotransmitter. In 1921 he performed an experiment that showed conclusively the effect of neurotransmitters. The idea for Loewi's experiment came to him in a dream. In his book *From the Workshop of Discoveries* (1953, University of Kansas Press), he said:

> *In the night of Easter Saturday, 1921, I awoke, turned on the light, and jotted down a few notes on a tiny slip of paper. Then I fell asleep again. It occurred to me at six o'clock in the morning that during the night I had written down something most important, but I was unable to decipher the scrawl. That Sunday was the most desperate day in my whole scientific life. During the next night, however, I awoke again, at three o'clock, and I remembered what it was. This time I did not take any risk; I got up immediately, went to the laboratory, made the experiment on the frog's heart, described above, and at five o'clock the chemical transmission of nervous impulse was conclusively proved.*

The experiment that Loewi performed involved the use of two hearts from freshly killed frogs. The still beating hearts were placed in separate beakers of salt solution. Heart A still had the vagus nerve attached; heart B did not. When the vagus nerve of heart A was electrically stimulated, the heart slowed down. Loewi then took a dropper of the salt solution from around the slowly beating heart A and placed the fluid into the salt solution surrounding heart B. After a short time, heart B slowed down. Loewi concluded that a chemical produced by the vagus

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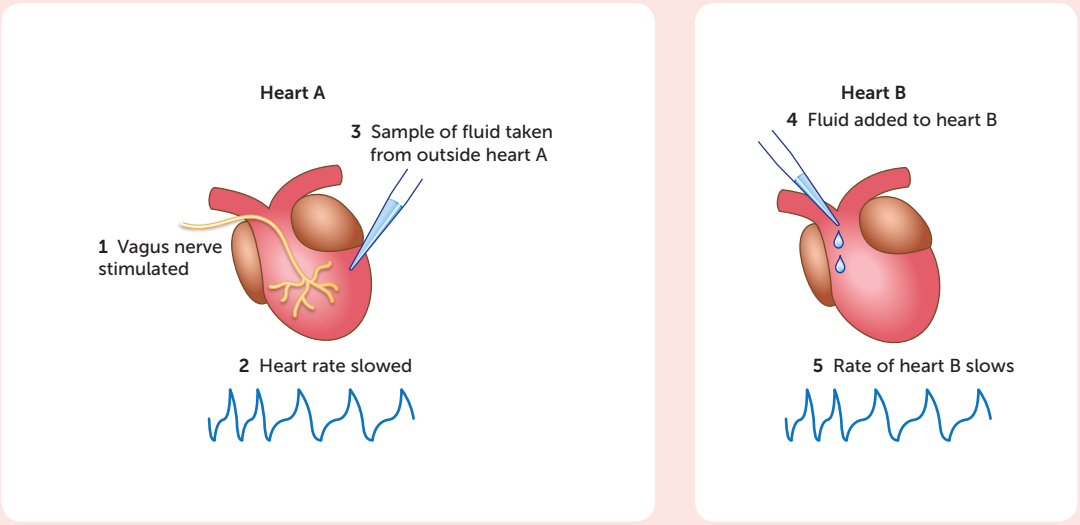
nerve of heart A had caused heart B to slow down. In 1936, Loewi was awarded a Nobel Prize for his discovery.



Questions

1. Explain how the result of Loewi's experiment enabled him to claim that a chemical was involved in slowing the rate of beating of the hearts.
2. Would Loewi have gotten the same result if he had placed both hearts in the same beaker of salt solution?
3. What control experiments would have been necessary before Loewi could claim that a chemical secreted by nerve cells was involved in slowing the hearts?
4. Loewi called the chemical 'vagusstoff' (or 'vagus stuff' when translated into English). Find out what we now call the neurotransmitter that is released at neuromuscular junctions.
5. If Loewi was doing such an experiment today, what do you think he would write down as his:
   a. hypothesis?
   b. prediction?

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ACTIVITY 3.4 Investigating synapse response in *Daphnia*

Daphnia, commonly known as 'water fleas', are small freshwater invertebrate animals with an exoskeleton and paired appendages. *Daphnia* are translucent, making them an excellent organism in which to observe digestion and to study metabolic rates. This also makes *Daphnia* a great organism for studying homeostasis, as its clear external skeleton (carapace) allows visibility of the heart, located in its back. Homeostasis is the maintenance of a stable internal environment. Homeostatic mechanisms within animals are triggered by increases in cellular respiration. These mechanisms increase breathing and heart rate, so that more oxygen is available to cells and more carbon dioxide is removed from cells.

