SUPPORT IN TERRESTRIAL PLANTS

Importance of support in terrestrial plants

1. Enables holding leaves to receive maximum sunlight for photosynthesis
2. Enables exposing flowers in the most suitable position for pollination
3. Allows holding fruits and seeds in the possible favourable position for dispersal
4. Maintains plant shape.

SUPPORT MECHANISMS IN TERRESTRIAL DICOTS

1. Turgidity of cells

Turgor pressure: outward pressure from the inside of a fully turgid cell.
When fully turgid, the close packing of parenchyma cells in cortex and pith of the stem causes them to press against one another to keep herbaceous plants and young woody plants erect. Absence / insufficient water reduces turgor pressure causing loss of support due to wilts.

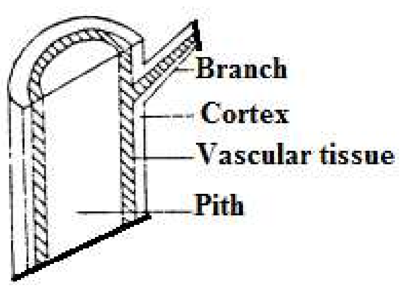
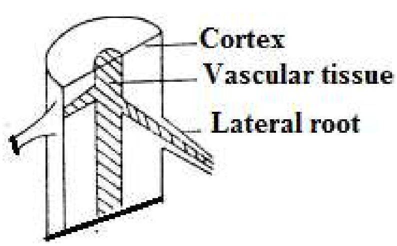
2. Mechanical tissues

(a) Collenchyma cells have uneven thickened cellulose cell walls, and are alive.
(i) Collenchyma tissue provide flexible support (a mechanical function) to stems and leaves, enabling withstanding the lateral force of the wind.
(ii) The walls of collenchyma cells can be deformed by pressure or tension and retain the new shape even if the pressure or tension ceases.
Location: in young plants, herbaceous plants and some organs such as leaves

(b) Sclerenchyma fibres and sclereids have lignified cell walls and are dead when mature.
(i) The tough and elastic cell wall of elongated fibres allow the cell to be deformed but can snap back to their original size and shape when the pressure or tension is released.
(ii) Provides great tensile or compressional strength in plants parts, such as in the vascular tissues of stems and roots and the bundle sheath of leaves
(iii) Support the tree while the elasticity allows the trunk and the branches to sway in the wind without breaking.
Location: found in small groups in cortex, pith, phloem and shells of coconuts.

3. Vascular tissues (xylem vessels and tracheids)

These are dead, the cell walls are lignified and thickened
(i) They provide the greatest mechanical strength to resist bending in the stem, reinforce against pulling in the root and are the most important supporting cells in the veins of leaves.

(ii) Vascular tissue in young dicot stems	**(iii) Vascular tissue in dicot roots**
Location: at the root periphery (near edge) This increases the resistance to the bending stresses produced by wind or the passing animals.  	***Location:*** at the root centre The solid cylinder increases the tensile strength to resist the uprooting force produced by the pulling effect of wind. The solid cylinder also provides sufficient incompressibility against the longitudinal compression by the load from overhead and against the lateral pressure exerted by the surrounding soil 

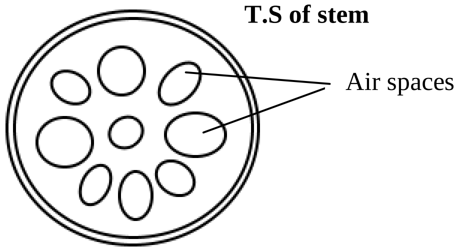
(iv) In leaves, vascular tissue is located at the upper side of midrib and lateral veins, and it extends throughout the leaf surface. This enables resisting tearing forces acting on the leaves blade by the wind.
(v) In woody stems, the lignified secondary xylem tissues (known as wood) occupy most part of the woody stem, which makes the stem very hard and rigid to avoid depending on cell turgidity for support

SUPPORT IN AQUATIC PLANTS (HYDROPHYTES)

Support from buoyancy is provided by:
1. Surrounding water, whose density is much higher than that of air, hence providing a larger upthrust force.
2. Presence of numerous large air spaces (intercellular spaces) in stems and leaves, which form air-filled cavities extending through the tissues, inside to give buoyancy.

Note: When removed from water, most hydrophytes collapse quickly because of having poorly developed (some lack) mechanical tissues (i.e. collenchyma and sclerenchyma) and xylem tissue is reduced, since it is unnecessary (no need to transport water within the body and buoyancy is provided by water for support).

COMPARISON OF SUPPORT IN TERRESTRIAL PLANTS AND HYDROPHYTES

Terrestrial Plants	**Aquatic Plants**
Require mechanical support because air will not hold up plant structures in the same way that water does.	Density of water is much higher than air, hence providing a larger upthrust force
The presence of collenchyma cells, sclerenchyma cells and the abundant highly lignified thick-walled xylem vessels in terrestrial plants implies that support depends on these specialized thick-walled cells.	No collenchyma and sclerenchyma cells are found in aquatic plants, and the poorly developed xylem vessels indicate that aquatic plants do not depend on these cells for mechanical support.
Small air spaces in stem since air with low density only provides limited support to plants.	There are numerous large air spaces in the stem and the leaf of aquatic plants suggest that aquatic plants depend on the buoyancy **T.S of stem** 

LOCOMOTION AND MOVEMENT

Locomotion: The act of changing position by the **entire** body.
Movement: The act of displacing body parts while maintaining the whole body in one position.

The study of movements is called **kinesiology.**

THE BASIC TYPES OF MOVEMENTS

Movement involves these basic mechanisms.

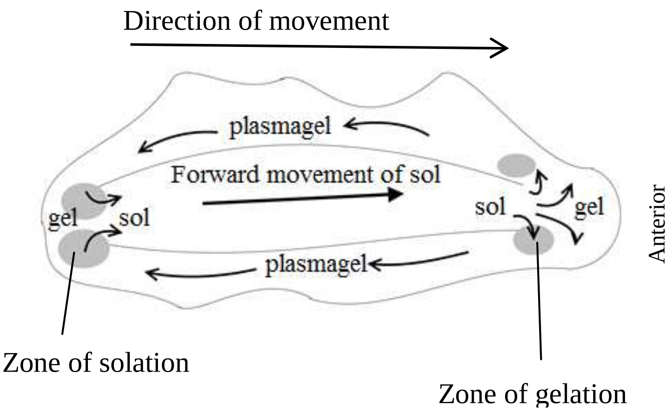
Mechanism	***Importance of the process to organisms involved***
Amoeboid movement	a) Enables amoeba to move about to **(i)** obtain food **(ii)** avoid dangers **(iii)** escape from energy. **b)** Enables white blood cells (Leucocytes) like phagocytes, macrophages of the lymph and Kupffer cells of liver to **(i)** engulf antigen or microbes **(ii)** immigrate in the circulatory fluid.

Ciliary and flagellar movement	**a)** Ciliary movement enables paramecium to **(i)** avoid danger **(ii)** drive water and food into their gullet. **b)** In certain molluscs Ciliary movement facilitates gaseous exchange by passing water currents over the gills **c)** In echinoderms Ciliary movement enables locomotion by driving water through the water vascular system. **d)** Ciliary movement of the cells lining the respiratory tract of humans drives away the microbes and dust particles towards the nose or mouth. **f)** Ciliary movement in the oviduct or fallopian tubes of human female moves ova towards the uterus. **g)** Ciliary movement in nephridia of annelids e.g. earthworms moves wastes **h)** Flagellum of sperms enables their swimming movement. **i)** Flagellum enables the movement in certain protozoans like euglena
Muscular movement	Muscular movements enable **(i)** animals to find food, mate up, avoid predators and unsuitable environmental conditions **(ii)** flow of contents in the gut and arteries **(iii)** positioning of eyes and external ears for effective functioning in some animals

AMOEBOID MOVEMENT

Definition: is a crawling-like type of movement characterised by protoplasmic protrusion to form temporary feet-like structures called pseudopodia.

●Several theories (about 8) have been advanced about the formation of pseudopodia, but the most accepted now-a-days is the **sol-gel-sol** transformation of the cytoplasm as given by ***Mast*** (1925).



Description of amoeboid movement according to the sol-gel-sol theory

● The plasmalemma attaches to the substratum

●Stimulation of the ectoplasm (plasmagel) at a certain point causes its conversion to plasmasol, and flowing of the pressured plasmasol (endoplasm) into the weakened area, forming first a bulge and then a tube.

●The movement is sustained by contraction of the outer gel layer which squeezes inwards, causing cytoplasmic streaming towards the tip of the pseudopodium.

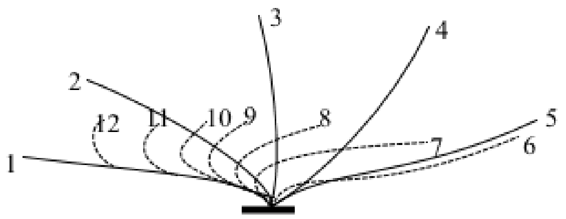
●Within the advancing tip at the **fountain zone**, plasmasol is converted to plasmagel which is then deposited on the sides of the pseudopodium. At the temporary posterior (rear/hind) end of the cell the plasma gel is converted to plasmasol, which then flows forwards into the newly formed pseudopodium so much so that the whole of body cytoplasm comes into it.

●Now the plasmagel tube contracts and the body moves forwards. Soon after this a new pseudopodium is again formed in this direction.

DESCRIPTION OF CILIARY MOVEMENT

Definition: the rhythmic beating of fine hair-like processes projecting from the cell membrane of certain cells (cilia).

Description by diagrammatic illustration



Description in words

●A ciliary beat cycle consists of an **effective (power) stroke phase** and a **passive recovery stroke phase.**

●During the **effective stroke phase** the fully extended cilium makes an oar-like movement towards one side exerting maximum force on the surrounding fluid. The cilia beat in reverse when the power stroke is directed toward the anterior end of the organism so as to propel it backwards while beating towards the posterior end causes the cell or organism to swim forward.

