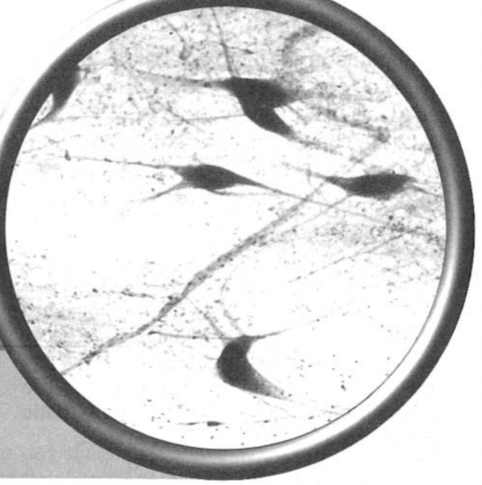
Nerves



OCR: Unit F214, Module 1: Communication and Homeostasis
4.1.2: Nerves

CIE: CORE SYLLABUS
N (f-k): Regulation and Control

Learning Objectives

☐ 1. Compile your own glossary from the **KEY WORDS** displayed in **bold type** in the learning objectives below.

Neurone Structure and Function *(pages 27-30)*

☐ 2. Describe the basic features of nerve cells (**neurones**), including reference to their electrical excitability. Describe the structure and functions of **sensory** and **motor** (**effector**) **neurones**.

☐ 3. Compare and contrast the structure of **myelinated** and **non-myelinated motor neurones**. Include reference to the role of supporting cells (**oligodendrocytes** and **Schwann cells)** in the myelination of motor neurones.

☐ 4. Contrast the nature of the nerve impulse in **myelinated** and **non-myelinated** fibres and explain reasons for the difference. Explain how myelination, axon diameter, and temperature affect the speed of impulse conduction.

☐ 5. Explain what is meant by a **reflex**. Using a diagram, describe the functioning of a simple spinal reflex arc involving three neurones and identify the neurone types involved. Appreciate the adaptive value of reflexes.

☐ 6. Explain how the **resting potential** of a neurone is established and maintained. Include reference to **ion pumps** and the movement of Na^+ and K^+, the differential permeability of the membrane, and the generation of an **electrochemical gradient**.

☐ 7. Describe the generation of the **action potential** (nerve impulse) with reference to the change in membrane permeability of the nerve leading to **depolarisation** and the **all-or-nothing** nature of the impulse. Explain the significance of the **frequency** of impulse conduction in encoding information about the stimulus strength.

☐ 8. Interpret graphs of the voltage changes occurring during the generation of an action potential.

☐ 9. Describe how an action potential is propagated along a myelinated nerve by **saltatory conduction**. Explain the roles of **myelin** and the **nodes of Ranvier** and include reference to the **voltage-gated** ion channels.

☐ 10. Explain the significance of the **refractory period** in producing discrete impulses.

Synapses *(pages 31-32)*

☐ 11. Describe the role of **synapses** in nervous systems. Understand that transmission at **chemical synapses** involves **neurotransmitters** and understand how these differ functionally from hormones.

☐ 12. Describe the structure of a **cholinergic synapse** and recognise the **neuromuscular junction** as a specialised cholinergic synapse.

☐ 13. Describe the sequence of events at a cholinergic synapse following arrival of an **action potential** at the **presynaptic terminal**. Describe the role of Ca^{2+} and **acetylcholine**, and the generation of the action potential in the **postsynaptic neurone**.

☐ 14. Describe the role of synapses in **unidirectionality** and **integration** through **summation** and **inhibition**.

Sensory Reception *(page 33)*

☐ 15. Describe the role of sensory receptors in mammals as **biological transducers**. Use examples to explain the following features of sensory receptors:
(a) They respond to specific stimuli by producing generator potentials.
(b) The strength of receptor response is proportional to the stimulus strength.
(c) They show **sensory adaptation**.

☐ 16. Using an example, describe the structure of a sensory receptor. Identify the stimulus for response in the receptor, and explain how the response is achieved.

Textbooks

See page 7 for textbook page references relating to this topic, and the lists on pages 5-6 for details of the texts below.

- Clegg, C.J., 1998. **Mammals: Structure and Function** (John Murray), pp. 58-69
- Rowett, H.G.Q., 1999. **Basic Anatomy & Physiology**, (John Murray), pp. 60-79.

Presentation MEDIA to support this topic: **Anatomy & Physiology**

Periodicals

See page 6 for details of publishers of periodicals:

STUDENT'S REFERENCE

- **Refractory Period** Biol. Sci. Rev., 20(4) April 2008, pp. 7-9. *The nature and purpose of the refractory period in response stimuli. The biological principles involved are discussed with in the context of the refractory period of the human heart.*
- **A Pacinian Corpuscle** Biol. Sci. Rev., 12(3) Jan. 2000, pp. 33-34. *An account of the structure and operation of a common pressure receptor.*
- **Making the Connection** Biol. Sci. Rev.,13(3) Jan. 2001, pp. 10-13. *The central nervous system, neurotransmitters, and synapses.*

