15 Control and co-ordination

15.1 Control and co-ordination in mammals

a) Similarities and differences between the nervous and endocrine systems

All the activities of multicellular organisms require co-ordinating, some very rapidly and some more slowly. The nervous system and the endocrine system provide co-ordination in mammals. Similar co-ordination systems exist in plants.

DIFFERENCES		
	NERVOUS	**ENDOCRINE**
communication	action potential / impulse	hormones
nature of communication	electrical (and chemical)	chemical
mode of transmission	neurone / nerve cell	blood
response destination	muscle / gland	target organs / tissue / cells
transmission speed	fast(er)	slow(er)
effects	specific / localised	(can be) widespread
response speed	fast(er)	slow(er)
duration	short-lived / temporary	can be long-lasting / permanent
receptor location	on cell surface membrane	either on cell surface membrane or within cell

SIMILARITIES	
cell signalling	both involve cell signalling
detail	both involve signal molecule binding to receptor
chemicals	both involve chemicals

b) Structures of sensory and motor neurones

- the mammalian nervous system is made up of the brain and spinal cord, which form the central nervous system (CNS)
- the cranial and spinal nerves form the peripheral nervous system (PNS)

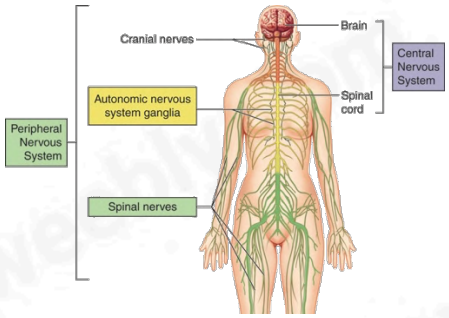
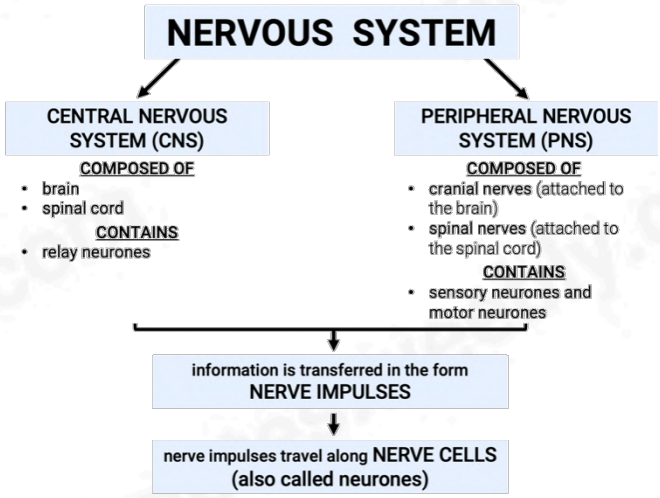


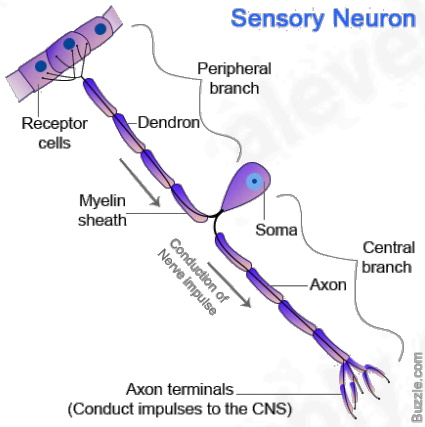
Image: http://learn.neurotechedu.com/the_nervous_system/



Neurones

- carry information directly to target cells
- are of three types –
  a) **sensory** *(receptor → CNS)*
  b) **intermediate / relay / connector** *(CNS → CNS)*
  c) **motor** *(CNS → effector)*
- the nucleus of a neurone is always in its cell body

1) **Sensory neurones** – transmit impulses from receptors to the CNS



1) has one long axon with a cell body that may be near the source of stimuli *or* in a swelling of a spinal nerve known as a ganglion

2) the nucleus is contained inside the cell body
3) lots of mitochondria and ribosomes are present inside the cell body
4) nodes of Ranvier may be present to facilitate the conduction of nerve impulses via saltatory conduction

2) **Motor neurones** – transmit impulses from the CNS to effectors (i.e., muscles and glands)

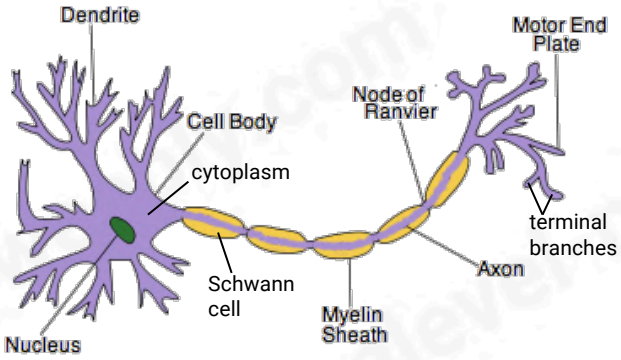


Image: https://ibguides.com/biology/notes/nerves-and-hormones/

1) has one very long axon which conducts impulses over long distances
   - the ends of branches of the axon have large numbers of mitochondria and vesicles (containing neurotransmitters)
2) nodes of Ranvier may be present to facilitate the conduction of nerve impulses via saltatory conduction
3) synaptic knobs are present at the end furthest from the cell body
4) the cell body lies within the spinal cord or brain
   - the nucleus is contained inside the cell body
   - the cytoplasm of the cell body contains lots of mitochondria, rough endoplasmic reticulum, and Nissl's granules
5) thin, short, and highly branches cytoplasmic processes extend from the cell body – these are called dendrites
   - a motor neurone has many highly branched dendrites to give a large surface area for the endings of other neurones

c) **Relay neurones** – transmit impulses from sensory to motor neurones

1) also called intermediate or connector neurones
2) found entirely within the CNS

c) Roles of sensory receptor cells *(refer to 15.1e & g first)*

- **receptor cells** – cells that respond to a stimulus by initiating an action potential (∴ they're mostly found in sense organs e.g., rod or cone cells in the retina)
- **transducers** – convert energy from one form (e.g., light, taste, smell, etc.) into energy in an electrical impulse in a neurone