●In the **passive recovery stroke phase** which follows the effective stroke, the cilium moves back by propagating a bend from base to tip in an unrolling motion to reduce drag.

●The cycles of adjacent cilia are slightly out of phase so that they do not bend at exactly the same moment, resulting in **metachronal rhythm** in which waves of ciliary activity pass along the organism from front to rear.

***Metachronal rhythm**:* movements produced by the sequential action of structures such as cilia, segments of worms or many legs, producing the appearance of a travelling wave.

MUSCULAR MOVEMENT

In this compilation, muscular movement has been limited to a few vertebrates, insects and earthworms.

The unique properties of muscles which enable their functionality include:
(a) Excitability (b) Contractibility (c) Extensibility and (d) Elasticity
Muscular movement is dependent on skeletal systems.

TYPES OF SKELETONS

Type of skeleton and example of animal having it	*Definitions of the skeletons and extra notes*
Hydrostatic skeleton or Hydroskeleton *It's the most widespread type of skeleton found in:* **a) Organisms** like annelids (e.g. earthworms), cnidarians (e.g. jellyfish, sea anemones), nematodes (e.g. round worms) **b) Structures** like mammalian eyes (the aqueous and vitreous humour), spinal cord (cerebrospinal fluid), extra embryonic membranes (amniotic fluid), hearts (move blood), and intestines (move food).	**Hydroskeleton:** a high-pressured fluid in a cavity (coelom), surrounded by muscle layers at different orientations. **(i)** The **main principle** on which the hydroskeleton operates is the low compressibility of liquid water (often assumed incompressible). Muscle contractions exert pressure on the coelomic fluid causing stiffening of the outer structures to form a strong rigid skeletal unit that provides a base against which movements can occur. **(ii)** The optimal volume of fluid for a particular system must remain constant for effective contraction and expansion of the antagonistic muscles. Too much loss of fluid causes limpness of tissues and pressure loss, and too much gain causes over swelling, both of which fail muscle stretching and hence movement fails. This explains why snails and earthworms are restricted in their activity to moist conditions.

Type of skeleton and example of animal having it	*Definitions of the skeletons and extra notes*
Exoskeleton ●***Chitinous exoskeleton*** is in: arthropods like insects, arachnids (e.g. spiders) crustaceans (e.g. crabs, lobsters), some fungi and bacteria ●***Calcified exoskeleton*** is in: shelled mollusks (e.g. snails, clams), some polychaetes like lugworms. ●***Silicated exoskeleton*** is in diatoms. ●***Bone, cartilage, or dentine*** make up the exoskeletons of turtles and primitive fish	**Exoskeleton:** a non living external body structure that supports and protects an organism. **(i)** Exoskeletons are secreted by **ectoderm** **(ii) Chitinous exoskeleton** has complex muscular system which enables insects to lift or pull an object 20 or more times heavier than their body weights! Grasshoppers have about 900 muscles, caterpillars up to 4,000 yet human beings have fewer than 700 muscles ***(The World Book Encyclopedia).*** **(iii)** Exoskeletons do not grow with the body so in arthropods they must be periodically shed to allow growth; mollusks e.g. snails continually enlarge their shells as they grow. **(iv**) In insects and spiders the epicuticle is waterproof.
Endoskeleton *Found in:* **a) Chordates:** birds, mammals, reptiles etc. **b) Echinoderms:** starfish, brittle stars, sea urchins, sea cucumbers **c) Poriferans:** sponges **d) Molluscs** (class Cephalopoda) e.g. cuttlefish **Note:** Some animals, such as the tortoise, have both an endoskeleton and an exoskeleton.	**Endoskeleton:** a living internal support structure of an animal, usually composed of mineralized tissue which develops within the skin or in the deeper body tissues. (i) The vertebrate endoskeleton is made up of bone and cartilage tissues. (ii) In sponges, the endoskeleton is purely for support, but in vertebrates and echinoderms it's also for attachment of muscle and locomotion. (iii) Echinoderms and chordates have a true endoskeleton derived from **mesodermal tissue**

ADVANTAGES / FUNCTIONS AND LIMITATIONS OF THE SKELETONS

	Advantages / Functions	Limitations / Disadvantages
Hydroskeleton	●Hydroskeleton is elastic and can bend accordingly when a muscle contracts enabling fitting in narrow burrows.	● Coelenterates that use a hydroskeleton regularly face a loss of pressure because their skeleton is also their gut. ● Due to lack of a strong supportive system, majority of the **invertebrates** are small ●The slow motion due to lack of effective ways to support a large body compromises the animals' escape response from predators. ●The organisms are limited to moist habitats because of the need to minimise water loss by evaporation

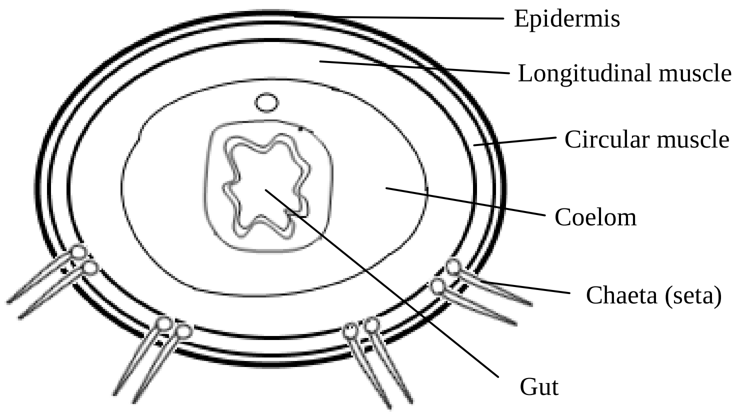
	Advantages / Functions	Limitations / Disadvantages
Exoskeleton	● Exoskeletons contain rigid and resistant components that offer protection against predators, bacterial attack and desiccation while on land. ●Exoskeletons contain rigid components that offer support enabling maintaining body shape. ●Exoskeleton of arthropods contains rigid framework of ingrowths known as apodemes which serve as attachment sites for muscles. ● In arthropods the exoskeleton is modified into appendages which offer more rapid locomotion than the hydroskeleton ● The arthropod exoskeleton contains various folds, flaps and parts modified for feeding and structures for respiration. ● Exoskeletons are often highly coloured for camouflage	● Since exoskeletons are rigid and do not grow with the body, in arthropods they disrupt smooth and steady growth and so must be periodically shed to allow growth, which makes the animal temporarily vulnerable for predation and water loss by evaporation until hardening. **NB:** Snails and many other mollusks solve that problem by continually enlarging their shells as they grow. ● An exoskeleton cannot support large sized animals because of their large volume and body mass in proportion to the cube of their linear dimensions, necessitating an impossibly heavy and thick exoskeleton. ●It requires modifications in movement. Many individual muscles are attached to the outer shell in order to create movement. In the appendages,

	from predators, recognition by mates, and warning to scare off predators. ●The arthropod exoskeleton is jointed enabling flexibility in locomotion.	these muscles are set up within multiple hinge joints, as these allow a wide range of motions.

	Advantages / Functions	**Limitations / Disadvantages**
Endoskeleton	●Vertebrates have a versatile support system and as a result, they develop faster and bigger bodies than invertebrates. ● It's jointed for flexibility to allow diverse range of locomotory patterns: swimming, digging, running, climbing, and flying, feeding (jaws). ●Endoskeleton does not limit space available for internal organs and can support greater weight. ●Bone are hard for protecting delicate parts like the brain, lungs, heart, spinal cord, etc. ●Bone tissue is mineralized and hence acts as mineral reserve for the body's' physiological processes. ●Mammalian bones manufacture the defensive leucocytes	●Endoskeletons are enclosed in other tissues do not offer much protection from predators in some animals. ● Endoskeletons do not contribute to minimizing water loss from the body by evaporation

DESCRIPTION OF HYDROSKELETON OF THE EARTHWORM

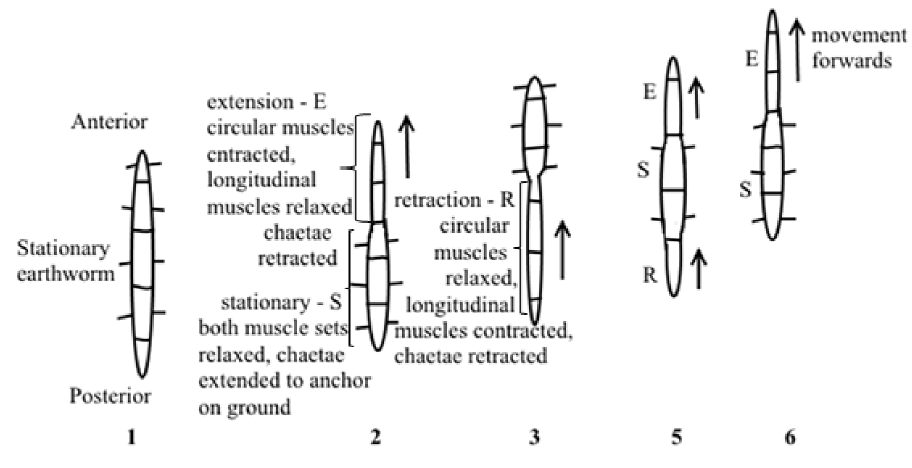
Only the structures that make up the skeleton are required, not description of the whole body.



The body is cylindrical (tubular), partitioned transversely into many small separate, but coordinated segments, enclosed by epidermis, a thick wall made of two layers of muscles i.e. circular muscles surrounding the cavity and longitudinal muscles running from anterior to posterior; the inside contains a highly pressured incompressible fluid-filled cavity (coelom); each body segment bears four pairs of chaetae (setae), except the first and last segments.