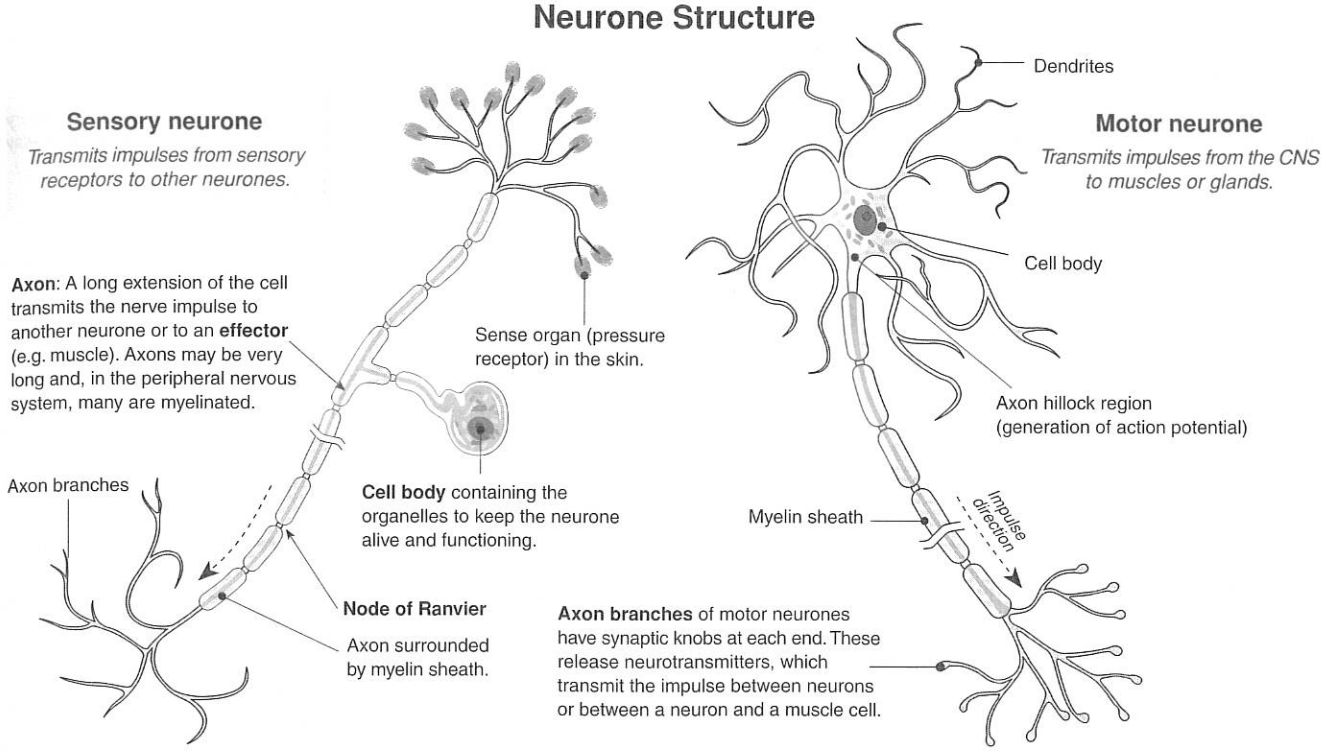
Internet

See pages 8-9 for details of how to access **Bio Links** from our web site: **www.biozone.co.uk**
From Bio Links, access sites under the topics:
ANATOMY & PHYSIOLOGY > **General sites**:
• Anatomy & Physiology • Human physiology lecture notes • WebAnatomy > **Neuroscience**:
• Basic neural processes • Neuroscience for kids
• Seeing, hearing, smelling the world

Neurone Structure and Function

The nervous and endocrine systems are the body's regulatory and coordinating systems. Homeostasis depends on the nervous system detecting, interpreting, and responding appropriately to both internal and external stimuli. Many of these responses are involuntary and are achieved through **reflexes** (overleaf). Information, in the form of electrochemical impulses, is transmitted along nerve cells (**neurones**) to effectors. The speed of impulse conduction depends primarily on the axon diameter and whether or not the axon is **myelinated**. Within the tolerable physiological range, an increase in temperature also increases the speed of impulse conduction. In cool environments, impulses travel faster in endothermic than in ectothermic vertebrates. Neurones typically consist of a cell body, dendrites, and an axon. The basic structure of sensory and motor neurones is described below.

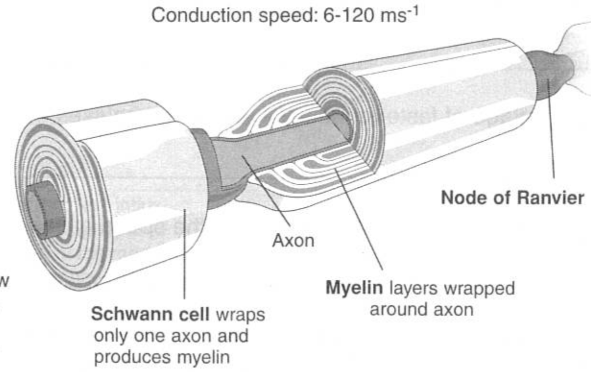
Neurone Structure

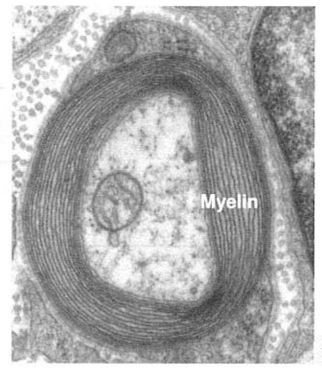


Where conduction speed is important, the axons of neurones are sheathed within a lipid and protein rich substance called **myelin**. Myelin is produced by **oligodendrocytes** in the central nervous system (CNS) and by **Schwann cells** in the peripheral nervous system (PNS). At intervals along the axons of myelinated neurones, there are gaps between neighbouring Schwann cells and their sheaths. These are called **nodes of Ranvier**. Myelin acts as an insulator, increasing the speed at which nerve impulses travel because it prevents ion flow across the neurone membrane and forces the current to "jump" along the axon from node to node.