Aim

To investigate how different stimulants and depressants affect the neurotransmitters within *Daphnia*

Time requirement: 45 minutes

You will need

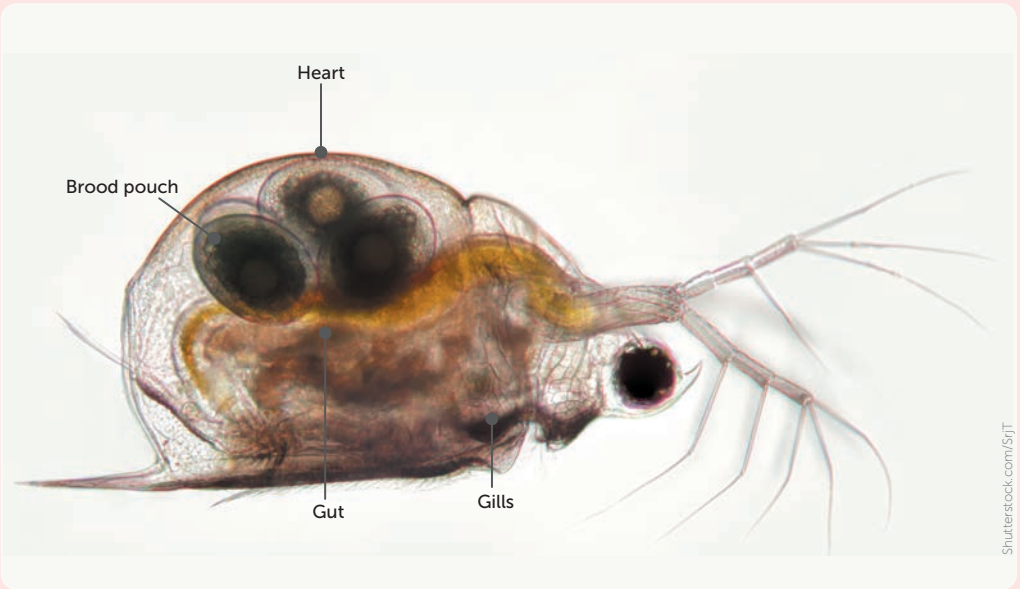
Concavity slides; 1% ethanol solution (1 drop); 1% caffeine solution (1 drop); 0.01% nicotine solution (1 drop); 1 plastic pipette (with the end cut); 3 plastic pipettes; *Daphnia* in culture; specimen container; cotton wool; vial for *Daphnia* disposal; paper towels; clock or stopwatch; compound microscope; disposable gloves

Risks

WHAT ARE THE RISKS IN THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Daphnia are harmless to humans, but swamp or pond water may contain pathogens.	Wash hands after touching *Daphnia*.
Ethanol is highly flammable.	Store and use away from ignition sources. Do not heat in a container over an open flame; use a water bath that is spark-proof.
Nicotine may cause eye irritation.	Wear lab coats, safety glasses and gloves; wash hands thoroughly at the end.
Caffeine can be toxic at high doses.	Do not consume.

What to do

1. Place a very small piece of cotton wool in the centre of a concavity slide.
2. Using a plastic pipette with the end cut off, carefully transfer a *Daphnia* along with one drop of the culture liquid on to the slide (on top of the cotton). Keep the liquid to a minimum to prevent the *Daphnia* from swimming out of your field of view. If necessary, use a paper towel to draw off some water. Take care to leave some water for the *Daphnia*, and do not touch it with the paper towel because it will stick to the paper.
3. Place the slide under the compound microscope and adjust the focus until the *Daphnia* is in clear view. You should be able to clearly see the beating of the heart. Use the image below as a guide to locate the heart.