The role of a chemoreceptor cell in the human taste bud in detecting stimuli and in stimulating the transmission of nerve impulses in sensory neurones

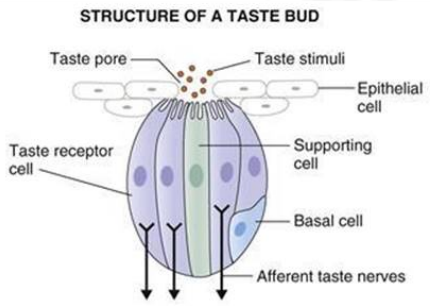


Image: https://doctorlib.info/physiology/physiology-2/23.html

1) chemicals act as a stimulus (e.g., salty, sweet)
2) chemoreceptors are specific in detecting taste and are transducers
3) Na+ diffuses into the cell upon stimulation of the receptor via microvilli
4) the membrane gets depolarised
5) Ca^{2+} channels are stimulated to open
6) Ca^{2+} enter cell
7) this causes the movement of vesicles containing neurotransmitter
8) the neurotransmitter is released by exocytosis and stimulates an action potential

d) Reflex arc

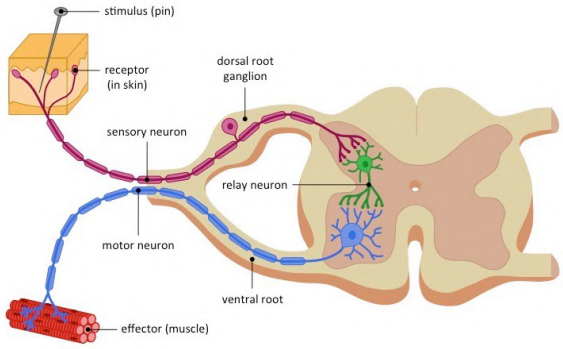
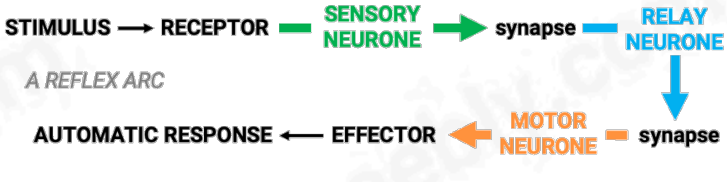


Image: https://ib.bioninja.com.au/

- **reflex arc** – the pathway along which impulses are transmitted from a receptor to an effector without involving 'conscious' regions of the brain
- **reflex action** – an immediate response by an effector to a specific stimulus without involving 'conscious' regions of the brain



e) Transmission of action potentials

- in a neurone, an action potential produces a nerve impulse, and in a muscle cell it produces the contraction required for movement
- neurones transmit electrical impulses which travel rapidly along the cell surface membrane from one end of the cell to another
- these signals are very brief changes in the distribution of electrical charge across the cell surface membrane, called **action potentials**

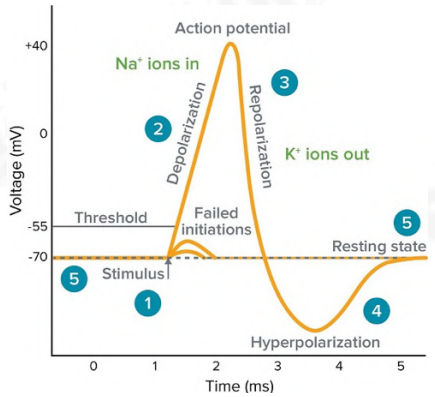
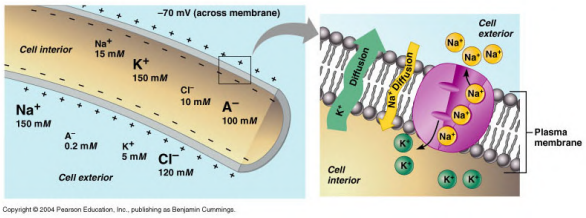


Image: https://www.moleculardevices.com/applications/patch-clamp-electrophysiology/what-action-potential#gref

Resting potential

- **resting potential** – difference in charge across the membrane when a neurone is not firing
- neurones have a negative resting potential most of the time, meaning there are more positively charged ions outside than inside the cell
- this value is typically around -70mV
- because there is a potential difference across the cell surface membrane, it's said to be polarised



1) How a resting potential is maintained

BY KEEPING MORE POSITIVE IONS OUTSIDE THAN INSIDE THE CELL

- **more Na^+ outside than inside the neurone**
- **more K^+ inside than outside the neurone**

1) done by using a Na^+/K^+ pump; it uses ATP to pump $3Na^+$ out and $2K^+$ in
    - results in a neurone with a more positive charge outside than inside, creating a negative resting potential
2) the membrane also has more protein channels for K^+ than Na^+, causing K^+ to leak out of the cell
    - due to the concentration of K^+ being higher inside, it diffuses out of the neurone down its concentration gradient, making the resting potential even lower
    - K^+ diffuses out the cell faster than Na^+ can diffuse in (due to less channel proteins for Na^+ compared to K^+)
3) many negatively charged molecules are also present inside the cell (e.g., Cl^- and organic anions), and the membrane is impermeable to them ∴ neurone is more negative inside

Action potentials

- **action potential** – rapid change in potential difference across the membrane caused by changes in the permeability of cell surface membrane to Na^+ and K^+ ions
- action potentials work on an all-or-none basis – it's either triggered or it isn't *(so they're all the same size)*
- action potentials are transmitted only one at a time
- strength of the response to a stimulus is determined by the *frequency* of action potentials transmitted *(stronger stimulus, greater action potential frequency)*

How an action potential is initiated

An action potential can be divided into 5 phases – resting potential, threshold potential, depolarisation, hyperpolarisation, and the refractory period.

2) Depolarisation

This is when a positive environment is created inside the cell. This is caused by stimulation of the cell by neurotransmitters or sensory receptor cells.