Myelinated Neurones

Diameter: 1-25 µm
Conduction speed: 6-120 ms^{-1}





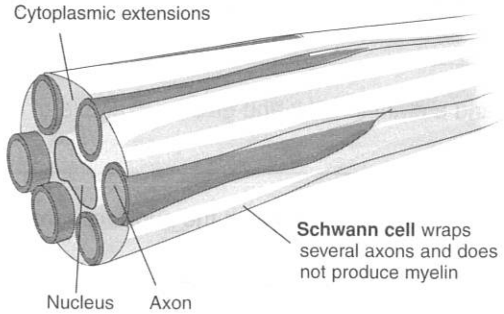
WIKI

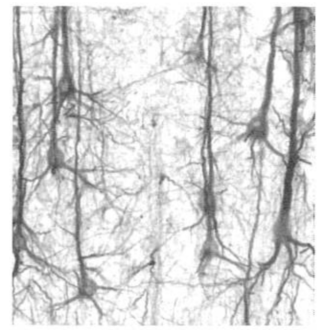
TEM cross section through a myelinated axon

Non-myelinated axons are relatively more common in the CNS where the distances travelled are less than in the PNS. Here, the axons are encased within the cytoplasmic extensions of oligodendrocytes or Schwann cells, rather than within a myelin sheath. The speed of impulse conduction is slower than in myelinated neurones because the nerve impulse is propagated along the entire axon membrane, rather than jumping from node to node as occurs in myelinated neurones. Conduction speeds are slower than in myelinated neurones, although they are faster in larger neurones (there is less ion leakage from a larger diameter axon).

Non-myelinated Neurones

Diameter: <1 µm in vertebrates
Conduction speed: 0.2-0.5 ms^{-1}





UC Regents David campus

Unmyelinated pyramidal neurons of the cerebral cortex

Related activities: Nervous Regulatory Systems, Action Potentials
Web links: Unipolar and Multipolar Neurones, Knee Jerk Reflex

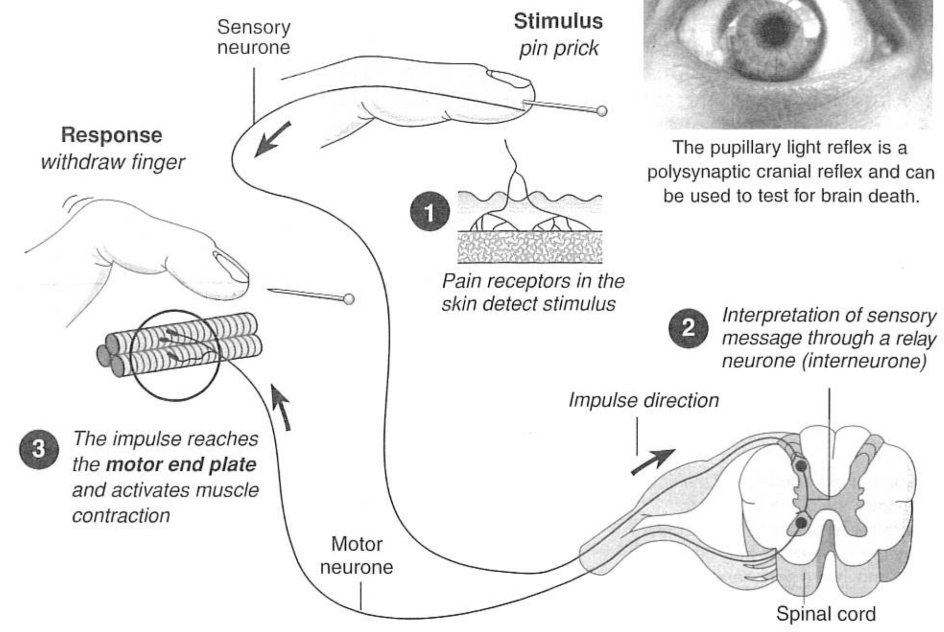
Nerves

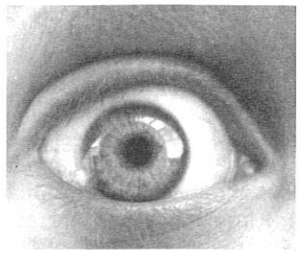
A **reflex** is an automatic, involuntary response to a stimulus involving a small number of neurones and a central nervous system (CNS) processing point (usually the spinal cord, but sometimes the brain stem). This type of circuit is often called a **reflex arc**.

Reflexes permit rapid, involuntary responses to stimuli. Reflexes are classified according to the number of CNS synapses involved: **monosynaptic reflexes** involve only one CNS synapse (e.g. knee jerk reflex), **polysynaptic reflexes** involve two or more (e.g. pain withdrawal reflex). Both of these are spinal reflexes.

The pupil reflex (opening and closing of the pupil in response to light on the retina) and is an example of a **cranial reflex**.

A Polysynaptic Reflex Arc: Pain Withdrawal





The pupillary light reflex is a polysynaptic cranial reflex and can be used to test for brain death.