4. Ensure the microscope light is turned off to avoid overheating the *Daphnia*.

Measuring control heart rate

5 Using a stopwatch, count the number of heartbeats you observe in 10 seconds. You may wish to do this in pairs, so you can count the heartbeats as your partner keeps time. Try to take your measurements as quickly as possible, as the *Daphnia* will become stressed when kept in a small volume of water for an extended period.
6 Fill in the number of heartbeats in 10 seconds in the table below, and multiply the number by six to find the number of beats per minute.
7 Repeat this test twice until you have three separate heart rate measurements, then carefully transfer the *Daphnia* into the used-*Daphnia* vial. Calculate the average heart rate of the three measurements. This will serve as your control.

Measuring heart rate under the influence of chemicals

8 Using a new plastic pipette, add one drop of 1% caffeine solution to a new concavity slide.
9 Transfer a single *Daphnia* on to it, using the same technique as previously. Try to add as little culture liquid as possible when transferring the *Daphnia* to avoid diluting the caffeine too much.
10 Wait 30 seconds, then turn on the microscope light and count the number of heartbeats in 10 seconds. Record the result in the table.
11 Repeat this test twice so that you have three separate heart rate measurements. Multiply each number by six to generate the heart rate per minute. Calculate the average of your three measurements.
12 Carefully discard the *Daphnia* into the used-*Daphnia* vial, and repeat steps 8 to 11 for nicotine and ethanol using a fresh *Daphnia* and slide each time. Record your results in the table.

Studying your results

1 Copy and complete the table below with the results of your experiment.

	CHEMICALS							
	CONTROL		STIMULANTS				DEPRESSANT	
			CAFFEINE		NICOTINE		ALCOHOL (ETHANOL)	
TRIAL	10 sec.	BPM (x6)	10 sec.	BPM (x6)	10 sec.	BPM (x6)	10 sec.	BPM (x6)
1								
2								
3								
AVERAGE								

2 Which chemical caused the *Daphnia* heartbeat to beat the fastest?
3 Which chemical caused the *Daphnia* heartbeat to beat the slowest?

Discussion

1 Evaluate the accuracy of your counting method. Suggest how the accuracy of the procedure might be improved.
2 Describe how each of these chemicals affects the heart rate of the *Daphnia*.
3 There are two kinds of neurotransmitters: inhibitory and excitatory. Excitatory neurotransmitters stimulate the brain. Inhibitory neurotransmitters calm the brain and help create balance. Describe how the chemicals you tested affect neurotransmitters in the *Daphnia*.

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4 What factors can cause neurotransmitter levels to become out of balance? Describe how imbalances in neurotransmitter levels may affect human health.

Taking it further

Test how temperature changes the heart rate in *Daphnia*.

ACTIVITY 3.5 Investigating reflexes

In this activity, you will examine some simple reflex responses.

You will need (for each pair)

Ruler

What to do

For each of the following tests, one member of the pair should act as the subject, the other as the investigator. After you have conducted the tests once, swap roles and test the reflexes of the other person.

Knee reflex

The subject should sit on a stool or a bench-top with one leg crossed over the other. Using a ruler, the investigator should lightly strike the subject's crossed leg just below the kneecap.

1 Describe the response that occurs. The stimulus for the response is the stretching of the patellar tendon just below the kneecap.
2 Describe the location of the muscle or muscles that produce the response.
3 Describe, in words, the reflex arc that is involved in the response. Try to get a response with the knee straight and bent at different angles.
4 Does the response seem to be stronger at any particular angle of flexion? If so, can you suggest an explanation?

Heel reflex

Stand the subject beside a stool or chair with one leg kneeling on the seat of the chair. Use a ruler to strike the back of the subject's ankle.

5 Describe the response.
6 What is the stimulus in this case?
7 In what ways is the heel reflex similar to the knee reflex?
8 Doctors often test reflexes such as the knee and heel reflex. What do you think testing such reflexes would tell a doctor?

Eye reflex

With the subject seated directly in front, the investigator should suddenly clap their hands in front of the subject's face.

9 Describe any response observed.
10 Is the response a natural or a learnt response?
11 Does the response have a purpose? Explain.

Conclusions

1 Do all the reflexes that you have investigated have the four important properties that were described in this chapter?
2 Write a brief statement summarising the importance of reflexes to the normal functioning of the human body.