NB: segmental partitioning prevents backflow of the coelomic fluid which would provide little elongation

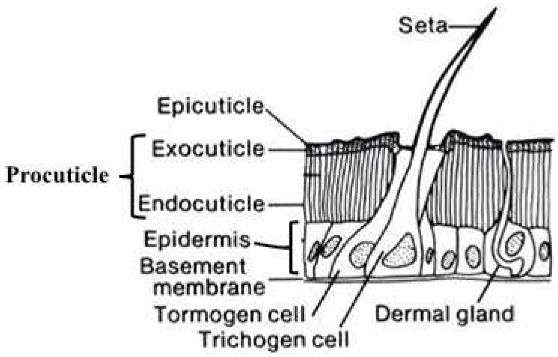
DESCRIPTION OF THE EARTHWORM'S LOCOMOTION



●Crawling is initiated when circular muscles at the anterior end contract while longitudinal muscles relax segment by segment backwards as a wave along the body, there by exerting pressure on the coelomic fluid, which is forced to move at right angles to the squeezing circular muscles, while at the same time the chaetae retract inwards in this region of contracted circular muscles. The net result is forward extension of the anterior end.
●The movement of the fluid stretches the set of longitudinal muscles, which then contract to stretch the circular muscles back to the relaxed position, causing segments to elongate and thin.
●Forward extension of the anterior end is coupled with contraction of longitudinal muscles and relaxation of circular muscles in the more posterior segments causing body swelling and protrusion of chaetae this region.
●As the successive peristaltic waves approach towards the rear end of the body, longitudinal muscles in the anterior region contract, circular muscles relax, the chaetae protrude to anchor at the ground and pull the rear end forward.
●Control of muscle contraction is brought about by a complex network of inter and intrasegmental neurones

LOCOMOTION WITH AN EXOSKELETON

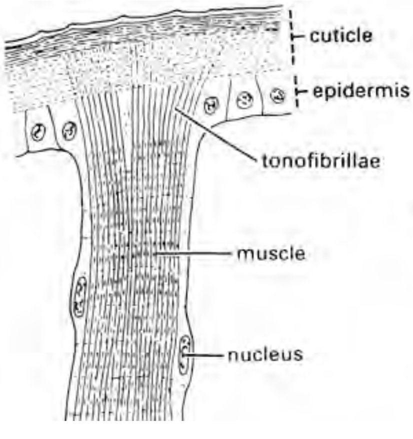
DESCRIPTION OF A TYPICAL ARTHROPOD EXOSKELETON

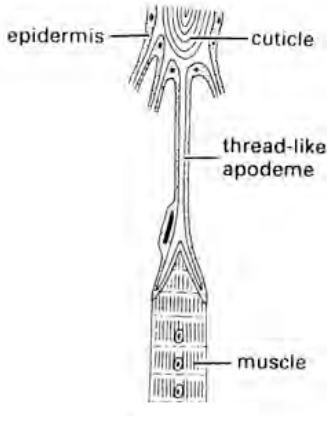


● It is a **multi-layered** structure with **4 main regions;** from out - inwards: ***epicuticle, procuticle, epidermis and basement membrane.***
●**Epicuticle:** a multi-layered external barrier made of lipoproteins, fatty acids, wax and some times cement. It prevents water loss (desiccation) and bacterial invasion.
●**Procuticle:** lies immediately below the epicuticle, is secreted by the epidermis, contains **chitin** surrounded by a matrix of protein. At times procuticle stratifies into a **sclerotized** exocuticle and a soft, inner endocuticle.
*(**Sclerotization** involves linking protein molecules together by quinone compounds into a solidified protein matrix, creating rigid "plates" of exoskeleton known as **sclerites)***
●**Epidermis:** made up of a single layer of epithelial cells, secretes the basement membrane and all of the overlying layers of cuticle.
●**Basement membrane:** a supportive bilayer of mucopolysaccharides and collagen fibers, it is where epidermal cells rest.

Types of insect muscles
1. Skeletal muscles – attacked to exoskeleton
2. Visceral muscles – found in the gut / alimentary canal.

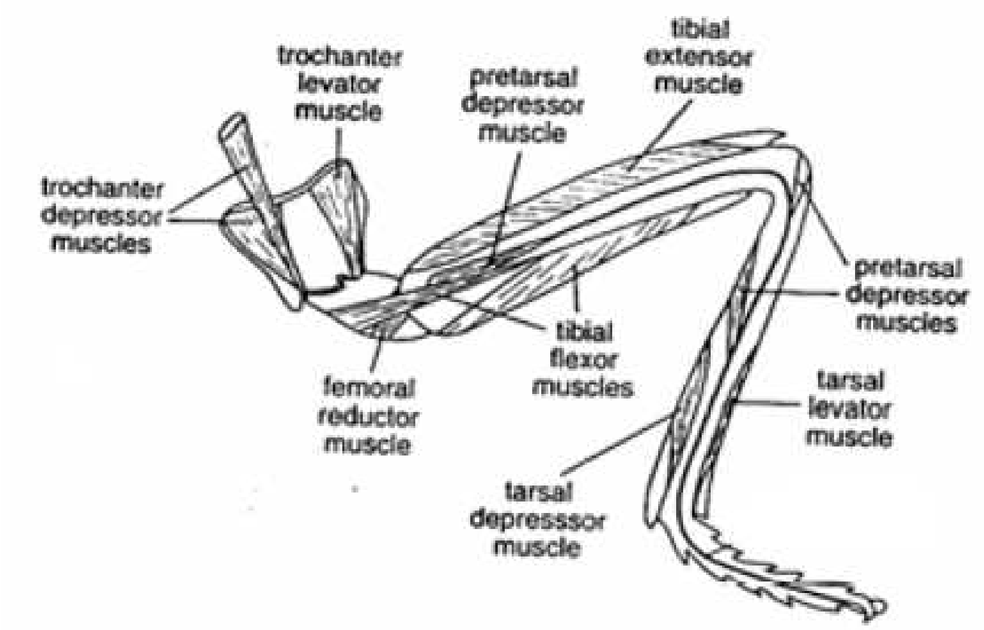
Attachment of insect muscles
(a) Some skeletal muscles using **tonofibrillae** attach on ectoderm (cuticle) through the epidermis.
(b) Other skeletal muscles attach on internal ridge-like cuticle called **Apodemes** and **Apophyses**
(c) Flight muscles attach on platelike invaginations called **phragma** in the thorax.



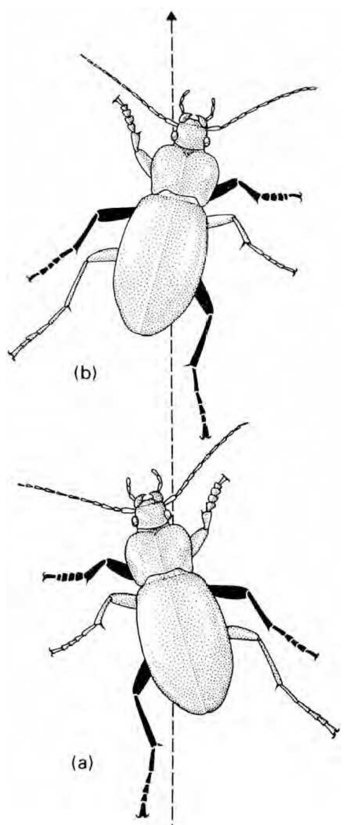


ANTAGONISTIC MUSCLES FOR INSECT LOCOMOTION

(a) Levator vs. depressor muscles for wings
(b) Flexor vs extensor muscles in legs



A. DESCRIPTION OF WALKING IN INSECTS



●Walking is achieved by the coordinated activity of 6 legs all attached on the thorax.

● Bending and straightening of limbs is brought about by the **reciprocal innervation** of flexor and extensor muscles attached to the inner surface of the exoskeleton on either side of a joint.
Reciprocal innervation: **Same time excitation of one muscle with the inhibition of its antagonist.**

●A limb bends (folds) by contraction of flexor muscle and relaxation of extensor muscle simultaneously (at the same time).

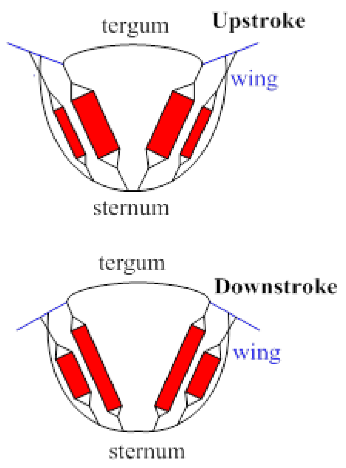
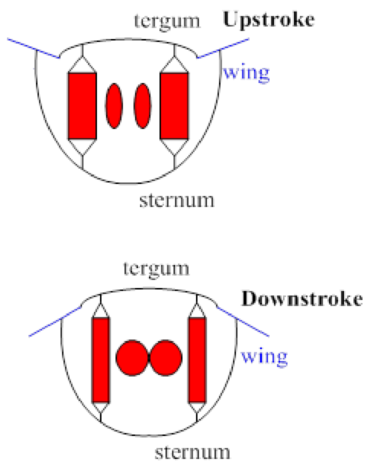
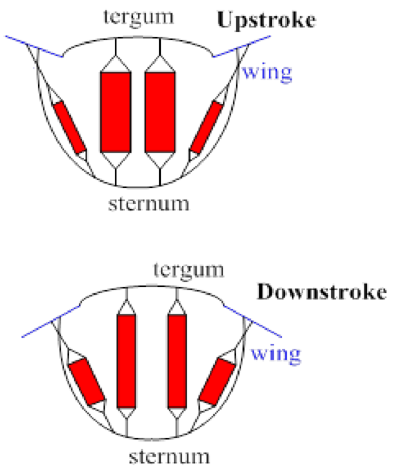
●A limb straightens (extends) by contraction of extensor muscle and relaxation of flexor muscle simultaneously.

