Neurones transmit messages in the form of nerve impulses. These impulses are electrical, but involve the movement of positively charged ions, not electrons. A nerve impulse can travel along a neurone at speeds as high as 100 metres per second.

## RESTING POTENTIALS

Neurones pump ions across their plasma membranes by active transport. Sodium is pumped out of the neurone and potassium is pumped in. Concentration gradients of both sodium and potassium are established across the membrane. The inside of the neurone develops a net negative charge, compared with the outside, because of the presence of chloride and other negatively charged ions.

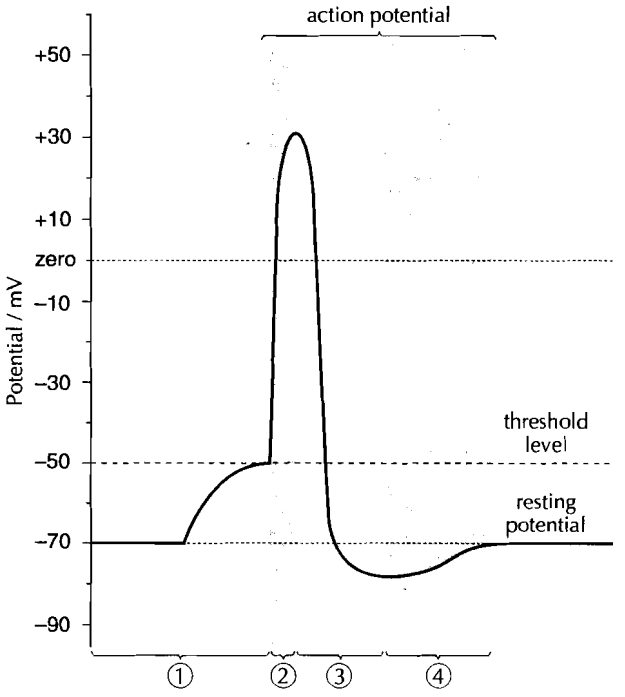
There is therefore an electrical potential or voltage across the membrane. This is called the **resting potential**.

*The resting potential is the electrical potential across the plasma membrane of a cell that is not conducting an impulse.*

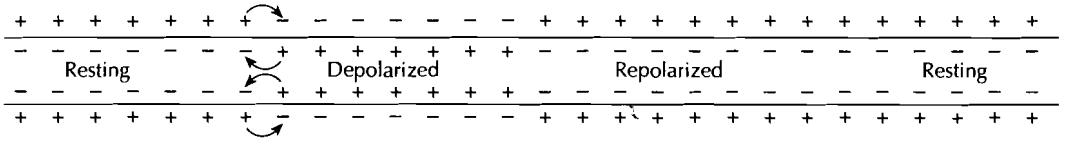
## ACTION POTENTIALS

When an impulse passes along the neurone, sodium and potassium ions are allowed to diffuse across the membrane, through voltage-gated ion channels. The electrical potential across the membrane is initially reversed but is then restored. This is called an **action potential**. The figure (right) shows the changes in membrane polarisation that occur during an action potential. The figure (below) shows the net charges inside and outside a neurone and the figure (bottom) shows ion movements.

*An action potential is the reversal and restoration of the electrical potential across the plasma membrane of a cell, as an electrical impulse passes along it.*




**Changes in net charge during an action potential**




## Stages in the passage of a nerve impulse

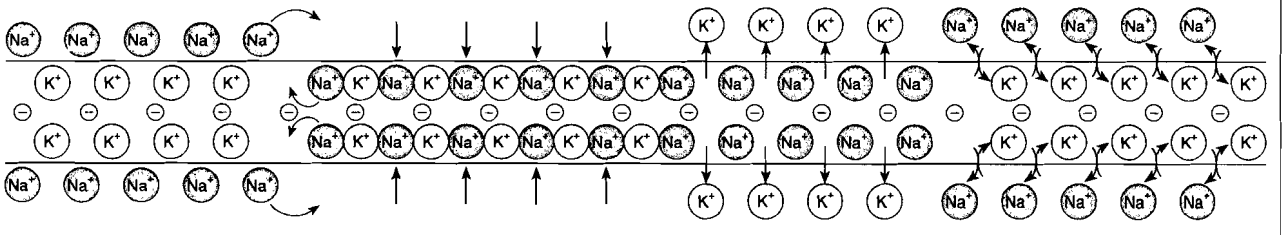
① An action potential in one part of a neurone causes an action potential to develop in the next section of the neurone. This is due to diffusion of sodium ions between the region with an action potential and the region at the resting potential. These ion movements, local currents, reduce the resting potential. If the potential rises above the threshold level, voltage-gated channels open.