1) stimulation of the axon causes Na^+ voltage-gated channels to open
2) Na^+ diffuses into the axon, down its concentration gradient
3) the membrane depolarises (meaning resting potential of cell decreases)
4) if this depolarisation reaches the threshold potential (-50 mV), more Na^+ voltage gated channels open, and an action potential has been generated
5) the inside has now reached a potential of +30mV
6) this is an example of positive feedback

3) Repolarisation

1) once +30mV has been reached, Na^+ voltage gated channels close and K^+ ones open
2) K^+ diffuses out as more K^+ is present inside the cell than out
3) Na^+/K^+ pump restarts, restoring the potential difference back to -70mv

4) Hyperpolarisation

- when hyperpolarized, the neurone is in a refractory period
- this is when membrane potential becomes even more negative than resting potential
- caused by K^+ channels being slow to close

Refractory periods

- the refractory period refers to the period of inactivity following an action potential before which the neurone can fire again
- during this time, the neurone is unresponsive to stimulation and the **ion distribution is being restored**
- Na^+ and K^+ channels are closed
- Na^+/K^+ pump is open

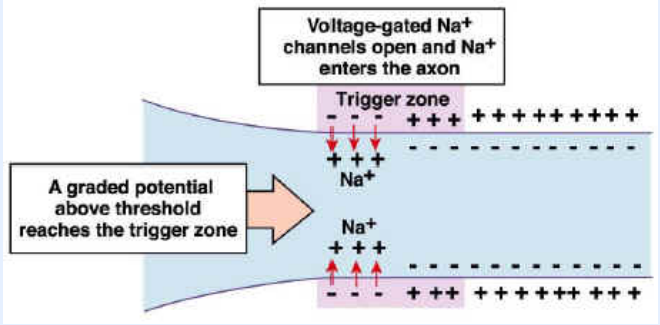
Purpose of the refractory period

1) makes action potentials discrete (they don't overlap) and unidirectional
2) the length of the refractory period determines the maximum frequency at which impulses are transmitted along neurones
3) give the neurone some time to replenish the packets of neurotransmitter found at the axon terminal, so that it can keep passing the message along

Transmission of an action potential (how an impulse is carried along the neurone)

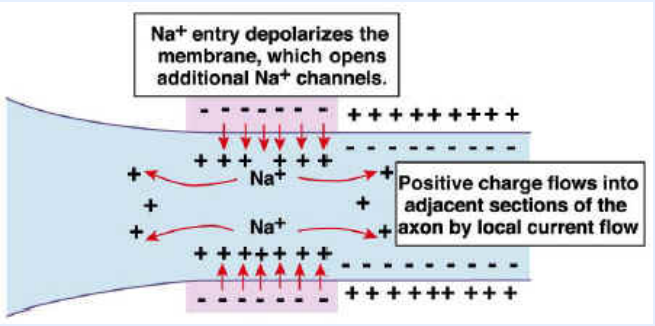
Nerve impulses are action potentials that move along the length of the axon as a unidirectional wave of depolarisation.

1) once an area on the axon has been stimulated, a local circuit is set up between the area where there is an action potential and the resting area next to it



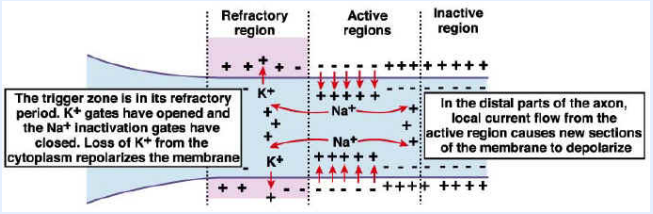
2) the flow of some Na^+ sideways towards the negative area next to it causes Na^+ channels in that area to open and depolarisation to occur there

the local reversal of the membrane potential is detected by the surrounding voltage-gated ion channels, which open when the potential changes enough



3) hence, depolarisation at one point of the axon triggers the opening of ion channels in the segment of the next axon

4) this way, the action potential is moved along the neurone



Images: http://www.biologymad.com/nervoussystem/nerveimpulses.htm

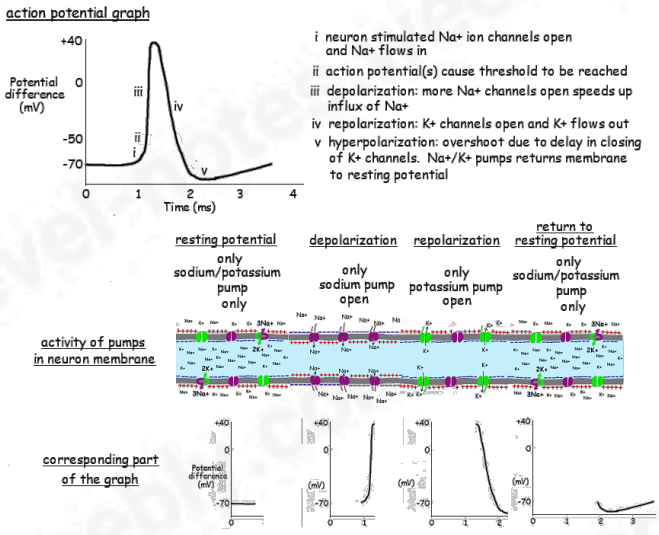
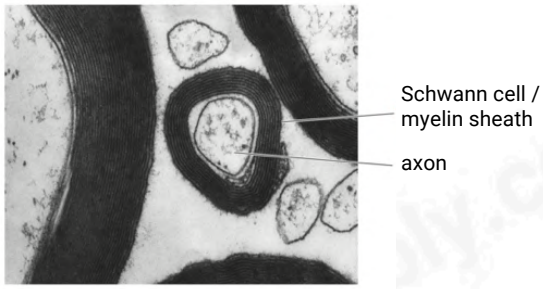


Image: http://ibbiologyhelp.com/HumanPhysiology/nervesandsynapses.html

f) Saltatory conduction

Myelination



- the axons of myelinated neurones are covered in myelin which functions as an insulating layer

- myelin is made by **Schwann cells**, and surrounds the axons of a third of motor and sensory neurones
- the Schwann cell spirals around encloses the axon in many layers of its cell surface membrane