●When the insect starts to walk, the 2nd leg on one side and the 1st and 3rd legs on the other side support the body off the ground while the other 3 move forward.

●The 1st leg on the side where the 2nd leg is stationary pulls the insect, while the 3rd leg of the same side and the 2nd leg on the other side push.

●The process is then repeated but with the role of each trio of limbs reversed.

INSECT FLIGHT MUSCLES

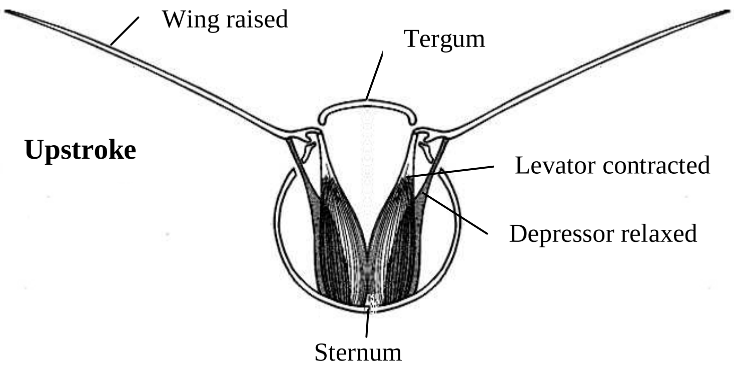
Direct muscles – directly attach to wings e.g. dragon flies, mayflies	**Indirect muscles** - attach to interior of thorax (NOT directly to wings) e.g. houseflies, honey bees, midges, etc	**Direct and indirect muscles** (mixed)
		

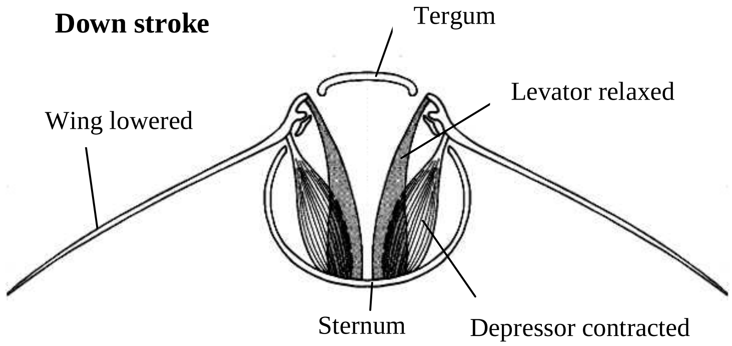
COMPARISON OF DIRECT AND INDIRECT FLIGHT MUSCLES

Direct muscles	**Indirect muscles**
1. Directly attach to wing bases e.g. dragon flies, mayflies 2. Are **Synchronous muscles i.e.** - One nerve impulse = one muscle contraction = one wing beat – One contraction and relaxation per 1 neural impulse. 3. Frequency of wing beat corresponds to the rate at which the nervous system can send impulses 4. Wing beat is slower (about 5-50 times/second)	1. Attach to interior of thorax (NOT directly to wings) e.g. houseflies, honey bees, midges, etc 2. Are **Asynchronous muscles i.e.** – More than 1 contraction and relaxation per 1 neural impulse. 3. Single nerve impulse required to initiate muscle contraction, single impulse to stop. - The muscles exhibit **stretch reflex** i.e. automatic contraction in response to being stretched. 4. Energy is conserved because the elasticity of the thorax restores its shape 5. Frequency of wing beat exceeds the rate at which the nervous system can send impulses (about 120-200 beats in house flies to 1000 beats /second in midges).

B. DESCRIPTION OF FLIGHT IN INSECTS

ACTION OF DIRECT FLIGHT MUSCLES
e.g. dragonflies, butterflies and grasshoppers.





1. Using Direct flight muscles

● During the ***upstroke***, the **elevator muscles** contract, the **depressor muscles** relax at the same time, the wings are elevated.

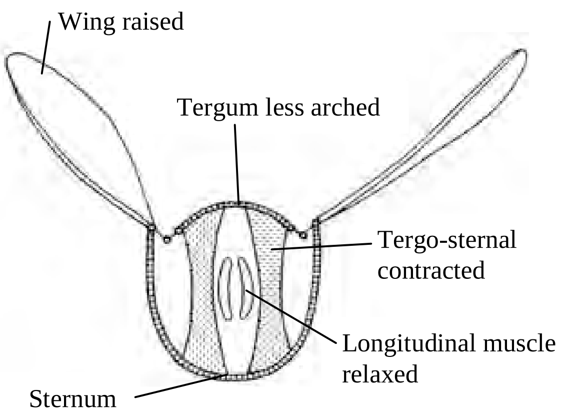
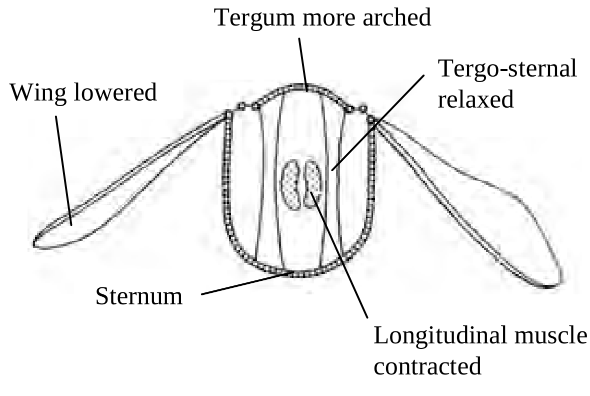
● During the ***downstroke***, the depressor muscles contract, the elevator muscles relax at the same time, the wings are depressed down.

2. Using Indirect flight muscles

●During the ***downstroke***, the **longitudinal muscles** (depressor muscles) contract, the **tergo-sternal muscles** (dorso-ventral muscles) relax at the same time, the thorax is compressed, its dorsal surface (notum) arches (bulges / bows upward), the wings flip downward (depress).

● During the ***upstroke***, the **tergo-sternal muscles** (elevator muscles) contract, the **longitudinal muscles** (depressor muscles) relax at the same time, the notum is pulled downward (flattens), causing the wings to flip upward (elevate).

ACTION OF INDIRECT FLIGHT MUSCLES e.g. houseflies, bees and wasps, etc.

Upstroke (wings raised / elevated)	**Down stroke** (wings lowered / depressed)
	

ENDOSKELETON
The vertebrate skeletal tissue is composed either of **cartilage only** like in elasmobranch fishes e.g. dogfish and sharks or **both cartilage and bone** covered by a muscular system.

MUSCULAR TISSUE
Muscular tissue is derived from the mesoderm and is specialised for contraction. It is made up of contractile units called muscle fibres bound in a framework f vascular connective tissue which also provides an anchorage to the skeleton or skin.

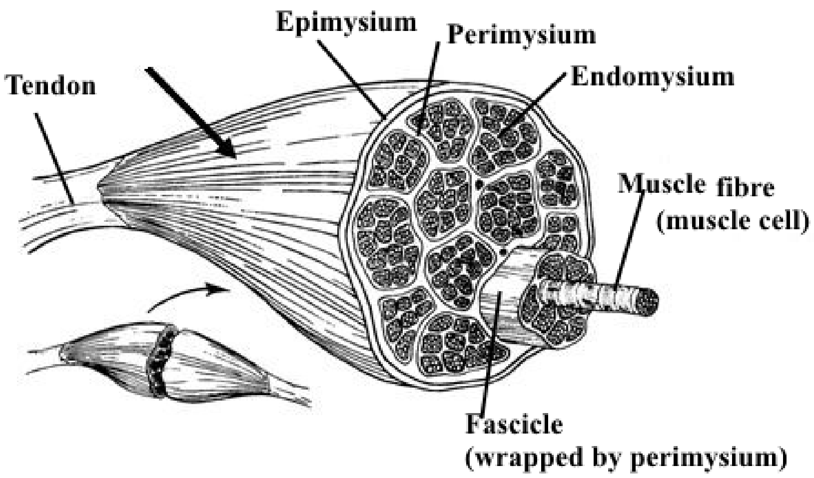
TYPES OF MUSCLE

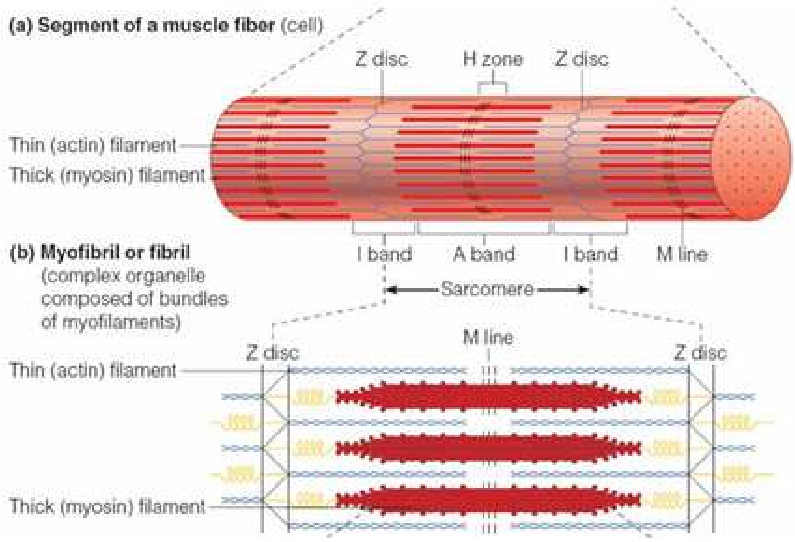
●**Smooth (Involuntary / visceral) muscle;**
Location: walls of blood vessels; ciliary muscle; erector (arrector) pili muscle; gastrointestinal, urinogenital and respiratory tracts