1. Describe a structural difference between a motor and a sensory neurone:

2. (a) Explain the function of myelination in neurones:

   (b) Name the cell type responsible for myelination in the CNS:

   (c) Name the cell type responsible for myelination in the PNS:

   (d) Explain why myelination is a typically a feature of neurones in the peripheral nervous system:

3. Explain how myelination increases the speed of nerve impulse conduction:

4. (a) Describe the adaptive advantage of faster conduction of nerve impulses:

   (b) Suggest why increasing the axon diameter also increases the speed of impulse conduction:

5. Multiple sclerosis (MS) is a disease involving progressive destruction of the myelin sheaths around axons. Explain why MS impairs nervous system function even though the axons are still intact:

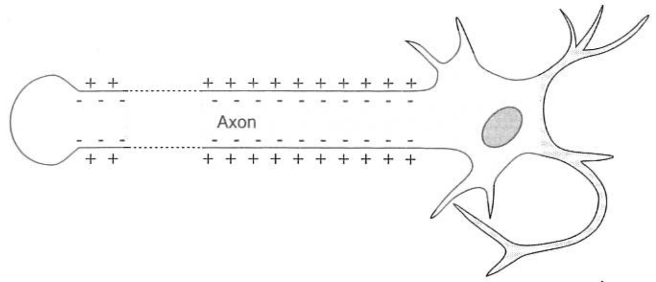
6. Explain why higher reasoning or conscious thought are not necessary or desirable features of reflex behaviours:

7. Distinguish between a spinal and a cranial reflex and give an example of each:

8. Describe the adaptive value of cranial reflexes such as the pupillary light reflex and the blink reflex:

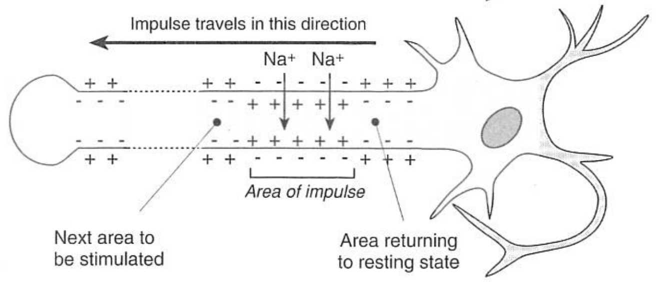
Action Potentials

The plasma membranes of cells, including neurones, contain **sodium-potassium ion pumps** which actively pump sodium ions (Na^+) out of the cell and potassium ions (K^+) into the cell. The action of these ion pumps in neurones creates a separation of charge (a potential difference or voltage) either side of the membrane and makes the cells **electrically excitable**. It is this property that enables neurones to transmit electrical impulses. The **resting state** of a neurone, with a net negative charge inside, is maintained by the sodium-potassium pumps, which actively move two K^+ into the neurone for every three Na^+ moved out (below left). When a nerve is stimulated, a brief increase in membrane permeability to Na^+ temporarily reverses the membrane polarity (a depolarisation). After the nerve impulse passes, the sodium-potassium pump restores the resting potential. The depolarisation is propagated along the axon by local current in non-myelinated fibres and by **saltatory conduction** in myelinated fibres. Impulses pass from neurone to neurone by crossing junctions called **synapses**.



The Resting Neurone

When a neurone is not transmitting an impulse, the inside of the cell is negatively charged compared with the outside of the cell. The cell is said to be electrically polarised, because the inside and the outside of the cell are oppositely charged. The potential difference (voltage) across the membrane is called the **resting potential** and for most nerve cells is about -70 mV. Nerve transmission is possible because this membrane potential exists.

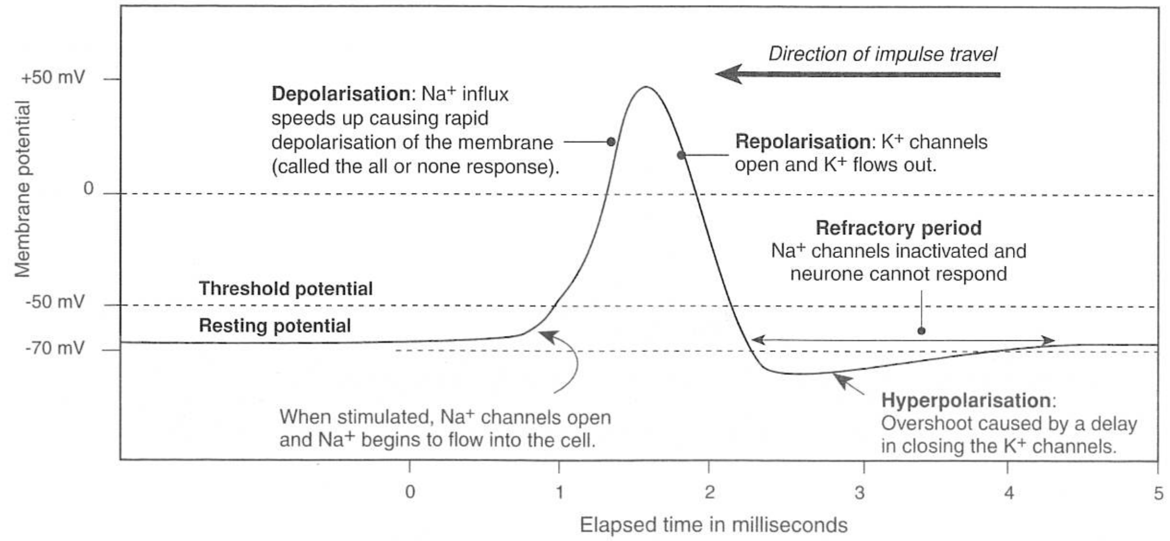


The Nerve Impulse

When a neurone is stimulated, the distribution of charges on each side of the membrane changes. For a millisecond, the charges reverse. This process, called **depolarisation**, causes a burst of electrical activity to pass along the axon of the neurone. As the charge reversal reaches one region, local currents depolarise the next region. In this way the impulse spreads along the axon. An impulse that spreads this way is called an **action potential**.