② Sodium channels open very quickly and sodium ions diffuse into the neurone down the concentration gradient. This reduces the membrane potential and causes more sodium channels to open. The entry of positively charged sodium ions causes the inside of the neurone to develop a net positive charge compared to the outside – the potential across the membrane is reversed. This is called **depolarization**.

③ Potassium channels open after a short delay. Potassium ions diffuse out of the neurone down the concentration gradient through the opened channels. The exit of positively charged potassium ions cause the inside of the neurone to develop a net negative charge again compared with the outside – the potential across the membrane is restored. This is called **repolarization**.

④ Concentration gradients of sodium and potassium across the membrane are restored by the active transport of sodium ions out of the neurone and potassium ions into the neurone. This restores the resting potential and the neurone is then ready to conduct another nerve impulse. As before, sodium ions diffuse along inside the neurone from an adjacent region that has already depolarized and initiate depolarization.

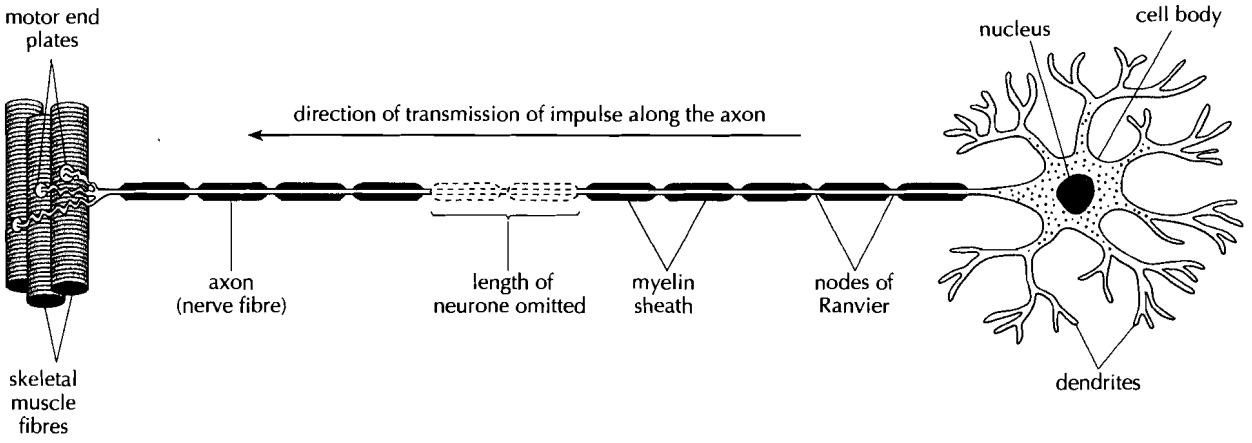
**Ion movements during an action potential**



# Neurones and synapses

## NEURONES

Neurones are nerve cells. The figure below shows the structure of a motor neurone. The function of a motor neurone is to carry impulses from the CNS (brain and spinal cord), to a muscle or to a gland. The cell body is always located in the grey matter of the CNS. The axon is located in one of the nerves of the PNS. The total length of a motor neurone can be more than one metre, most of which is omitted from the figure.