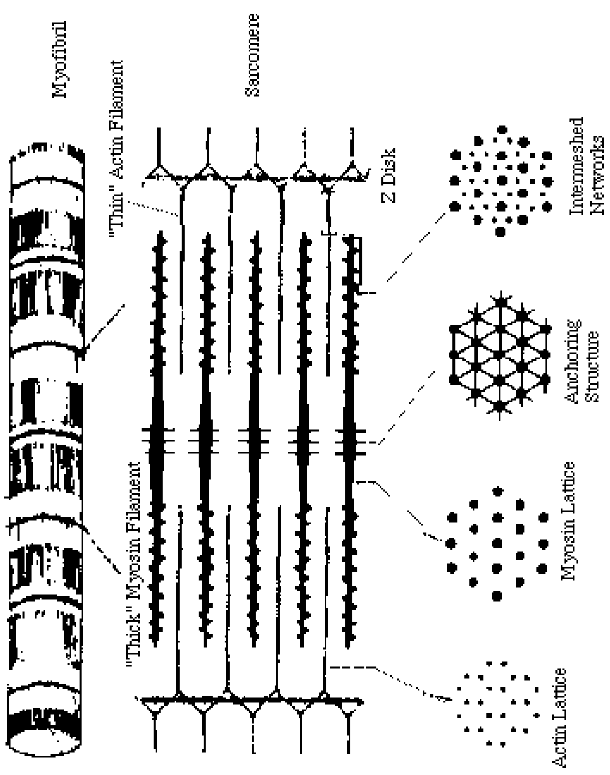
●**Skeletal (voluntary) muscle;**
Location: attached to bones; abdominal wall; diaphragm; rectus muscle; under skin; middle ear.

●**Cardiac (heart) muscle; *Location:*** found in the heart only.

GROSS AND MICROSCOPIC STRUCTURE OF SKELETAL MUSCLE







As seen under the light microscope

●Skeletal muscle is highly compartmentalized, and each compartment is treated as a separate entity (such as the biceps muscle).

●The entire muscle is a collection of several muscle fibre bundles enclosed by connective tissue called **epimysium**.

●One muscle fibre bundle contains many muscle fibres surrounded by connective tissue called **perimysium**.

●One muscle fibre is enclosed by **endomysium,** a meshwork of collagen fibres and fibroblasts**.**

●Each striated muscle cell (**muscle fiber**) has a fluidy **sarcoplasm** (cytoplasm); bound by the sarcolemma (plasma membrane); is multinucleate (is a **syncytium)**; the nuclei are at the periphery of the cell; is long; cylindrical; with longitudinally oriented threadlike structures-**myofibrils** exhibiting periodic cross striations repeatedly.

●**The sarcoplasm** contains Golgi apparatus, many mitochondria, ribosomes, sarcoplasmic reticulum (endoplasmic reticulum), glycogen, lipid droplets, and myoglobin.

Syncytium*: A multinucleated mass of cytoplasm that is not separated into individual cells.*

Details of myofibril (fine structure)

● One myofibril shows alternating cross striations; which are light (**isotropic**) and dark (**anisotropic**) bands.

● One myofibril is made of filamentous proteins; **myosin** (thick) and **actin** (thin) overlapping to give the striated appearance.

● Actin filaments are anchored at their midpoints to a structure called the **Z-line.**

●The region from one z-line to the next is called a **sarcomere,** which is the functional unit of muscle contractions.

● **Sarcomeres** are sections of **myofibril** that are separated from each other by areas of dense material called **"Z discs".**

● **"A band"** is the relatively darker area within the sarcomere that extends along the total length of the **thick filaments**.

●**"H zone"** is the region in which there are only thick filaments, and no thin filaments at the centre of the **A band** of each **sarcomere**.

The **"I band"** is the region between adjacent **A bands**, in which there are only **thin filaments**, and no **thick filaments**. (Each **I band** extends across two adjacent sarcomeres)

SLOW-TWITCH AND FAST-TWITCH MUSCLE FIBRES

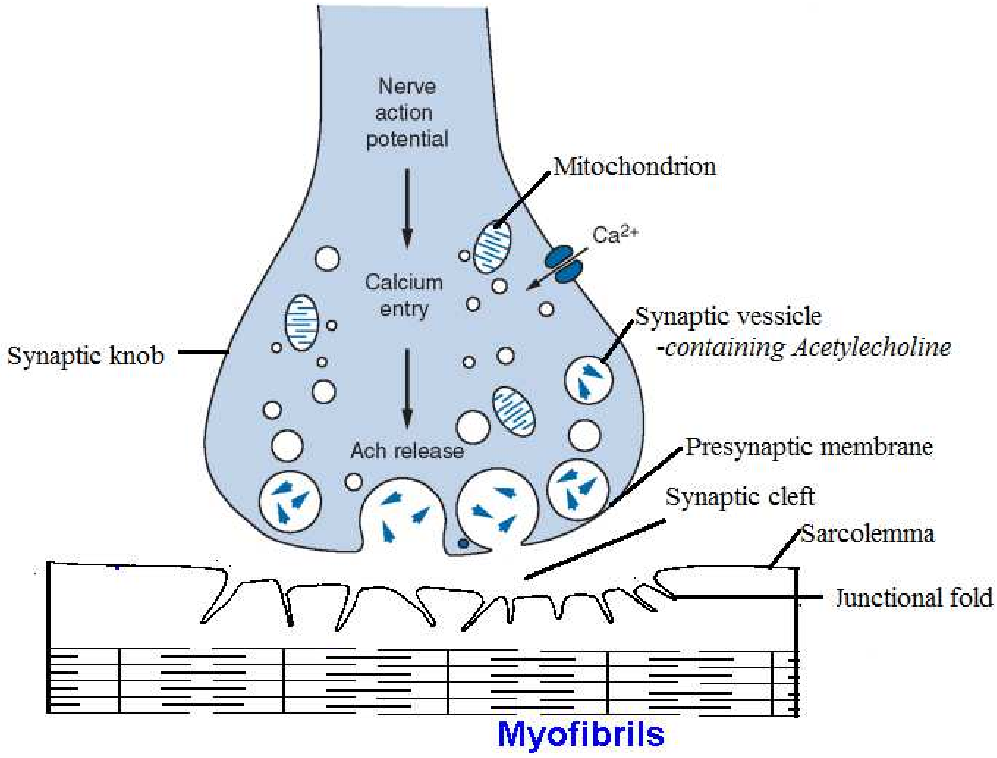
1. Slow-twitch fibres – e.g. calf muscle	**2. Fast-twitch fibres** – e.g. biceps muscle
Contract more slowly, less powerfully, over a longer period hence suited to endurance work e.g. marathon running. ***Adaptations:*** (i) Large reservoir of myoglobin for storage of oxygen which facilitate aerobic respiration to avoid accumulation of lactic acid which would make them less effective. (ii) Much glycogen to provide a source of metabolic energy. (iii) A rich supply of blood vessels to deliver oxygen and glucose needed in aerobic respiration to provide ATP. (iv) Numerous mitochondria to produce ATP that maintains muscle contraction.	Contract more rapidly, more powerfully, only for a short period hence suited to intense exercise e.g. weight lifting. ***Adaptations:*** (i) Thicker and more numerous myosin filaments. (ii) High concentration of enzymes involved in anaerobic respiration. (iii) Store of phosphocreatine, a molecule that can rapidly generate ATP from ADP in anaerobic conditions and so provide energy for muscle contraction.

HOW SKELETAL MUSCLE STRUCTURE RELATES TO FUNCTIONING

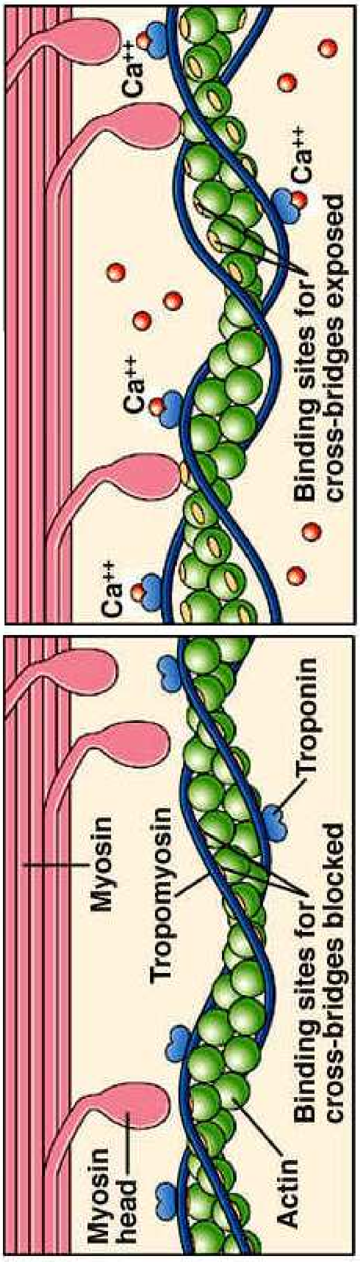
●Each muscle cell is long to allow considerable contractile effect.
●The fibres are parallel to each other so that contractile effect is transmitted along same axis.
●Muscle fibres taper at both ends for interweaving to improve muscle strength.
●Muscle fibres have very many mitochondria to provide much ATP needed in muscle contraction.
●Cross bridges enable actin and myosin to fit into each other to allow sliding during muscle contraction.
●There is a rich supply of blood vessels to supply nutrients to and drain wastes away from cells.
●There is much myoglobin for storage of oxygen needed very much in aerobic respiration during exercising.
●There are motor end plates to allow innervation that result in contraction.
●There is a dense network of internal membrane system (including transverse tubules) for calcium ion storage which is very much needed in muscle contraction.
●Reciprocal innervation ensures antagonistic muscular contraction to bring about realistic movement

WHAT IS A NEUROMUSCULAR JUNCTION (NMJ) / MOTOR END PLATE?