The Action Potential and the All or Nothing Law

The depolarisation described above can be illustrated as a change in membrane potential (in millivolts). In order for an action potential to be generated, the stimulation must be strong enough to reach the **threshold potential**; the voltage at which the depolarisation of the membrane becomes unstoppable and the action potential is generated. The action potential is **all or nothing** in its generation and because of this, impulses (once generated) always reach threshold and move along the axon without attenuation. The resting potential is restored by the movement of potassium ions (K^+) out of the cell. During this **refractory period**, the nerve cannot respond, so nerve impulses are discrete. Note that action potentials are always the same size, but the frequency of impulses can convey information about the stimulus intensity; the higher the frequency of impulses, the stronger the stimulus



1. In your own words, explain what an action potential is:

Related activities: Neurone Structure and Function
Web links: Nerve Action Potential, Neurobiology

2. (a) Describe a defining feature of neurones: ______________________

____

(b) Explain how the supporting cells of nervous tissue (e.g. Schwann cells) differ from neurones: ______________________

____

3. Explain how an action potential is able to pass along a neurone: ______________________

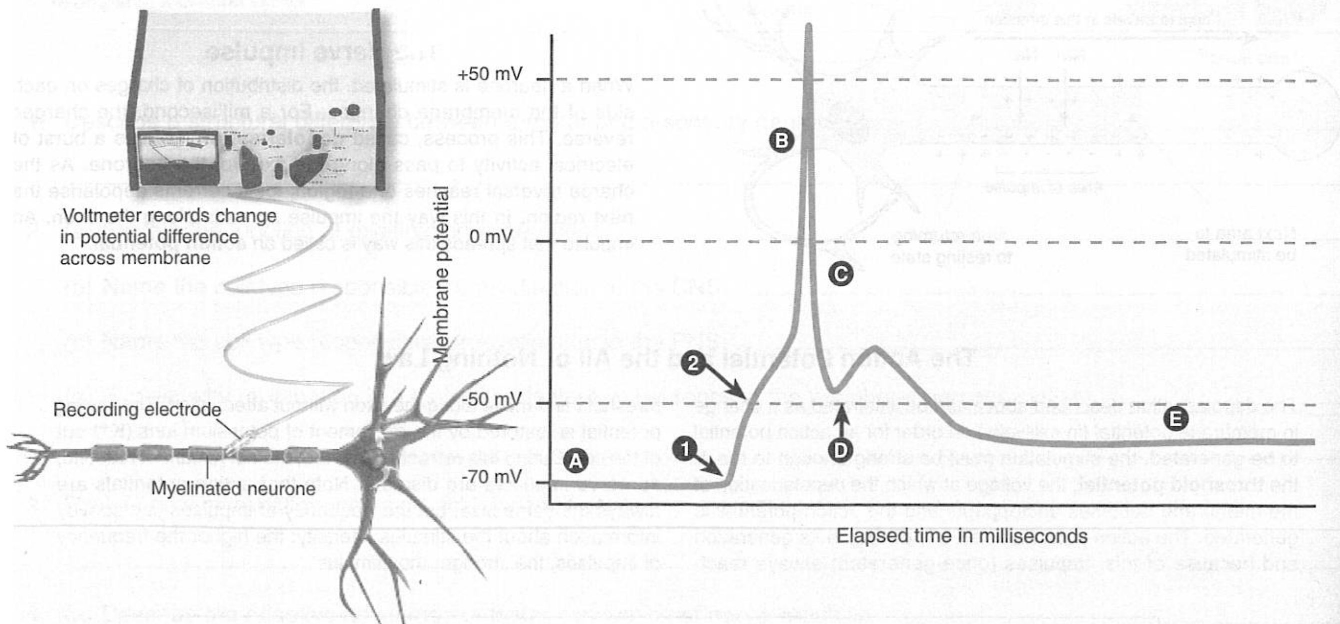
____

____

4. Explain how the refractory period influences the direction in which an impulse will travel: ______________________

____

____



5. Action potentials themselves are indistinguishable from each other. Explain how the nervous system is able to interpret the impulses correctly and bring about an appropriate response:

____

____

____

6. (a) The graph above shows a recording of the changes in membrane potential in an axon during transmission of an action potential. Match each stage (**A-E**) to the correct summary provided below.

☐ Membrane depolarisation (due to rapid Na^+ entry across the axon membrane).

☐ Hyperpolarisation (an overshoot caused by the delay in closing of K^+ channels).

☐ Return to resting potential after the stimulus has passed.

☐ Repolarisation as the Na^+ channels close and slower K^+ channels begin to open.

☐ The membrane s resting potential.