## SYNAPSES

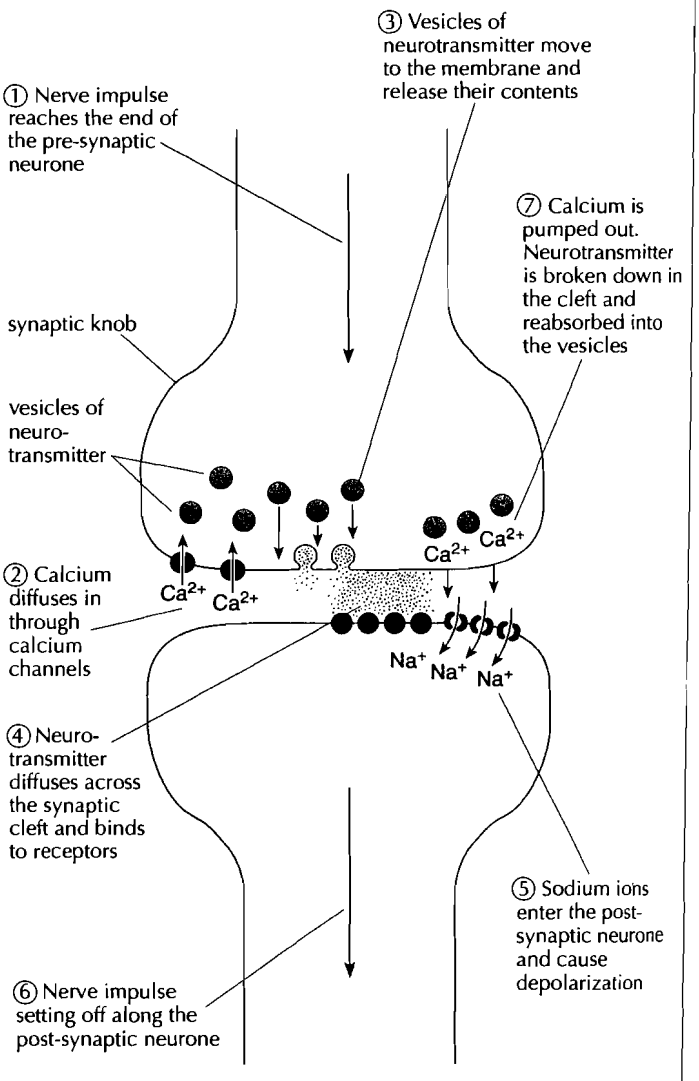
A synapse is a junction between two neurones. The plasma membranes of the neurones are separated by a narrow fluid-filled gap called the synaptic cleft. Messages are passed across the synapse in the form of chemicals called **neurotransmitters**. The neurotransmitters always pass in the same direction from the pre-synaptic neurone to the post-synaptic neurone.

Many synapses function in the following way.

1. A nerve impulse reaches the end of the pre-synaptic neurone.
2. Depolarization of the pre-synaptic membrane causes voltage-gated calcium channels to open. Calcium ions diffuse into the pre-synaptic neurone
3. Influx of calcium causes vesicles of neurotransmitter to move to the pre-synaptic membrane and fuse with it, releasing the neurotransmitter into the synaptic cleft by exocytosis.
4. The neurotransmitter diffuses across the synaptic cleft and binds to receptors in the post-synaptic membrane.
5. The receptors are transmitter-gated ion channels, which open when neurotransmitter binds. Sodium and other positively charged ions diffuse into the post-synaptic neurone. This causes depolarization of the post-synaptic membrane.
6. The depolarization passes on down the post-synaptic neurone as an action potential.
7. Neurotransmitter in the synaptic cleft is rapidly broken down, to prevent continuous synaptic transmission. For example, acetylcholine is broken down by cholinesterase in synapses that use it as a neurotransmitter. Calcium ions are pumped out of the pre-synaptic neurone into the synaptic cleft.

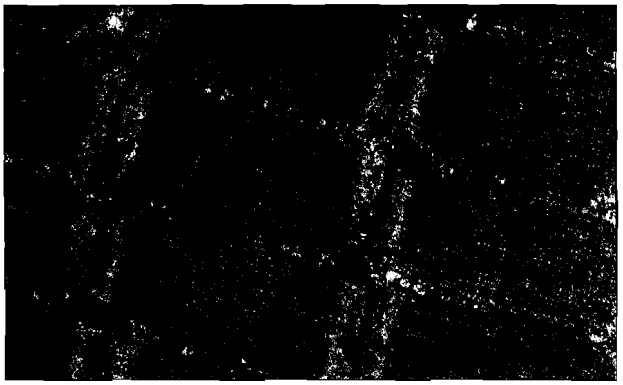
The figure (right) shows the events that occur during synaptic transmission.