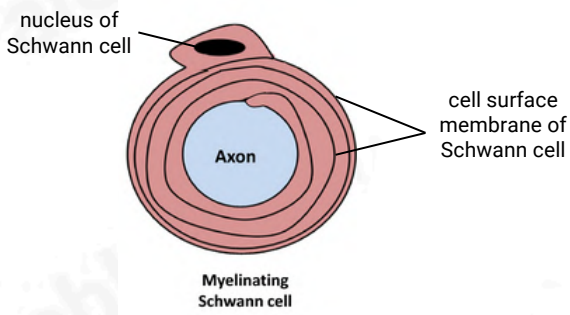


Image: https://onlinelibrary.wiley.com/doi/full/10.1111/jnc.13929

- this enclosing sheath is called the myelin sheath
- the small, uncovered areas of axon between the Schwann cells are called **nodes of Ranvier**

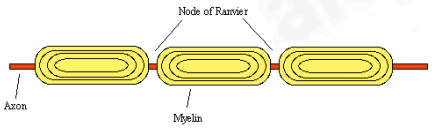


Image: https://faculty.washington.edu/chudler/salt.html

The importance of the myelin sheath

The main purpose of the myelin sheath is to increase the speed of impulses via saltatory conduction.

- along unmyelinated neurones, action potentials propagate sequentially along the axon in a continuous wave of depolarisation
- in myelinated neurones, Na^+ and K^+ cannot flow through the myelin sheath as it is insulating
- they can only move in and out of the cytoplasm at the nodes of Ranvier
- because of this, the action potential will 'jump' from one node to the next, and will travel much faster than in an unmyelinated neurone
- this process is called saltatory conduction

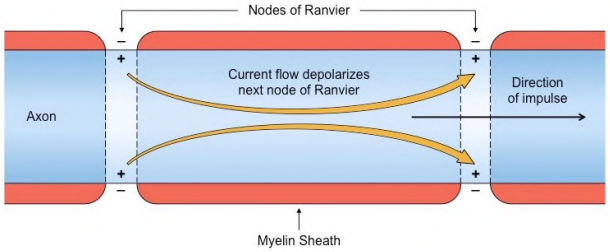


Image: https://ib.bioninja.com.au/

Summary of saltatory conduction:

1) action potential 'jumps' from node to node
2) local circuits are set up between nodes
3) conduction velocity / speed of impulses becomes faster

g) Cholinergic synapses

Cholinergic synapses are synapses that use acetylcholine (Ach) as a transmitter substance.

Structure

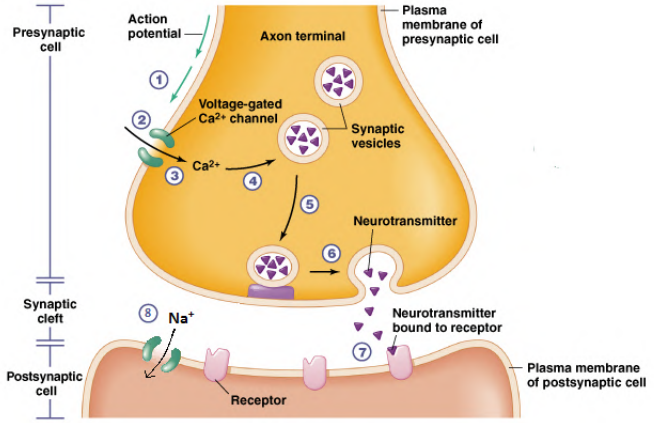


Image: http://biology4alevel.blogspot.com/2016/06/122-synapses.html

How a cholinergic synapse functions

1) action potential reaches synaptic knob (pre-synaptic membrane)
2) it stimulates opening of Ca^{2+} voltage-gated channels
3) Ca^{2+} diffuses into cytoplasm of pre-synaptic neuron
4) this causes vesicles containing ACh to move towards pre-synaptic membrane and fuse with it
5) ACh is released via exocytosis and diffuses across synaptic cleft
6) it binds to receptors on post-synaptic membrane
7) this causes ligand-gated/chemically gated Na^+ channels to open and Na^+ enter post-synaptic neuron
8) Na^+ depolarizes the membrane; an action potential is generated
9) ACh is recycled via the following steps and transported back to pre-synaptic vesicles

ACETYLCHOLINE —(ACETYLCHOLINESTERASE)→ **ACETATE + CHOLINE**

CHOLINE + ACETYL COENZYME A → **ACh**

h) Roles of synapses in the nervous system

Synapses –

1) ensure one way-transmission
   - neurotransmitters are only released on one side and receptors are present on the other
2) allow connections between one neurone and many others (interconnection of nerve pathways)
   - synapses allow neurones to connect via neurotransmitters with many other neurones which increases the range of possible responses to stimuli
3) allow the integration of impulses
   - ensures that the brain is not overloaded with sensory information

i, j) Striated muscles

Striated muscles are one of three types of muscle tissue mammals have (others being cardiac and smooth muscle).

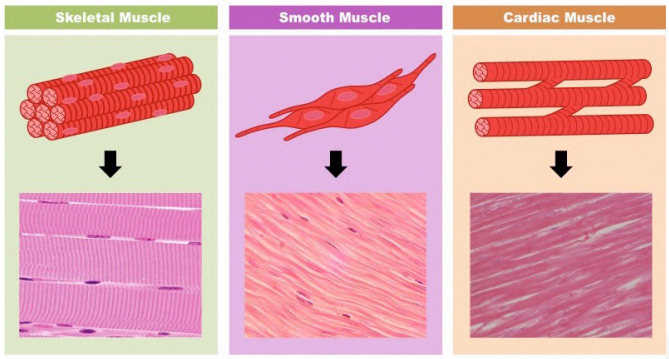


Image: https://ib.bioninja.com.au/higher-level/topic-11-animal-physiology/112-movement/types-of-muscles.html

Striated muscles have the following features:

- attached to the skeleton via tendons
- neurogenic – contact when stimulated to do so by impulses that arrive from motor neurones
- each muscle 'cell' is multinucleate and is called *syncytium*