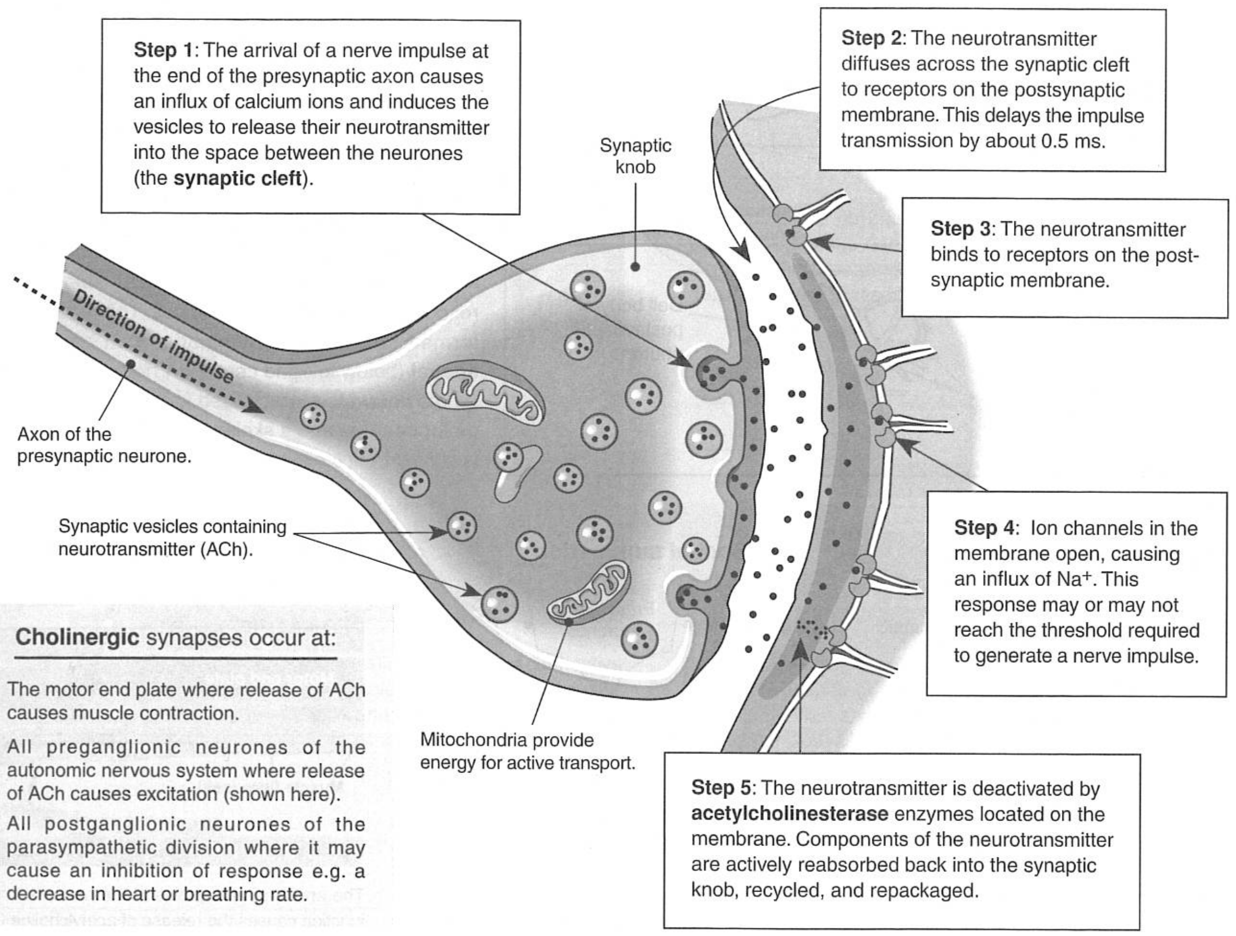
(b) Explain what is happening at point **1** on the graph: ______________________

(c) Explain what is happening at point **2** on the graph: ______________________

The Cholinergic Synapse

Action potentials are transmitted between neurones across **synapses**: junctions between the end of one axon and the dendrite or cell body of a receiving neurone. Electrical synapses, where cells are electrically coupled through gap junctions between cells, occur in heart muscle and in the retina, but they are relatively uncommon elsewhere. Most synapses in the nervous system are **chemical synapses**. In these, the axon terminal is a swollen knob, and a small gap, the **synaptic cleft**, separates it from the receiving neurone. The synaptic knobs are filled with tiny packets of chemicals called **neurotransmitters**. Nerve transmission involves the diffusion of the neurotransmitter across the cleft, where it interacts with the receiving membrane and causes an electrical response. The response of a receiving (post-synaptic) cell to the arrival of a neurotransmitter depends on the nature of the cell itself, on its location in the nervous system, and on the neurotransmitter involved. Synapses that release acetylcholine (ACh) are termed **cholinergic**. In the example below, ACh results in membrane depolarisation and an action potential (an excitatory response). Unlike electrical synapses, transmission at chemical synapses is always unidirectional.

The Structure of a Cholinergic Synapse



Cholinergic synapses occur at:

- The motor end plate where release of ACh causes muscle contraction.
- All preganglionic neurones of the autonomic nervous system where release of ACh causes excitation (shown here).
- All postganglionic neurones of the parasympathetic division where it may cause an inhibition of response e.g. a decrease in heart or breathing rate.