### Stages in synaptic transmission

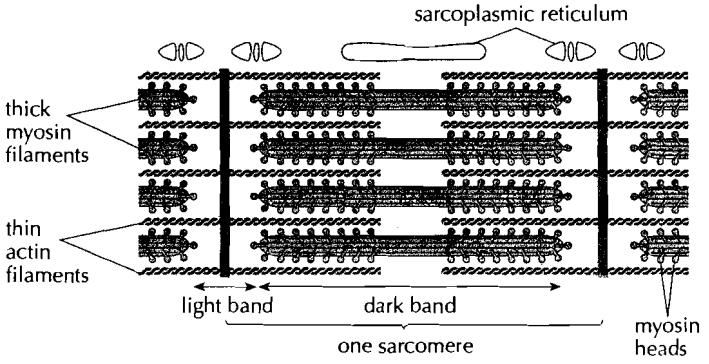


## THE STRUCTURE OF SKELETAL MUSCLE

When viewed with a light microscope, skeletal muscle is seen to consist of large multinucleate cells called **muscle fibres**. These have a striated or striped appearance. Electron micrographs show the reason for this. Muscle fibres contain cylindrical structures called **myofibrils**. The myofibrils consist of repeating units called **sarcomeres**, which have light and dark bands. Around each myofibril is a special type of endoplasmic reticulum, called sarcoplasmic reticulum. There are also mitochondria between the myofibrils. The figures are electron micrographs of skeletal muscle and the figure (below right) is a drawing.



### Structure of a sarcomere



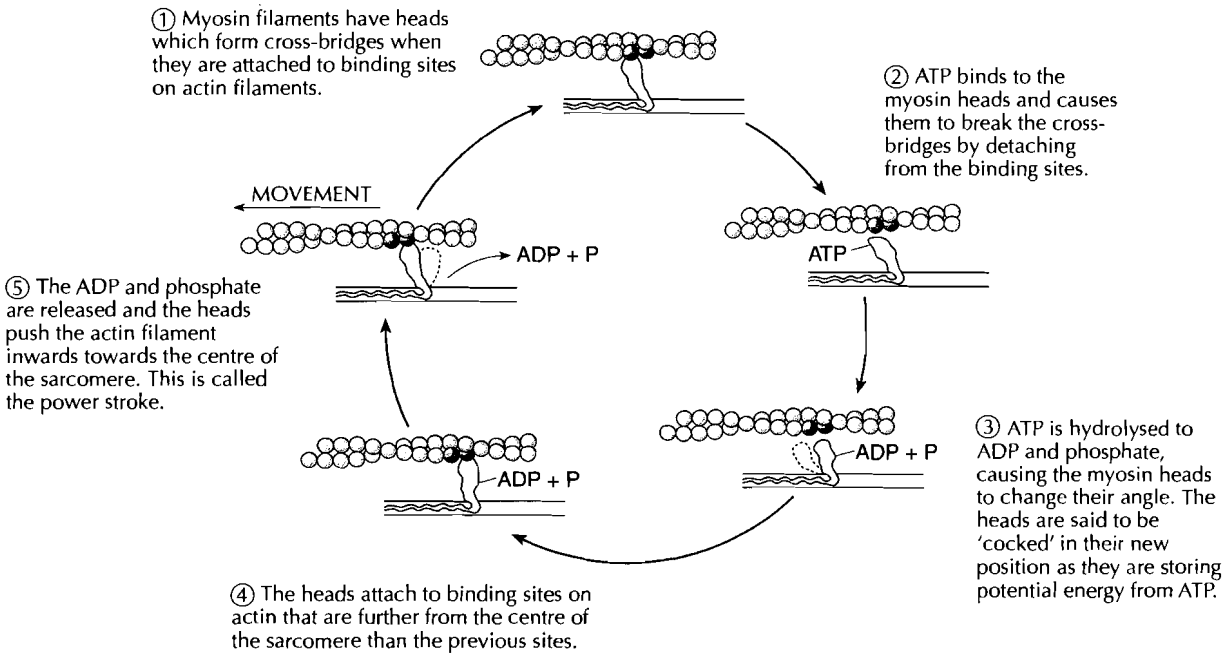

## CONTRACTION OF SKELETAL MUSCLE

The contraction of skeletal muscle is due to the sarcomeres in the myofibrils becoming shorter. This is achieved by the sliding of actin and myosin filaments over each other, using ATP to provide the necessary energy. The figure (below) shows how this occurs.