Ultrastructure of striated muscle

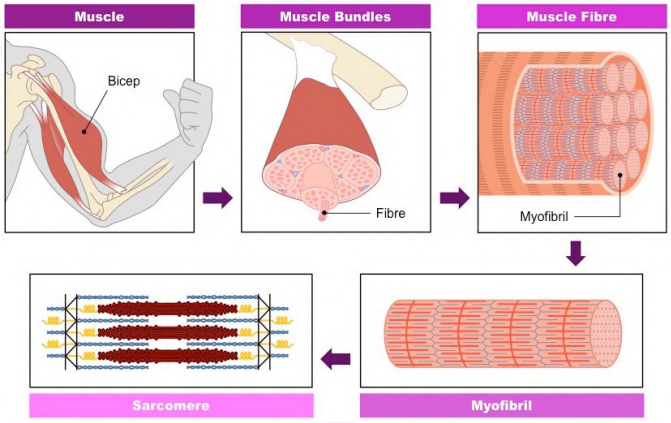


Image: https://ib.bioninja.com.au/higher-level/topic-11-animal-physiology/112-movement/muscle-fibres.html

- a muscle such as a biceps is made up of thousands of muscle fibres
- each muscle fibre is a specialised 'cell' with many nuclei – the term *syncytium* is used to describe the multinucleate muscle fibre
- the parts of the fibre are known by different terms –

* **sarcolemma – cell surface membrane**
* **sarcoplasm – cytoplasm**; lots of mitochondria present between myofibrils which generate the ATP required for muscle contraction
* **sarcoplasmic reticulum – endoplasmic reticulum**; membranes of the SR have lots of protein pumps that transport Ca^{2+} to the cisternae of the SR
* **transverse system tubules/t-tubules – infolding/invagination of the sarcolemma**

- formed by the inward extension of the sarcolemma
- function of t-tubules:
  1) allows impulses from the sarcolemma to pass to the SR
  2) maintains the Ca^{2+} store in the SR

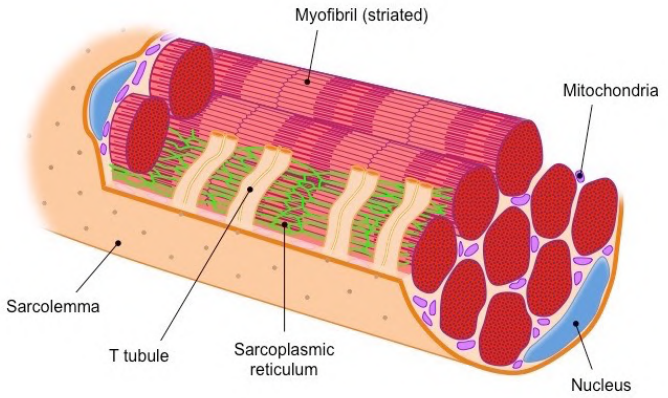
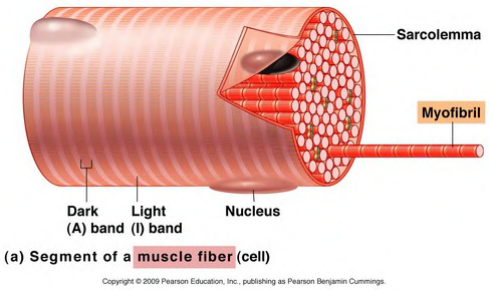
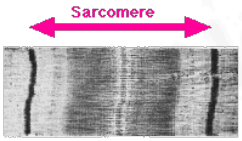


Image: https://ib.bioninja.com.au/higher-level/topic-11-animal-physiology/112-movement/types-of-muscles.html

- muscle fibres also contain tubular myofibrils that run the length of the fibre
- myofibrils are rod-like organelles
- they are responsible for muscle contraction
- these myofibrils are arranged in a very regular arrangement in the sarcoplasm, and produces the striations of the muscle



Myofibrils



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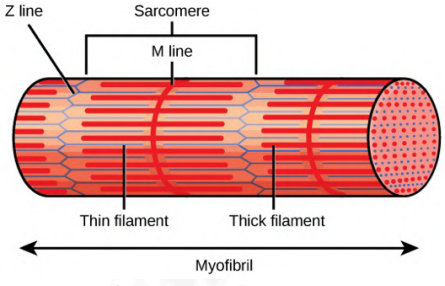

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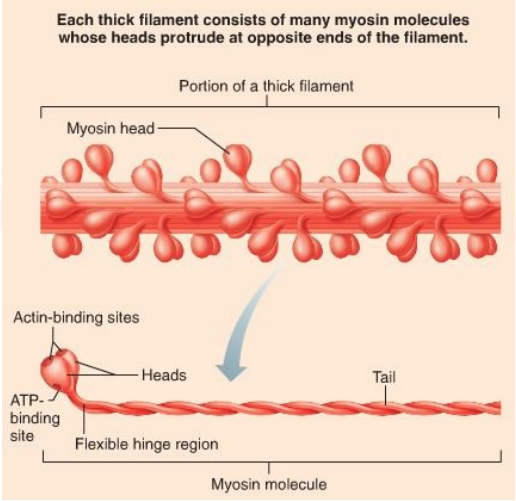
- each myofibril is made up of smaller components called filaments
  - there are thick and thin filaments, both made of proteins
  - thick filaments are made of myosin
  - thin filaments are made of actin

Structure of thick and thin filaments

Thick filaments



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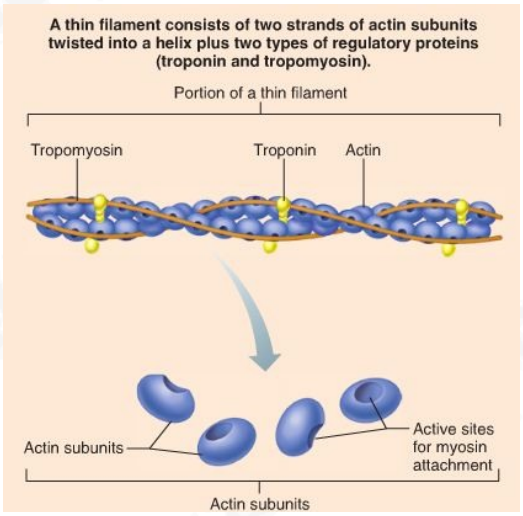
- made of myosin – a fibrous protein with two globular heads and a tail
- the heads attach to myosin binding sites present on the thin filaments
- the heads contain the ATPase enzyme which releases energy from ATP to power muscle contraction
- the globular heads point away from the M-line