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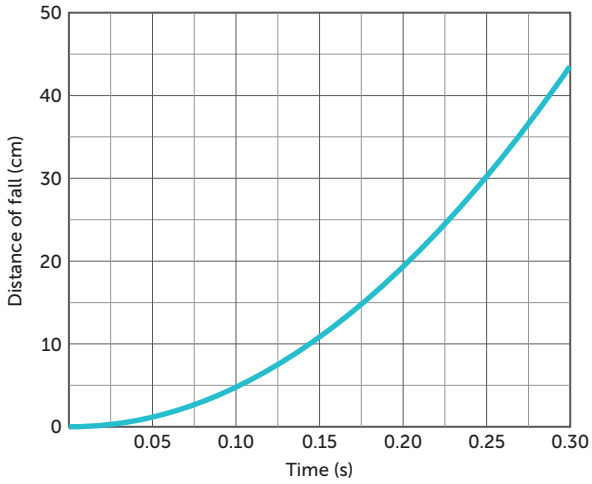
ACTIVITY 3.6 Investigating reaction time

Responses do not occur instantaneously; even reflex responses require time for perception of the stimulus, for conduction of impulses to and from the brain or spinal cord, and for the effector to carry out the response. Reaction time is the time it takes to respond to a stimulus. It depends on many factors, including the type and intensity of the stimulus and whether conscious thought is involved in the response.

Design and carry out an investigation into reaction time. Some things to consider are:

- What variable will you test? For example, you might test left vs right hand, different ages, different times of the day, males vs females, the effect of drinking caffeine, the effect of practice or of distraction.
- What is your hypothesis?
- What reactions will you test? For example, you might test how quickly a person is able to catch a falling ruler or to react to a light coming on.
- How will you measure the reaction time? You may be able to use an electronic device, a test on the Internet, or measure the distance of a falling object. (See the following graph for converting the distance into time.)
- How many trials will you conduct?
- What format will you use to record your results?
- How can you maximise the accuracy, reliability and validity of the investigation?
- What conclusion can you reach? Does it support your hypothesis?



Graph showing time taken for an object to fall a given vertical distance

ACTIVITY 3.7 Testing more reaction times

Reaction time is the time that elapses between a stimulus and the response to the stimulus. You can test your reaction time by following the weblink.

Reaction times

1. Describe the pathway taken by the nerve impulses involved in detecting the stimulus and making the response.
2. Is the response an innate or an acquired response?
3. Draw a column graph showing your reaction time for five trials.
4. Does your reaction time decrease with practice? If so, suggest why.
5. Do five trials with your left hand and then five trials with your right hand. Describe and explain any difference between the two sets of trials.

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CHAPTER 3 SUMMARY

- Neurons are specialised cells that allow rapid communication within the body.
- Neurons are made up of:
  - a cell body, which contains organelles and controls the functioning of the cell
  - dendrites, which take messages to the cell body
  - axons, which take messages away from the cell body.
- Axons are surrounded by a myelin sheath that is produced by Schwann cells.
- The gaps between the myelin sheath are called nodes of Ranvier.
- The gap between adjacent neurons is called a synapse. Neurotransmitters cross the gap and transmit messages from one neuron to the next.
- Neurons can be classified as sensory, motor or interneurons based on their function.
- Neurons can also be classified as multipolar, bipolar, unipolar or pseudounipolar based on their structure.
- Axons are also known as nerve fibres. These are arranged in bundles that are surrounded by connective tissues. Multiple bundles are joined together to form a nerve.
- Messages travel along nerve fibres by an electrochemical change known as a nerve impulse.
- A potential difference is created by a separation of positive and negative charges. In the case of cells, it is due to ions creating a negative charge inside the cell and a positive charge outside the cell.
- The fluid outside the cell has a high concentration of positive sodium ions. The fluid inside the cell has a high concentration of positive potassium ions in addition to negative organic ions. This difference creates a resting membrane potential of –70 mV, meaning that the inside is 70 mV more negative than the outside.
- Ions are able to cross the membrane through leakage channels that are always open, or through gated channels that only open in response to a particular stimulus.
- Sodium and potassium ions are also moved across the membrane through a sodium–potassium pump, which moves three sodium ions out of the cell for every two potassium ions that move into the cell. This goes against the concentration gradient and, therefore, is active transport.
- An action potential is the rapid depolarisation and repolarisation of the cell membrane.
- Depolarisation is started by a stimulus from another neuron or a receptor. This stimulus opens some sodium ion gated channels, resulting in an influx of sodium ions that makes the inside of the cell more positive. If the membrane potential increases by 15 mV, then it reaches the threshold which leads to the opening of voltage-gated sodium ions, resulting in a greater flow of sodium ions into the cell. The inside of the cell becomes more positive than the outside, reaching approximately +40 mV.
- Repolarisation occurs due to the closing of the sodium channels and opening of potassium channels. The flow of sodium ions into the cell decreases and the flow of potassium ions out of the cell increases. This process makes the inside of the cell more negative than the outside, reducing the membrane potential.
- An action potential in one area of the membrane stimulates an action potential in the adjacent area. Thus, the action potential moves along the nerve fibre in a nerve impulse.
- The sodium ion voltage-gated channels become inactivated after they open, and so they cannot be stimulated for the period during and shortly after the action potential, the refractory period. This means that a nerve impulse cannot travel backwards.