●A single synapse or junction made between one motor neuron and one muscle fiber.



MECHANISM OF MUSCLE CONTRACTION AND RELAXATION



The sliding filament theory / Ratchet mechanism

Excitation-Contraction coupling *(see next page for definition)*

●Arrival of an **action potential** at the synaptic terminal of motor neuron causes the influx of Ca^{2+} ions from the extracellular fluid into the presynaptic neuron's cytosol followed by exocytosis of synaptic vesicles containing acetylcholine.

●A**cetylcholine** diffuses across the synaptic cleft of neuromuscular junction to depolarize the sarcolemma and trigger an action potential that spreads through the **transverse tubules,** causing the sarcoplasmic reticulum to release Ca^{2+} into the sarcoplasm.

●Ca^{2+} bind to troponin of actin to cause cooperative conformational changes in troponin-tropomyosin system, releasing the inhibition of actin and myosin interaction.

●Myosin hydrolyses ATP and undergoes a conformational change into a high-energy state.

●The myosin head binds to actin forming a cross-bridge between the thick and thin filaments.

●This is accompanied by energy release, ADP and inorganic phosphate dissociation from myosin.

●The resulting relaxation entails rotation of myosin head, which flexes the cross bridge to move **actin** a small distance pulling the Z-discs towards each other, thus shortening the sarcomere and the I-band.

●The collective flexing of many cross bridges by myosin to move actin in the same direction results in muscle contraction.

Relaxation

● Ca^{2+} are pumped back into sarcoplasmic reticulum.

●Again **ATP** binds to myosin head, detaching it from actin as the myosin head “recharges” or “cocks”.

●Troponin-tropomyosin regulated inhibition of actin and myosin interaction is restored

● Finally, active tension disappears and the rest length is restored. This completes the contraction-relaxation cycle.

NB: high concentration of Ca^{2+} in the sarcoplasm coupled with lack of ATP results in Rigor mortis (see below for details on this phenomenon)

EVIDENCE OF SLIDING FILAMENT THEORY (OBSERVATIONS) IN A CONTRACTING MUSCLE FIBRE

● Each **sarcomere shortens** / Z lines come closer

●**I Band shortens**

●**H zone** shortens greatly (usually **disappears)**.

●**A Band remains** unchanged in length during contraction or relaxation

●Cross bridges are visible between actin and myosin in photomicrographs.

CHANGES DURING MUSCLE PASSIVE STRETCHING

●Sarcomere lengthens

● **I Band** elongates.

WHAT IS RIGOR MORTIS?

●The progressive stiffening of the body that occurs several hours after death as a result of failure of contracted muscles to relax.

WHAT CAUSES RIGOR MORTIS?

●Upon death, there's increased permeability of sarcoplasmic membrane to Ca^{2+}, allowing Ca^{2+} influx into the sarcoplasm hence promoting the cross-bridge formation between actin and myosin (muscle contraction).
●However efflux of Ca^{2+} from the sarcoplasm into the sarcoplasmic reticulum fails because of lack of ATP since respiration would have ceased. This causes the muscle to remain contracted, relaxing only when decomposition starts.
NB: Interestingly, meat is generally considered to be tenderer if it is consumed after expiry of **rigor mortis.**

WHAT IS EXCITATION-CONTRACTION COUPLING?

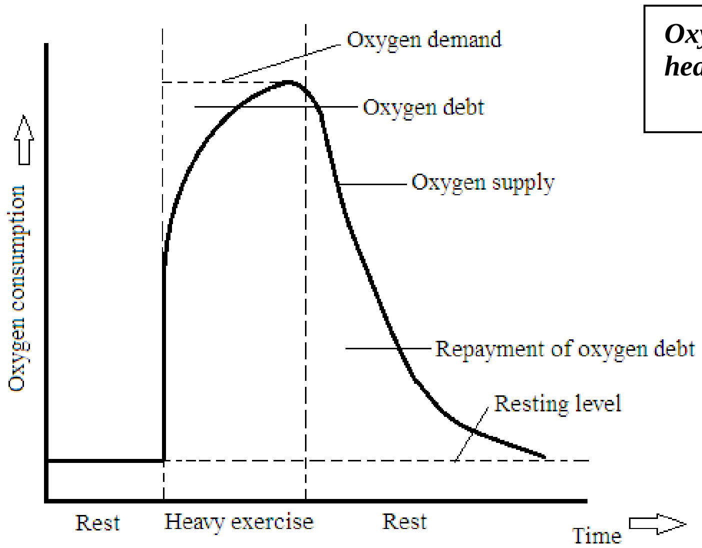
●The sequence of events by which an action potential in the plasma membrane of the muscle fibre leads to force production via an increase in intracellular calcium and cross bridge formation and turn-over ***(see previous page for explanation)***

ATP PRODUCTION DURING MUSCLE CONTRACTION

1. Phosphorylation of ADP by creatine phosphate provides a very rapid means of forming ATP at the onset of contractile activity. **Phosphocreatine + ADP $\Leftrightarrow$ ATP + creatine**
In a resting muscle fiber, the concentration of ATP is always greater than ADP leading to the reformation of creatine phosphate.
2. Oxidative phosphorylation of ADP in mitochondria during aerobic respiration (need myoglobin for oxygen transfer)
3. Substrate phosphorylation of ADP in glycolysis during anaerobic respiration to form lactic acid in the process. The accumulation of lactic acid is associated with muscle fatigue, which is broken down later in the liver using oxygen to constitute what is called **oxygen debt.**

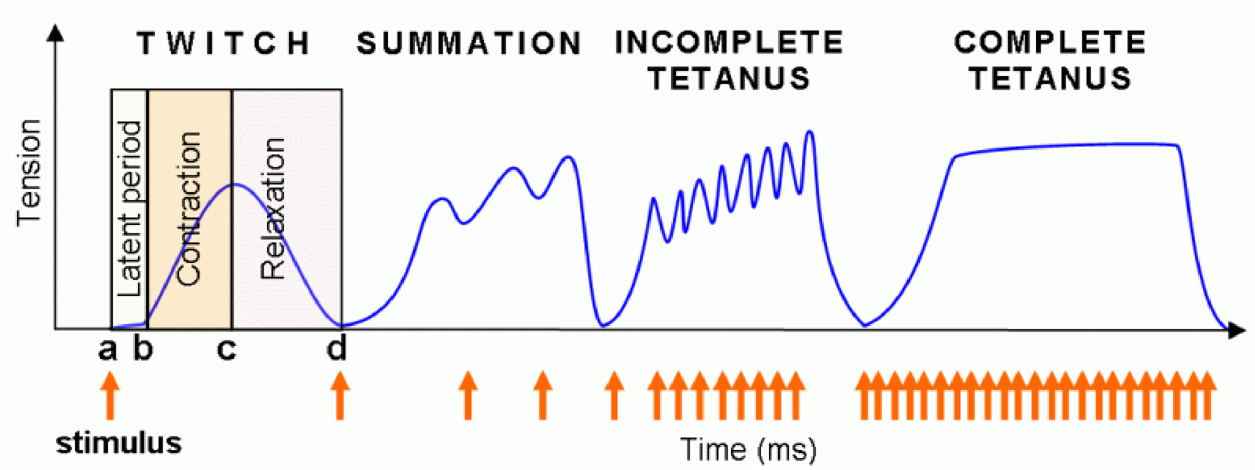
WHAT IS THE OXYGEN DEBT?

The amount of extra oxygen required by muscle tissue to oxidize lactic acid and replenish depleted ATP and phosphocreatine following vigorous exercise.



Oxygen uptake at rest, in heavy exercise and in recovery

MUSCLE STIMULATION FREQUENCY AND THE LENGTH-TENSION RELATIONSHIP



MUSCLE TWITCH
This is the rapid muscle contraction in response to a single stimulation

LATENT PERIOD
A very brief interval between stimulus application and onset of muscle fibre contraction. During latent period, excitation of muscle fibre followed by contraction occur

ALL-OR-NOTHING LAW OF THE MUSCLE
The response of one muscle fiber is independent of the intensity of the stimulus, provided the stimulus is of threshold strength.
The **entire skeletal muscle doesnot** obey the all-or-none law because the total amount of contraction depends on the number of muscle fibres that are contracted at a time.
NB: the all-or-none law holds only for the unit of tissue; i.e. the nerve cell (for nervous tissue), one muscle fiber (for skeletal muscle) and the entire auricles or the entire ventricles (for the heart).

THRESHOLD
The electrical potential (less negative than the resting potential) at which an action potential is triggered.
If the frequency of stimulation progressively increases such that it gives **first, little time** and **later no time** for complete relaxation, the graph below shows what can be observed.

MECHANICHAL SUMMATION / UNFUSED TETANY
The condition whereby multiple stimulation of a muscle or nerve before full relaxation results in a series of twitches added together to produce a more sustained contraction.

TETANY
●Smooth, sustained maximal contraction of a muscle in response to rapid firing by its motor neuron.
NB: The ability of a muscle to undergo tetany depends upon its **refractory period.**

REFRACTORY PERIOD
●A short period of inexcitability in a nerve or muscle cell following stimulation.
●The amount of time it takes for an excitable membrane to be ready for a second stimulus once it returns to its resting state following excitation.