Thin filaments



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- made of actin (a globular protein)
- many actin molecules link to form a chain
- 2 such chains twist to form an actin filament
- tropomyosin, a fibrous protein, is twisted around the 2 chains/actin filament
- another protein called troponin is also attached to the actin chain at regular intervals, and is the binding site for Ca^{2+}

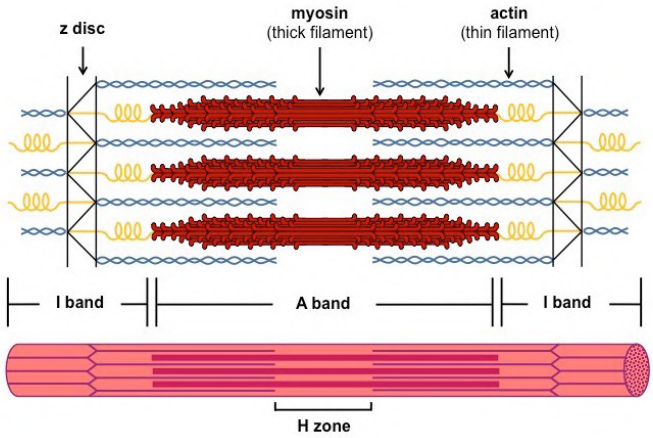


Image: https://ib.bioninja.com.au/higher-level/topic-11-animal-physiology/112-movement/sarcomeres.html

- the striated appearance of skeletal muscle is a result of repeating bands of these thin and thin filaments
  - darker parts of the stripes correspond to the thick (myosin) filaments
  - lighter parts (**I-bands**) correspond to where there are only thin (actin) filaments
  - **A-bands:** centre of the sarcomere appears darker due to the overlap of both actin and myosin filaments
  - **H-band:** within the A-band, this is where only myosin is present
  - **M-line:** the attachment site for thick filaments (myosin)
  - **Z-line/disc:** the attachment site for thin filaments (actin)
  - the part of the myofibril between 2 Z-lines is called a **sarcomere**
- sarcomeres are the repeating contractile units that make up a myofibril
- each individual sarcomere is separated by protein discs called Z-lines

k) Muscular contraction

The process of muscular contraction can be summarised in the following key steps:

a) depolarisation and Ca^{2+} release
b) sliding filament model
c) sarcomere shortening (muscle contraction)

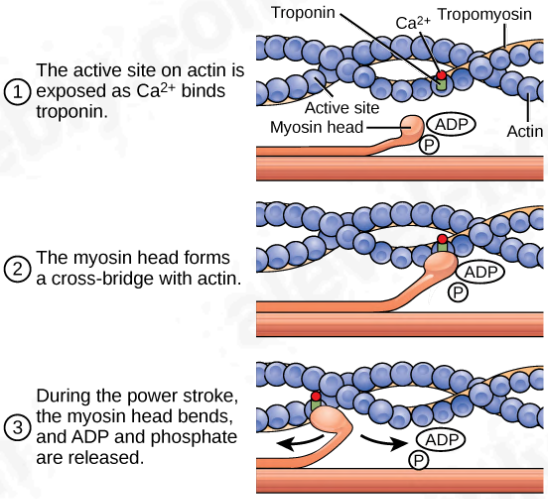
a) depolarisation and Ca^{2+} release

1) an action potential from a motor neurone triggers the release of ACh at the pre-synaptic membrane
2) ACh diffuses across the neuromuscular junction and binds to receptor proteins on the sarcolemma (post-synaptic membrane)

3) ACh initiates depolarisation within the sarcolemma, which is spread through the muscle fibre via t-tubules
   * the binding of ACh triggers ion channels to open
   * Na^+ enter and depolarise the membrane
   * an action potential is ∴ generated in the sarcolemma
   * impulses pass along the sarcolemma and t-tubules, towards the centre of the muscle fibre
4) arrival of impulses causes Ca^{2+} ion channels in the SR membrane to open
   * Ca^{2+} diffuses into the sarcoplasm surrounding the myofibrils
   * Ca^{2+} play a pivotal role in initiating muscular contractions

b) Sliding filament model

1) Ca^{2+} are released from stores in SR and bind to troponin, changing its shape
2) troponin and tropomyosin move to different positions on thin filament, exposing myosin binding sites on the actin chain
3) myosin heads then bind to exposed binding sites, forming cross-bridges between thick and thin filaments
4) ATP then binds to the myosin head, breaking the cross-bridge between actin and myosin
   - *when the ATP is broken down is only when myosin heads can attach again to actin binding sites*
5) each myosin head is an ATPase – when ATP is hydrolysed to ADP and P_i, the energy released is used to carry out the power stroke
   - *power stroke – myosin head attaching to actin binding sites while ADP and P_i remain bound*
6) the myosin heads bind to the new actin site and return to their original conformation
7) this reorientation drags the actin along the myosin in a sliding mechanism



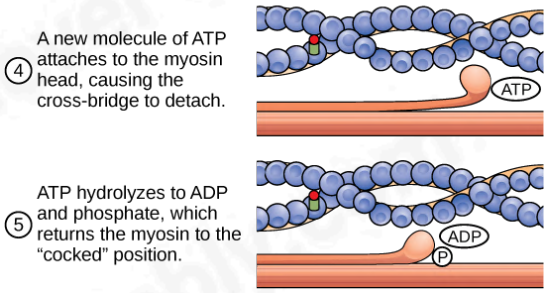


Image: "ATP and Muscle Contraction" by LibreTexts is licensed under notset.

c) Sarcomere shortening

1) the repeated reorientation of the myosin heads drags the actin filaments along the length of the myosin
2) as actin filaments are anchored to Z lines, the dragging of actin pulls the Z lines closer together, shortening the sarcomere
3) as the individual sarcomeres become shorter in length, the muscle fibres as a whole contracts