1. Explain what is meant by a **synapse**: ______________________

2. Explain what causes the release of neurotransmitter into the synaptic cleft: ______________________

____

3. State why there is a brief delay in transmission of an impulse across the synapse: ______________________

____

4. (a) State how the neurotransmitter is deactivated: ______________________

(b) Explain why it is important for the neurotransmitter substance to be deactivated soon after its release:

____

5. Consult a reference source to identify one function of acetylcholine in the nervous system: ______________________

____

6. Suggest one factor that might influence the strength of the response in the receiving cell: ______________________

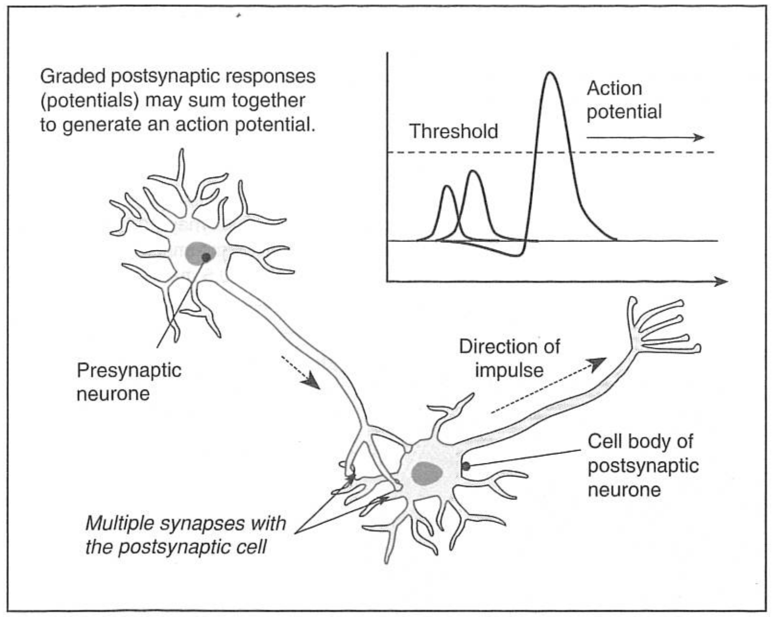
____

Nerves

Related activities: Action Potentials, Integration at Synapses
Web links: Nerve Synapse

Integration at Synapses

Synapses play a pivotal role in the ability of the nervous system to respond appropriately to stimulation and to adapt to change. The nature of synaptic transmission allows the **integration** (interpretation and coordination) of inputs from many sources. These inputs need not be just excitatory (causing depolarisation). Inhibition results when the neurotransmitter released causes negative chloride ions (rather than sodium ions) to enter the postsynaptic neurone. The postsynaptic neurone then becomes more negative inside (hyperpolarised) and an action potential is less likely to be generated. At synapses, it is the sum of **all** inputs (excitatory and inhibitory) that leads to the final response in a postsynaptic cell. Integration at synapses makes possible the various responses we have to stimuli. It is also the most probable mechanism by which learning and memory are achieved.

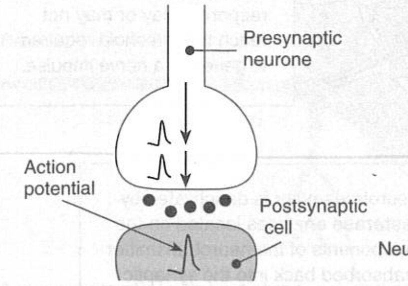


Synapses and Summation

Nerve transmission across chemical synapses has several advantages, despite the delay caused by neurotransmitter diffusion. Chemical synapses transmit impulses in one direction to a precise location and, because they rely on a limited supply of neurotransmitter, they are subject to fatigue (inability to respond to repeated stimulation). This protects the system against overstimulation.

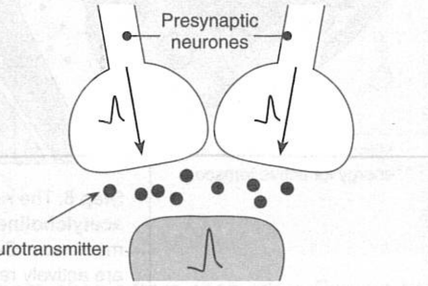
Synapses also act as centres for the **integration** of inputs from many sources. The response of a postsynaptic cell is often graded; it is not strong enough on its own to generate an action potential. However, because the strength of the response is related to the amount of neurotransmitter released, subthreshold responses can sum to produce a response in the post-synaptic cell. This additive effect is termed **summation**. Summation can be **temporal** or **spatial** (below left and centre). A neuromuscular junction (photo below) is a specialised form of synapse between a motor neurone and a skeletal muscle fibre. Functionally, it is similar to any excitatory cholinergic synapse.

1 Temporal summation



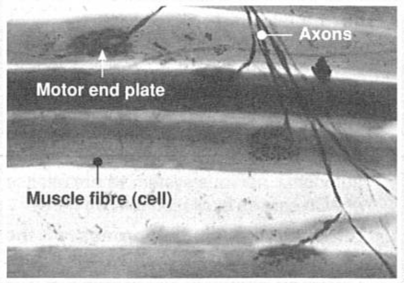
Several impulses may arrive at the synapse in quick succession from a single axon. The individual responses are so close together in time that they sum to reach threshold and produce an action potential in the postsynaptic neurone.