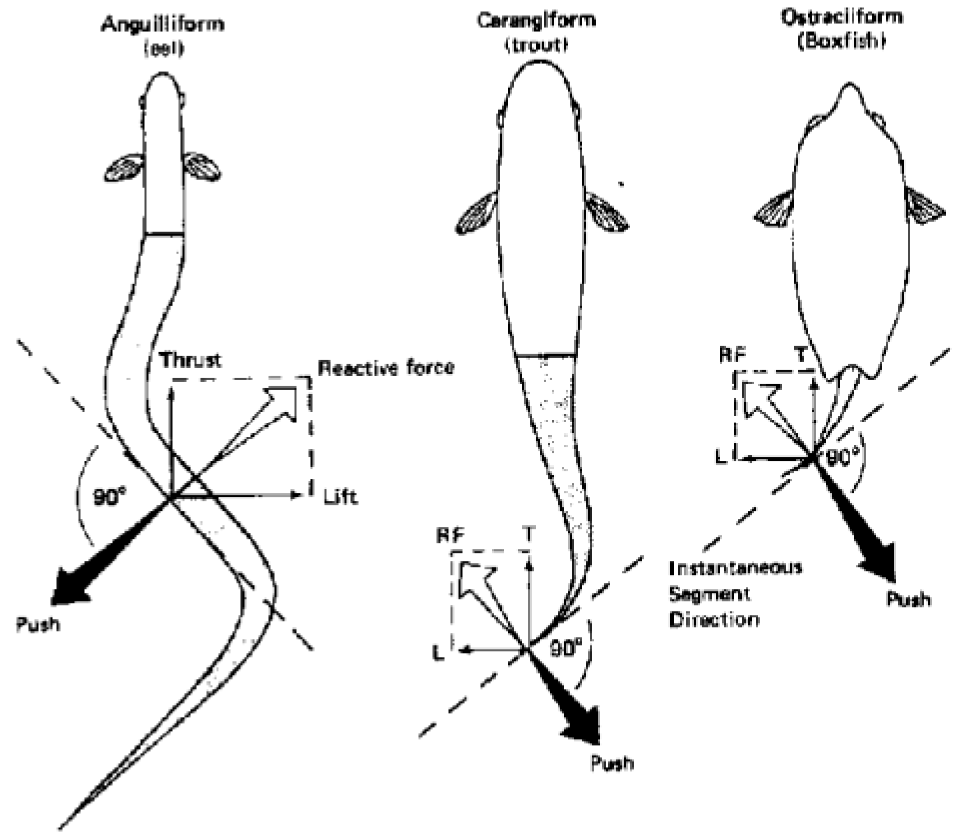
MUSCLE FATIGUE
●A condition of the muscle in which its capacity to produce maximum voluntary action, or to perform a series of repetitive actions, is reduced.
Muscle fatigue results when there is tissue oxygen deprivation, glycogen or Phosphocreatine depletion, and increased level of blood and muscle lactic acid in an exercised muscle.

LOCOMOTION IN FISH

Most fish have a line of muscle blocks, called **myomeres (myotomes),** along each side of the vertebral column. To swim, they alternately contract one side and relax the other side in a progression which goes from the head to the tail. In this way, an undulatory locomotion results, first bending the body one way in a wave which travels down the body, and then back the other way, with the contracting and relaxing muscles switching roles. They use their fins to propel themselves through the water in this swimming motion.

TYPES OF LOCOMOTION IN FISH

Anguilliform e.g. eel	***Carangiform e.g. dog fish, perch***	***Ostraciform e.g.*** Ostracium (trunk fish)



●When myotomes on one side of body contract; those of the opposite side relax at the same time; the tail pushes against the water towards the contracted side; generating a thrust that can be resolved into 3 forces:

(a) The reaction force which is the reaction of the water against the pushing action of the water and is equal and opposite to the thrust.

(b) The forward (propulsive) force that pushes the fish forward.

(c) Lateral drag (sideways) force that swings the tail towards the left and the head towards the right and thus slows (drags) the fish. Lateral drag is countered by:

(i) Pressure of the water against the head

(ii) Pressure of the water against the dorsal fin, both of which enable to move forward without swinging from side to side very much i.e. the lateral forces essentially cancel out.

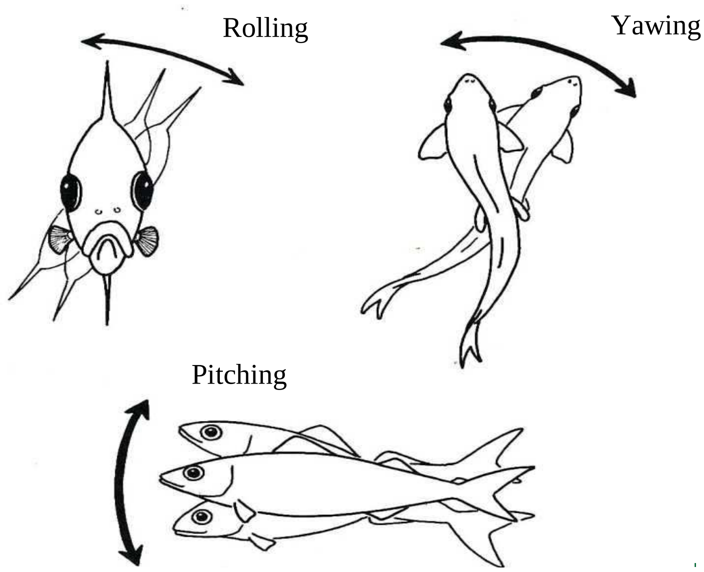
NOTE

Many invertebrates like round worms and some flagellated cells including spermatozoa exhibit the principles involved in propulsion as in the above fishes.

SUPPORT (BUOYANCY) IN FISH

Elasmobranchs like dog fish sharks, skates and rays.	**Teleosts like perch**
●Support is provided by **constant swimming** using **fins.** ●These fish's density is slightly greater than that of water and must swim continuously to avoid sinking. ●How they are adapted to this: **(1)** possession of large pectoral and pelvic fins which direct swimming upwards **(2)** possession of **heterocercal** tail i.e. a tail with smaller upper and larger lower lobes for generating much lift and forward motion ●During forward motion the pectoral and pelvic fins are all held at a slight angle to the body, generating a force which can be resolved into upward and backward components. ●The upward component force lifts the anterior end up in the water while the backward component force called **backward drag** being small only slightly impedes motion and is easily suppressed.	●Support is provided by adjusting air in the **swim bladder** which may be **(1)** a closed swim bladder filled with gaseous mixture of oxygen, nitrogen and carbondioxide – all secreted from blood vessels in its wall. ***The closed type is the most common in bony fish.*** **(2)** an open swim bladder having a duct connection to the pharynx and operates as follows: ●Expulsion of air from the swim bladder increases the fish's relative density and it sinks. If it's to stay afloat, the fish first swims to the water surface then gulps air into the swim bladder to decrease the specific gravity so that the body weight equals the weight of water displaced. **NB:** Unlike in elasmobranchs, the teleost's pectoral fins are only moved at will e.g. during braking and steering but do not act as main support structures.

INSTABILITY IN FISH



Rolling: rotation of the body about its longitudinal axis. It's **counteracted** by dorsal, ventral (vertical) and pectoral (horizontal) fins acting like stabilizers on a ship.

Pitching: tendency of the fish's anterior end to plunge vertically downwards (transverse axis rotation). It's **counteracted** by **(i)** pectoral fins and to a lesser extent pelvic fins **(ii)** dorsal-ventral flattening of the body in the dogfish.

Yawing: lateral side to side deflection of the anterior part of body resulting from the propulsive action of the tail (vertical axis rotation). It's **counteracted** by **(i)** general massiveness of anterior part of body **(ii)** water's pressure against the body side **(iii)** water's pressure against the vertical fins (dorsal, anal, ventral fins) **(iv)** lateral flattening (compression) of the body

ADAPTATIONS FOR LOCOMOTION IN FISH

●Fish's body is fusiform-shaped (spindle shaped) and laterally compressed to reduce water resistance during swimming
●The slippery layer of mucus on the skin reduces water resistance during swimming
●The presence of many rayed-fins enables the fish to swim and also maintain its balance / stability in water
●The lateral line enables sensitivity of fish and also functions as an echo location process for the fish to identify its surroundings while in water
●Scales are arranged in a head to tail direction to reduce water resistance during swimming
●The swim bladder in bony fish maintains buoyancy
●Extensive blood vascular system supplies oxygen and nutrients to the muscle tissues for contraction and drain away wastes
●Body is highly muscular to generate great propulsive force against water resistance
●The neuromuscular activity is highly coordinated resulting in **reciprocal innervation.**

LOCOMOTION IN BIRDS

EXTERNAL AND INTERNAL FEATURES THAT ADAPT BIRDS TO LOCOMOTION

●Birds' bodies are streamlined (spindle shaped) during flight for overcoming air-resistance during flight.
●The endoskeleton is hollow **(pneumatized)** to reduce weight, and many unnecessary bones are fused into a single structure e.g. some vertebrae, pelvic girdle, finger and leg bones.
●Many unnecessary parts like urinary bladder and pinna are totally eliminated while reproductive organs (testes, ovaries and oviducts) are kept tiny during non-breeding seasons to reduce weight.
●The sternum bone is extended into a large keel, for the attachment of large powerful flight muscles.
●The vanes of the feathers have hooklets called **barbules** that zip them together, giving the feathers the strength needed to hold the airfoil.
●The major wing bones have internal **strut-like reinforcements** to prevent buckling during stress.
●The respiratory system is extensive and very efficient in supplying muscles with oxygen to facilitate much energy release needed in muscle contraction during respiration
●Their efficient circulatory system powered by a four-chambered heart enables fast supply of oxygen and food to the body tissues and carry away wastes.
●The large brains that are connected to eyes coupled with high-speed nerve transmission enable quick decision making especially when landing.
●The large size of eyes in relation to their body size, coupled with eye keenness enable high visual acuity without crashing into objects.
●The flight muscles of most birds contain oxygen-carrying compounds, (myoglobin and cytochrome) for storing much oxygen which facilitates the release of much energy needed in muscle contraction.
●The forelimbs have become modified into wings which act as aerofoil, generating lift when passed into air.
●They have high body temperature which maintains the high metabolic rate for generating much energy.