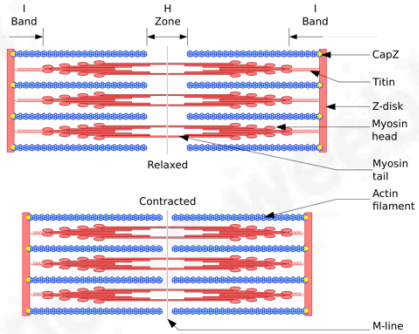


Image: By David Richfield https://commons.wikimedia.org/w/index.php?curid=2264027

Providing energy for muscular contraction

A contracting muscle requires lots of ATP. This comes from the following sources:

1) **aerobic respiration in mitochondria**
2) **lactic acid fermentation in sarcoplasm**
3) **creatine phosphate** – stored in the sarcoplasm and acts as an immediate source of energy when ATP is sarcoplasm runs out

creatine phosphate + ADP → creatine + ATP

when energy demand is less, ATP recharges creatine:

creatine + ATP → creatine phosphate + ATP

when energy demand is high, but no ATP is available to recycle creatinine:

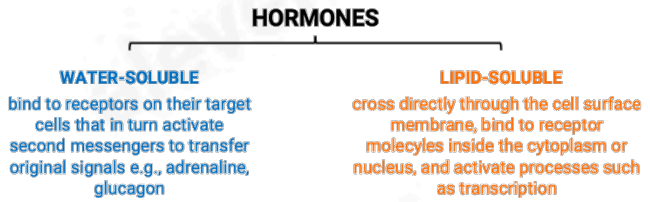
creatine → creatinine (excreted in urine)

l) Hormones and the menstrual cycle

Hormones

- are cell-signalling molecules
- they're made in endocrine glands (also called ductless glands)
- hormones are secreted directly into blood

- hormones are of a few different types, two are considered below:



The menstrual cycle

- the hormones in the menstrual cycle are steroid (lipid-soluble hormones)
- the uterine and menstrual cycles are synchronised
- the menstrual cycle is coordinated by glycoprotein hormones secreted by the anterior pituitary gland and ovaries

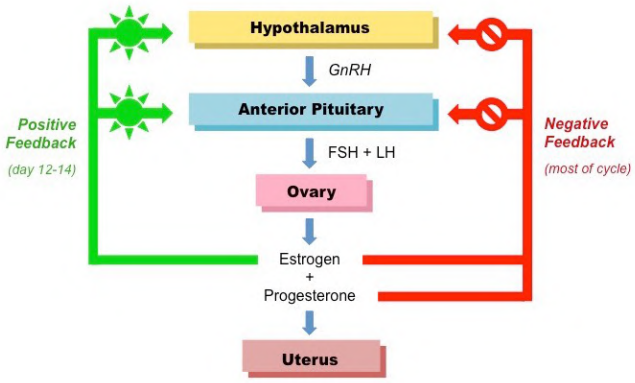
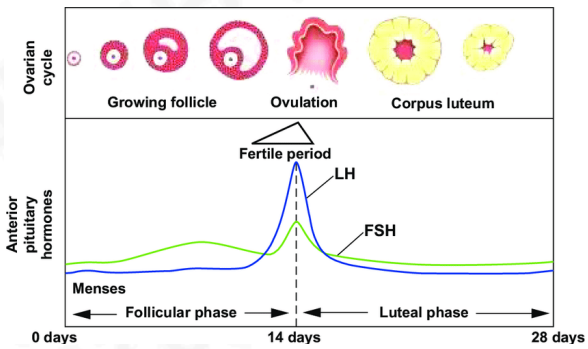


Image: https://ib.bioninja.com.au/standard-level/topic-6-human-physiology/66-hormones-homeostasis-and/menstrual-cycle.html



https://www.researchgate.net/publication/259878362_Emerging_Options_for_Emergency_Contraception

There are 4 main stages of a menstrual cycle:

a) follicular phase (days 5-13)

1) FSH (follicle stimulating hormone) and LH (luteinising hormone) are secreted from the anterior pituitary gland
2) this stimulates ovarian follicles to develop, but only one (the dominant follicle, also called Graafian follicle) matures completely
3) the Graafian follicle produces oestrogen, which inhibits FSH secretion via negative feedback to prevent other follicles from maturing
4) oestrogen stimulates the endometrium to grow, thicken, and develop numerous blood capillaries

b) ovulation (day 14)

5) midway through the cycle *(around day 12)*, when the oestrogen concentration is at a certain level *(around 2-4x its level at the start of the cycle)*, it stimulates a large surge in the secretion of LH and a lesser surge of FSH via positive feedback
6) the surge of LH causes the Graafian follicle to rupture and release an egg (secondary oocyte) into the oviduct – this is called ovulation

c) luteal phase (days 15-28)

7) the ruptured follicle develops into a slowly degenerating corpus luteum (yellow body)
8) the corpus luteum secretes high levels of progesterone, as well as lower levels of oestrogen
9) oestrogen and progesterone inhibit FSH secretion, preventing any more follicles from developing
10) oestrogen and progesterone also thicken the endometrial lining (in preparation for pregnancy)

d) menstruation (days 1-4)

11) if fertilisation occurs, the developing embryo will implant in the endometrium and release hormones to sustain the corpus luteum
12) if fertilisation doesn't occur, the corpus luteum eventually degenerates, which causing oestrogen and progesterone levels to drop
13) this decrease in oestrogen and progesterone means the endometrial lining can no longer be maintained and is sloughed away (a person's period)
14) as oestrogen and progesterone concentrations are too low to inhibit the anterior pituitary gland, the cycle resets

Summary of hormones involved in the menstrual cycle and their functions

ENDOCRINE GLAND	HORMONE	FUNCTION
anterior pituitary	FSH	1) stimulates follicular growth in the ovaries 2) stimulates oestrogen secretion (from developing follicles)
	LH	1) surge midway through the cycle causes ovulation 2) results in the formation of the corpus luteum

ovaries	oestrogen	1) thickens the endometrium 2) inhibits FSH and LH for most of the cycle 3) stimulates LH and FSH secretion pre-ovulation
	progesterone	1) thickens the endometrium 2) inhibits FSH and LH

m) Contraceptive pills

Q) Outline the biological basis of contraceptive pills containing oestrogen and progesterone [8 marks]

1) contain synthetic hormones
2) as they do not get broken down quickly so act for longer
3) oestrogen/progesterone blood concentrations remain high
4) this suppresses FSH
5) by the anterior pituitary gland (via negative feedback)
6) Graafian follicle does not develop
7) LH is not secreted
8) ovulation prevented
9) cervical mucus thickens which decreases ability of sperm to penetrate through it
10) prevents implantation / endometrium less well developed

15.2 Control and co-ordination in plants

a) Venus fly trap

The Venus fly trap is a carnivorous plant that obtains a supply of nitrogen compounds by trapping and digesting small animals, mostly insects.