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- Myelin acts as an insulator on the cell membrane, preventing the formation of an action potential. Therefore, the action potentials jump from one node of Ranvier to the next. This is called saltatory conduction and means that the nerve impulse travels much faster in myelinated fibres than in unmyelinated fibres.
- Nerve impulses are always the same strength. They can, however, differ in the frequency of impulses and the number of nerve fibres affected. This allows us to differentiate between stimuli.
- When a nerve impulse reaches a synapse, calcium ion voltage-gated channels are opened, allowing calcium ions to flow into the cell. This stimulates the release of neurotransmitters by exocytosis. The neurotransmitters diffuse across the synapse and bind to receptors on the next neuron, stimulating an action potential.
- There are different receptors to detect different stimuli, including thermoreceptors, osmoreceptors, chemoreceptors, pain receptors and touch receptors.
- Reflexes are a rapid, automatic response to a change in environment. They often protect the body from harm, and may be innate or learnt.
- Spinal reflexes are carried out without input from the brain. They involve a stimulus, a receptor, a sensory neuron, possibly one or more interneurons, a motor neuron and an effector.
- The endocrine and nervous systems both transmit messages through the body.
- The nervous system reacts quickly and affects specific targets, but the effect is short lasting.
- The endocrine system is slower to react and generally has a broader target, but the effect is longer lasting.

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CHAPTER 3 GLOSSARY

Acquired reflex A response to a stimulus that has been learnt through practice

Action potential The rapid depolarisation and repolarisation of the cell membrane

Afferent neuron *see* sensory neuron

All-or-none response A response of a constant size regardless of the strength of the stimulus; with respect to nerve cells, a nerve impulse is transmitted at full strength or not at all

Association neuron *see* interneuron

Axon An extension of the cell body of a nerve cell; carries nerve impulses away from the cell body

Axon terminal The end of a branch of the axon

Bipolar neuron A neuron with two processes – one axon and one dendrite – arising from opposite sides of the cell body; these neurons are sensory, such as the neurons found in the retina of the eye

Cell body The part of a neuron that contains the nucleus

Chemoreceptor A receptor sensitive to particular chemicals

Connector neuron *see* interneuron

Core temperature The temperature inside the body

Dendrite An extension of the body of a nerve cell; carries nerve impulses into the cell body

Depolarisation The process of becoming depolarised

Depolarised Describes the membrane of a nerve cell when there is no difference in electrical charge between the inside and outside of the membrane

Effector neuron *see* motor neuron

Efferent neuron *see* motor neuron

Electrochemical change The change in electrical voltage brought about by changes in the concentration of ions inside and outside the cell membrane of a neuron

Extracellular fluid Fluid outside the body cells; includes tissue fluid and blood plasma

Hyperpolarisation The process of becoming hyperpolarised

Hyperpolarised Describes the membrane of a nerve cell when it has a lower membrane potential than normal

Innate reflex A response to a stimulus that is acquired genetically and is therefore present at birth

Interneuron A nerve cell in the brain or spinal cord that carries messages between other nerve cells; also called association neuron, connector neuron or relay neuron

Intracellular fluid The fluid inside cells

Ion A charged atom or molecule

Leakage channel A protein channel that is always open

Membrane potential The electrical voltage across the membrane of a cell (usually a nerve cell)