## CONTROLLING MUSCLE CONTRACTION

When a skeletal muscle fibre is relaxed, a protein called **tropomyosin** blocks the myosin binding sites on actin. If a motor neurone stimulates the muscle fibre, calcium ions are released from the sarcoplasmic reticulum. These calcium ions bind to another protein called **troponin**. Troponin then causes tropomyosin to move, which exposes the myosin binding sites and allows contraction to begin.

## STAGES IN MUSCLE CONTRACTION



# Muscles, joints and locomotion

## THE ROLES OF MUSCLES IN LOCOMOTION IN ANIMALS

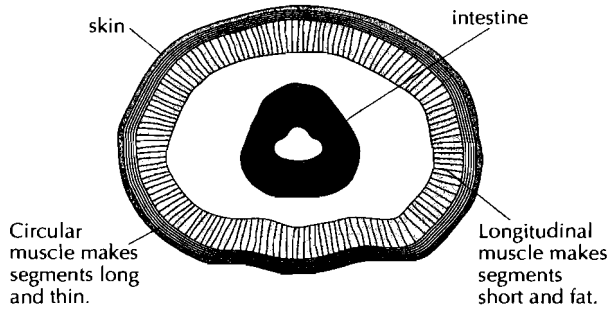
Most animals can move from one place to another. This is called **locomotion**. Animals show a wide diversity of types of locomotion. The figures (below) show four examples of locomotion. When muscles contract they provide the force needed for locomotion. Muscles only do work when they contract so pairs of muscles are needed to carry out opposite movements. These are called **antagonistic pairs**.

## THE ROLES OF NERVES AND BONES IN LOCOMOTION

Nerves stimulate muscles to contract. They stimulate each of the different muscles used in locomotion to contract at the correct time, so the movement is coordinated.
Bones provide a firm anchorage for muscles in many animals. They also act as levers, changing the size or direction of forces generated by muscles. Junctions between bones are called **joints**. The figures (bottom) show the structures of the elbow joint and their functions.

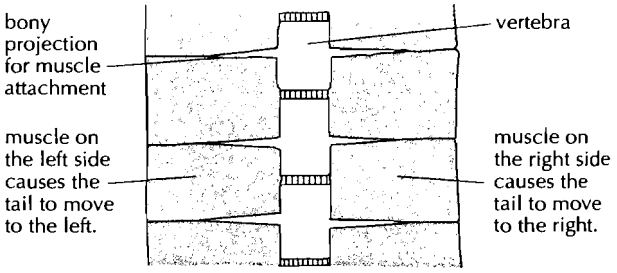
## LOCOMOTION IN EARTHWORMS

Earthworms slide forwards by making their segments alternately longer and shorter.



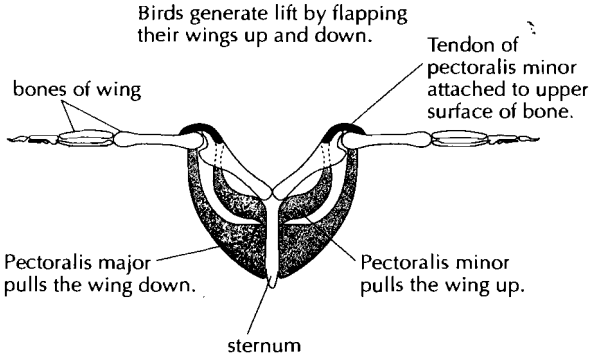

## SWIMMING IN BONY FISH

Bony fish generate a force that pushes the fish forwards by beating the tail from side to side.



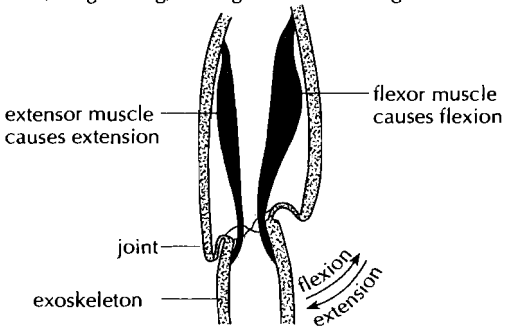

## FLYING IN BIRDS

Birds generate lift by flapping their wings up and down.




## WALKING IN AN ARTHROPOD

Crabs walk by flexing (bending) and extending (straightening) the segments of their legs.




## THE ELBOW JOINT