2 Spatial summation



Individual impulses from spatially separated axon terminals may arrive **simultaneously** at different regions of the same postsynaptic neurone. The responses from the different places sum to reach threshold and produce an action potential.

3 Neuromuscular junction



The arrival of an impulse at the neuromuscular junction causes the release of acetylcholine from the synaptic knobs. This causes the muscle cell membrane (sarcolemma) to depolarise, and an action potential is generated in the muscle cell.

1. Explain the purpose of nervous system integration: ______

2. (a) Explain what is meant by **summation**: ______

   (b) In simple terms, distinguish between temporal and spatial summation: ______

3. Describe two ways in which a neuromuscular junction is similar to any excitatory cholinergic synapse:

   (a) ______

   (b) ______

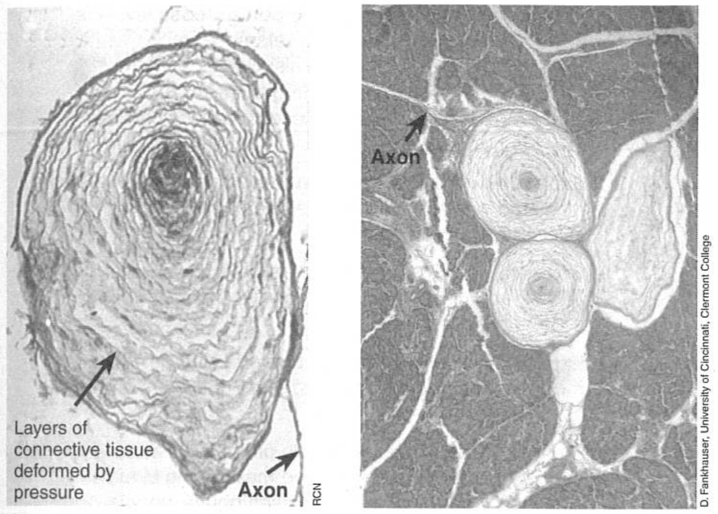
Related activities: Action Potentials, The Cholinergic Synapse

The Basis of Sensory Perception

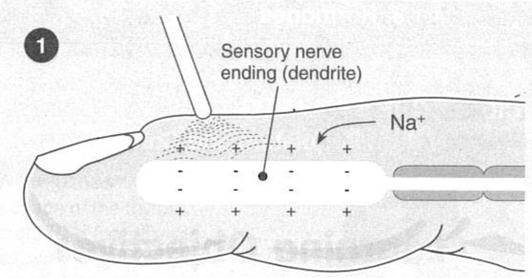
Sensory receptors are specialised to detect stimuli and respond by producing an electrical discharge. In this way they act as **biological transducers**, converting the energy from a stimulus into an electrochemical signal. Stimulation of a sensory receptor cell results in an electrical impulse with specific properties. The frequency of impulses produced by the receptor cell encodes information about the strength of the stimulus; a stronger stimulus produces more frequent impulses. Sensory receptors also show **sensory adaptation** and will cease responding to a stimulus of the same intensity. The simplest sensory receptors consist of a single sensory neuron (e.g. free nerve endings). More complex sense cells form synapses with their sensory neurons (e.g. taste buds). Sensory receptors are classified according to the stimuli to which they respond (for example, photoreceptors respond to light). The response of a simple **mechanoreceptor**, the Pacinian corpuscle, to a stimulus (pressure) is described below.

The Pacinian Corpuscle

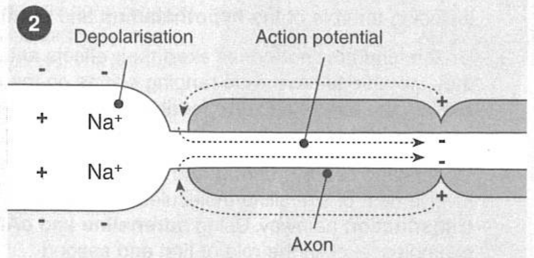
Pacinian corpuscles are pressure receptors occurring in deep subcutaneous tissues all over the body. They are relatively large and simple in structure, consisting of a sensory nerve ending (dendrite) surrounded by a capsule of layered connective tissue. Pressure deforms the capsule, stretching the nerve ending and leading to a localised depolarisation. Once a **threshold** value is reached, an **action potential** propagates along the axon.



Pacinian corpuscle (above, left), illustrating the distinctive layers of connective tissue. The photograph on the right shows corpuscles grouped together in the pancreas. Pacinian corpuscles are rapidly adapting receptors; they fire at the beginning and end of a stimulus, but do not respond to unchanging pressure.



Deforming the corpuscle leads to an increase in the permeability of the nerve to sodium. Na^+ diffuses into the nerve ending creating a localised depolarisation. This depolarisation is called a **generator potential**.



A volley of **action potentials** is triggered once the generator potential reaches or exceeds a **threshold value**. These action potentials are conducted along the sensory axon. A strong stimulus results in a high frequency of impulses.

1. Explain why sensory receptors are termed 'biological transducers': ______

2. Explain the significance of linking the magnitude of a sensory response to stimulus intensity: ______

3. Explain the physiological importance of sensory adaptation: ______

4. (a) Describe the properties of a generator potential: ______

   (b) Suggest why a simple mechanoreceptor, such as the Pacinian corpuscle, does not fire action potentials unless a stimulus of threshold value is reached:

   ______

Nerves

Related activities: Action Potentials
Web links: Neurone Information Coding and Transfer, Hair Cell Transduction