Motor neuron A nerve cell that carries messages from the brain or spinal cord to effector organs (muscles and glands); also called an effector neuron

Multipolar neuron A nerve cell with one axon and many dendrites; the most common type of neuron

Myelin sheath A white, fatty sheath that surrounds some nerve fibres

Myelinated fibre A nerve fibre that has a myelin sheath

Nerve A bundle of nerve fibres

Nerve fibre A projection from a nerve cell body with its associated coverings; usually refers to an axon

Nerve impulse The electrochemical change that travels along the membrane of a nerve cell; the message carried by a nerve

Neurilemma A sheath surrounding a nerve fibre

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Neuromuscular junction The junction between branches of a motor nerve cell and a muscle fibre; also called the motor end plate

Neuron A nerve cell; the basic structural and functional unit of the nervous system

Neurotransmitter A molecule that carries a nerve impulse across the small gap between branches of adjacent nerve cells

Node of Ranvier A gap in the myelin sheath of a nerve fibre

Osmoreceptor A receptor sensitive to osmotic pressure of body fluids

Pain receptor A receptor that is stimulated by damage to tissues

Polarised Describes the situation when the inside of the membrane of a nerve cell has a negative electrical charge compared with the outside

Potential difference A difference in electrical charge between two locations

Pseudounipolar neuron A neuron with a single process that splits into two; the cell body is to one side of the axon; in humans, such neurons are sensory and carry messages to the spinal cord

Receptor A structure that detects a stimulus

Receptor neuron *see* sensory neuron

Reflex A rapid, automatic response to a change in the external or internal environment; tries to restore homeostasis

Reflex arc The pathway travelled by nerve impulses from receptor to effector in a reflex

Refractory period A short period following a stimulus during which a nerve cell or a muscle fibre cannot be stimulated again

Relay neuron *see* interneuron

Repolarisation The process of becoming repolarised

Repolarised A membrane that has returned to a polarised state

Resting membrane potential The membrane potential of unstimulated nerve cells

Saltatory conduction The conduction of a nerve impulse along a myelinated nerve fibre; the impulse seems to jump from one node of Ranvier to the next

Schwann cell A cell that wraps around a nerve fibre, forming the myelin sheath

Sense organ Receptors grouped into a discrete organ such as the eye

Sensory neuron A nerve cell that carries messages from receptors to the brain or spinal cord; also called a receptor neuron

Sodium–potassium pump A mechanism in the membrane of a nerve cell that transports sodium ions out of the cell and potassium ions into the cell by active transport

Spinal reflex A reflex carried out by the spinal cord without involvement of the brain

Spinal reflex arc The pathway travelled by a nerve impulse from receptor to effector in a spinal reflex

Stimulus Any change, internal or external, that causes a response (plural: stimuli)

Synapse The junction between the branches of adjacent neurons

Thermoreceptor A temperature receptor; located in the skin or the hypothalamus

Threshold The potential after which an all-or-none response occurs

Touch receptor A receptor sensitive to touch

Unipolar neuron A neuron with a single process, an axon; does not occur in humans

Unmyelinated fibre A nerve fibre that has no myelin sheath

Voltage-gated channel A protein channel that is opened by an electrical stimulus

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CHAPTER 3 REVIEW QUESTIONS

Recall

1 Describe how the sheath of a myelinated fibre is formed.

2 One way that neurons can be classified is based on their function. Name the three types of neurons and describe the function of each.

3 a Define 'electrical potential'.
  b What is the potential of the membrane of a nerve cell when it is not conducting a nerve impulse?

4 a Define 'action potential'.
  b Formation of an action potential is an all-or-none response. Define 'all-or-none response'.

5 What is the 'refractory period' of an action potential?

6 a Explain how a nerve impulse passes along a nerve fibre.
  b Explain the difference between the way a nerve impulse is conducted along a myelinated and an unmyelinated nerve fibre.