Anatomy of the Venus fly trap

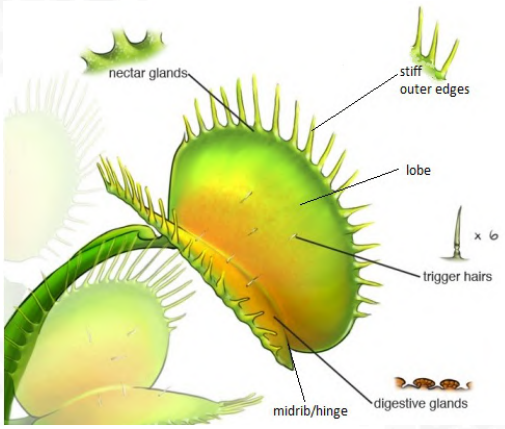


Image: http://biology4alevel.blogspot.com/2016/06/126-venus-fly-trap.html

The rapid response of the Venus fly trap

1) sensory hair is deflected
2) Ca^{2+} channels at the base of the hair open and flow in, generating a receptor potential
3) if more stimulation of the sensory hairs occurs, action potentials spread across the lobe
4) ongoing activation of the trigger hairs further triggers action potentials in the lobe
5) deflections of the hairs by the insect also stimulate Ca^{2+} entry into gland cells
6) here, Ca^{2+} stimulates the exocytosis of vesicles containing digestive enzymes
7) once the insect has been digested, the cells on the upper surface of the midrib grow slowly, opening the leaf so the trap is set yet again

Q) Describe how the production of action potentials in the leaf cells of the Venus fly trap can result in the leaves closing and trapping an insect. [5 marks]

1) action potential reaches lobe of leaf
2) H^+ pumped across surface membrane into cell wall
3) cell wall loosens / cross-links broken
4) calcium pectate breaks down in middle lamella
5) Ca^{2+} ions enter cells
6) water enters by osmosis
7) midrib cells expand and become turgid
8) leaves / lobes become concave

b) Auxin

The role of auxin in elongation growth by stimulating proton pumping to acidify cell walls

- auxins are a type of plant growth regulator (or hormone) which controls growth
- synthesised in meristems (growing tips of shoots and roots)
- transported from cell to cell via active transport, and to a lesser extent in phloem sap

Mechanism of auxins

1) auxin binds with receptors on the cell surface membrane
2) proton pumps are activated
3) H^+ are pumped into the cell wall which lowers the pH
4) expansins are activated by this decrease in pH
5) they loosen the bonds between cellulose microfibrils
6) K^+ ions enter the cells which lowers the water potential
7) cells take in water by osmosis
8) the increase in turgor causes cell walls to stretch

c, d) Gibberellin

Gibberellins are plant growth regulators that are synthesised in most parts of plants (mainly young leaves and seeds, and in stems).

The role of gibberellin in the germination of wheat or barley

- when seeds are shed from its parent plant, it's in a state of dormancy
- it contains very little water and is metabolically inactive
- useful because this allows the seed to survive adverse conditions

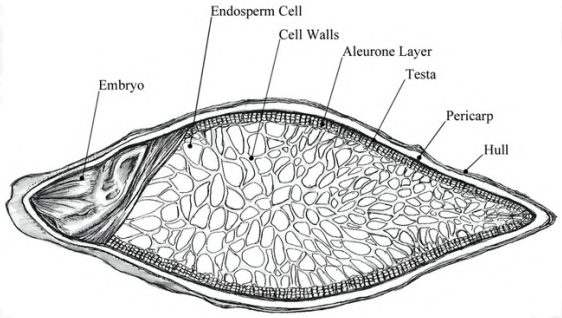
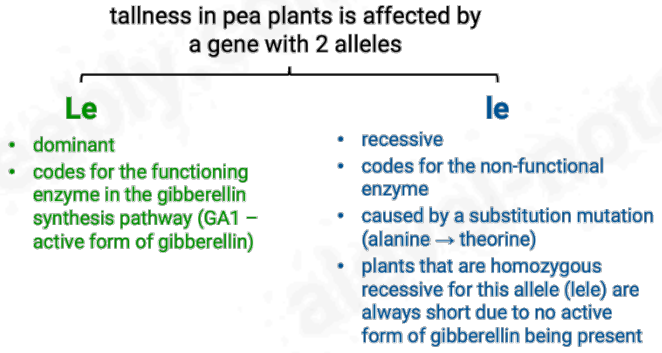


Image: https://jonathanreich.art/barley-seed-final/

1) absorption of water stimulates germination
2) embryo produces gibberellin in response to water uptake
3) gibberellin moves into aleurone layer
4) gibberellin stimulates the production of amylase
5) amylase moves into endosperm and hydrolyses starch (starch reserves present in the embryo) to maltose
6) maltose/glucose moves into embryo for ATP production for the growth of the embryo

The role of gibberellin in stem elongation

The height of some plants is partly controlled by genes:



Le (dominant) allele codes for the enzyme that converts inactive gibberellin into active gibberellin (GA1).

- active gibberellin (GA1) stimulates stem elongation by causing the breakdown of DELLA protein repressors so that growth genes can be expressed
    - DELLA proteins inhibit cell division and the expansion that drives the growth of plant organs; plant growth is stimulated via the destruction of DELLA proteins
- when these growth genes are expressed, the following occurs:
    - cell division
    - cell elongation
    - increase in internode length