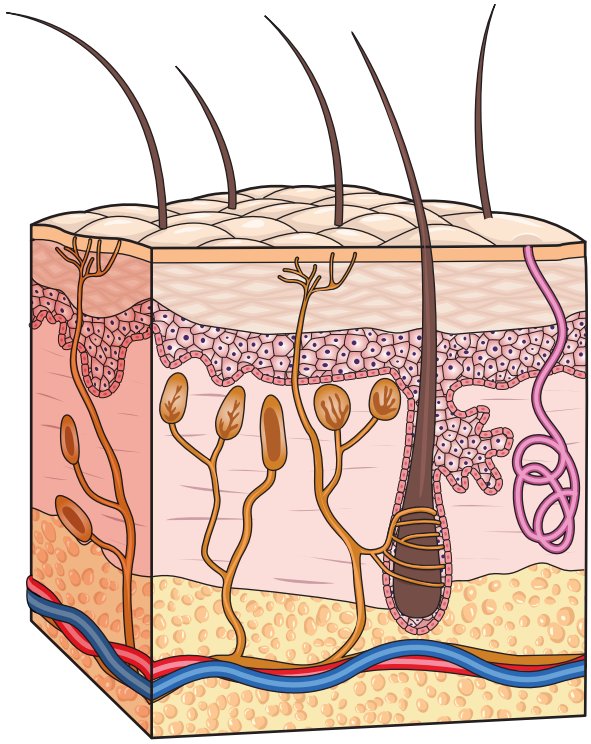
7 a What is a synapse?
  b Describe how a nerve message is carried across a synapse.

8 What is the difference between a synapse and a neuromuscular junction?

9 a Describe three differences between the action of nerves and that of hormones.
  b Describe some of the similarities between the nervous and endocrine systems.

10 In what parts of the body are thermoreceptors found?

11 In the diagram below, identify the receptors that would be stimulated by:
  a light touch
  b pressure or vibration
  c movement of hairs
  d pain.



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Explain

12 Explain the difference between a myelinated fibre and an unmyelinated fibre.

13 a Explain the difference between multipolar, bipolar, unipolar and pseudounipolar neurons.
   b Give an example of where each of these can be found.

14 Explain the difference between a neuron, a nerve and a nerve fibre.

15 Explain how the potential of a resting nerve cell membrane is maintained.

16 Explain the role of calcium ions in the transmission of a nerve impulse across a synapse.

17 Explain why a nerve impulse can only cross a synapse in one direction.

18 Explain how we are able to distinguish between a light touch and heavy pressure on the skin.

Apply

19 In what ways do nerve cells differ from most body cells?

20 A nerve impulse is often described as an electrochemical change. Explain why it is described in this way.

21 Hyperkalaemia is a higher-than-normal level of potassium in the blood and therefore in the extracellular fluid. What effect would hyperkalaemia have on the resting membrane potential of nerve cells?

22 In an examination a student stated that 'an action potential is another name for a nerve impulse'. Is this statement correct? Explain your answer.

23 Lightly press a pencil point on to the skin of your palm. Gradually increase the force with which you are pushing the pencil. How are you able to distinguish different intensities of the same stimulus?

24 The speed of transmission of nerve impulses can vary from 2 m/s to 140 m/s. Explain how there can be such a wide range of speeds of transmission of impulses.

25 Name the type of receptor that would recognise:
   a an increase in carbon dioxide in the blood
   b a graze on an elbow
   c a light breeze blowing.

26 Many reflexes are protective. List five protective reflexes.

27 A driver approaching traffic lights saw the lights change from green to amber. She transferred her foot from the accelerator to the brake in order to stop. Describe the pathways of the nerve impulses that would be involved in this response.

28 When you withdraw your hand from a painful stimulus, the response occurs before you become consciously aware that you have hurt yourself. Explain how this is possible.

29 Why would it be unwise to continually take painkillers for a particular pain without seeking medical help?

Extend

30 Multiple sclerosis is caused by destruction of the myelin sheath. Use references to find out how damage to the sheath results in the jerky body and limb movements, double vision, slurred speech and paralysis that may occur as a result of the disease.

31 Doctors may use reflexes to find out whether a patient has an impairment of the nervous system. Absence or exaggeration of a particular reflex may indicate damage to nerves or to the spinal cord through injury or disease. Conduct research to find out about the following reflexes and what absence or exaggeration of the reflex could indicate:
   a patellar reflex (knee jerk)
   b Achilles reflex (ankle jerk)
   c abdominal reflex
   d plantar reflex and Babinski sign.