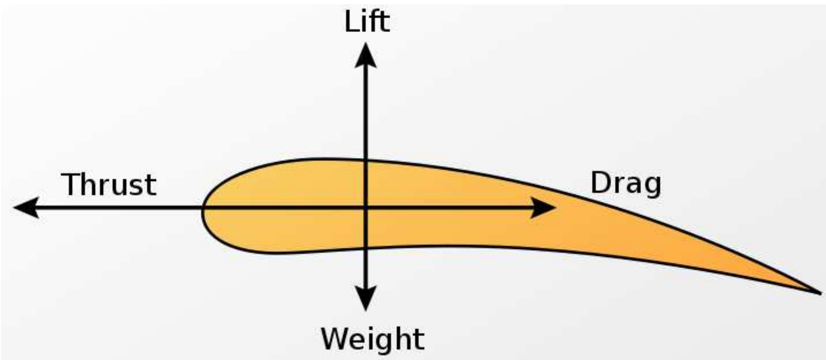
FLIGHT BIOMECHANICS (FLIGHT BIOPHYSICS)

THE BIRD'S WING AS AN AEROFOIL / AIRFOIL

Aerofoil / Airfoil: A structure whose shape and orientation provides lift, propulsion, stability, or directional control in a flying object.
An airfoil-shaped body moved through a fluid (air or liquid) produces an **aerodynamic force,** which is the resultant forces exerted on a body by the air in which the body is immersed, and is due to the relative motion between the body and the fluid.

PRINCIPLES OF THE AEROFOIL

The **four** basic forces at work when a bird is in flight are: **Lift, Thrust, Gravity (weight)** and **Drag** of which only **gravity** is **constant** (unchanging), the remaining three forces can be altered.
NB: Weight is a body force, not an aerodynamic force.



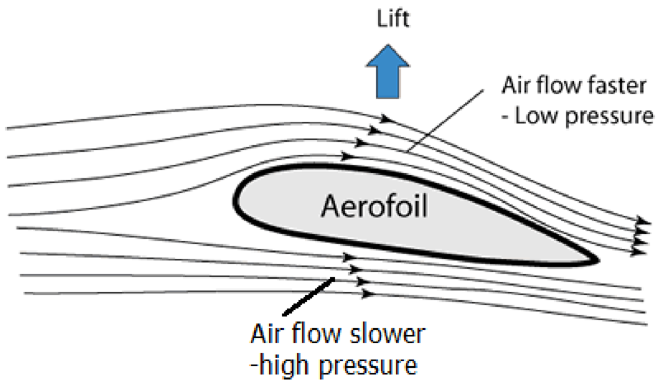
In a bird flying level at a constant speed, all four of these forces are in balance or equilibrium.
Weight: a continuous downward force (force of gravity) that flying objects must constantly overcome to stay in the air (aloft). The opposing force of gravity is lift.
Thrust: the force generated by flapping the wings which moves the bird forward and opposes drag. To move forward the flying bird must overcome drag. Drag can be reduced by streamlined shapes.
Drag (air resistance): is the friction between the moving object and the air, opposing thrust. The more streamlined or aerodynamic an object is, the less air resistance the object generates.

Drag is higher when
(i) The surface area of the object exposed to the fluid flow is higher (the reason why birds spread out their wings to slow down or land)
(ii) The object is moving faster (or the relative fluid flow is faster)
(iii) The fluid has more momentum, or inertia (high fluid viscosity and density e.g. at low altitudes)
Note that air at lower altitudes has more oxygen to facilitate muscle contraction of wings, but is thicker and therefore increases drag.

Lift: the mechanical aerodynamic force generated by the wings which directly opposes the (gravity) weight of a bird. Lift is higher when
(i) The area of the bottom of the wing is larger
(ii) The animal is moving faster
(iii) Fluid viscosity and density are higher.
Thicker air increases thrust by supplying the wings with more mass to move.

BERNOULLI'S PRINCIPLE AND AEROFOIL OPERATION

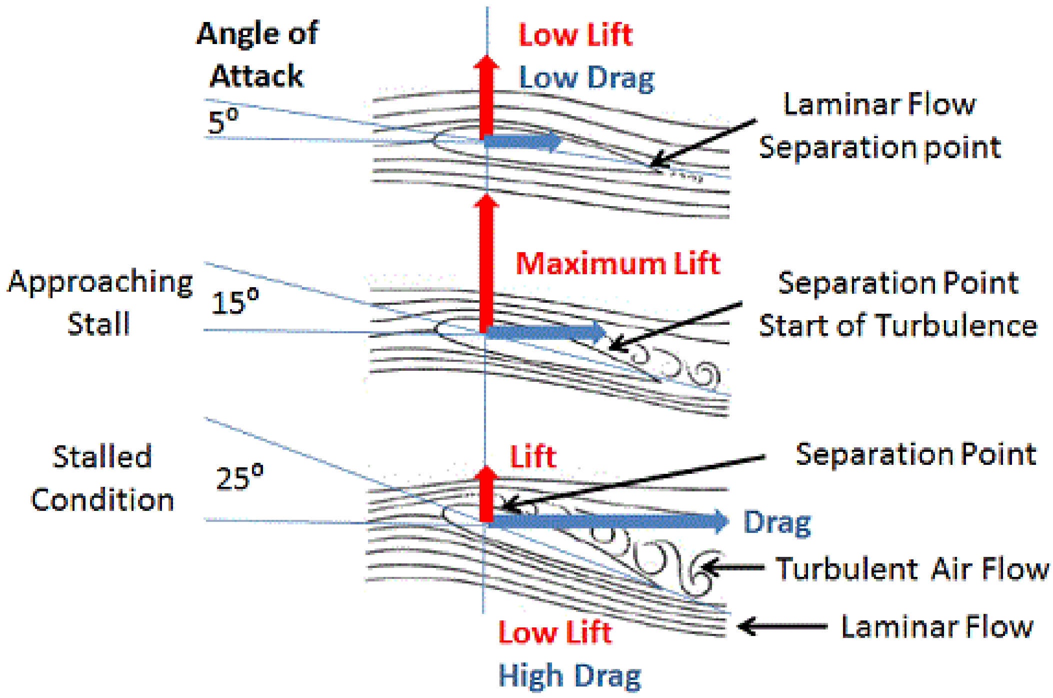
Daniel Bernoulli's theorem: an increase in the speed of a fluid produces a decrease in pressure and a decrease in the speed produces an increase in pressure.



As the bird flies, the air splitting at the front of the wing must rejoin at the back of the wing so as not to create a vacuum. The curved top surface being longer forces the air to move faster across the top than the bottom. Faster moving fluids create less pressure, so the bottom of the wing creates greater pressure than the pressure exerted downward above the wing, resulting in a net **upward force,** or **lift.**
The faster air moves across the wing the more lift the wing will produce, so moving it through the air by flapping increases this airflow and thus increases lift. The bird doesn't propel air underneath its wing; instead it cuts into the air with the leading edge to obtain the flow over the surface that it requires.

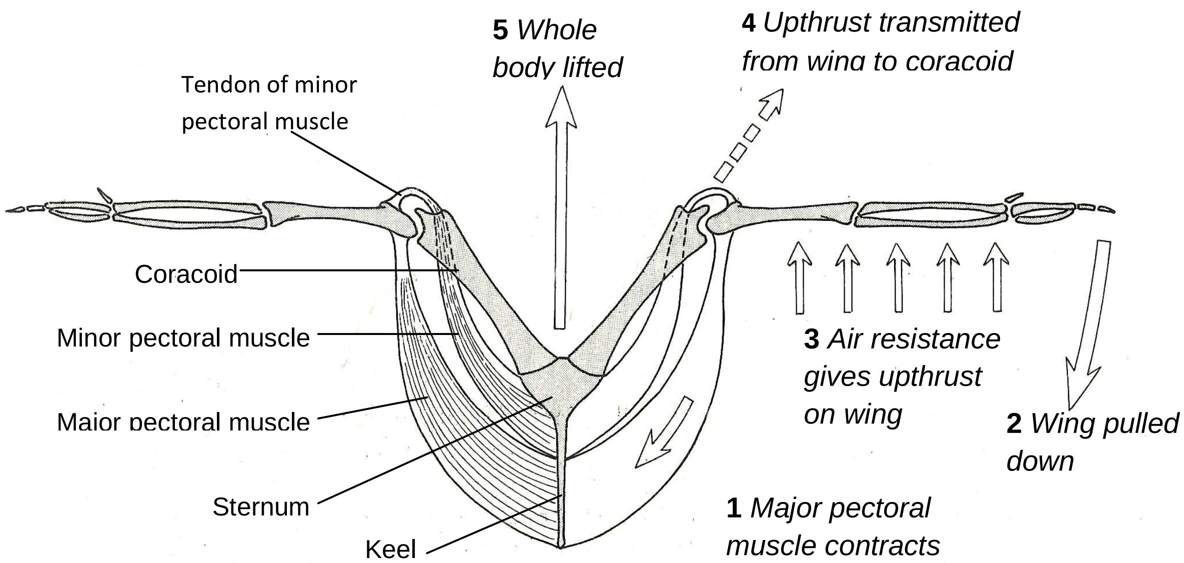
EFFECT OF ANGLE OF ATTACK ON LIFT

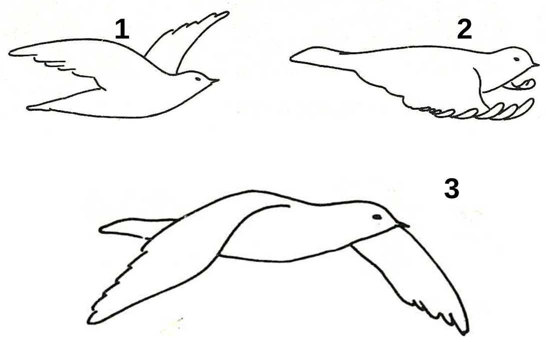
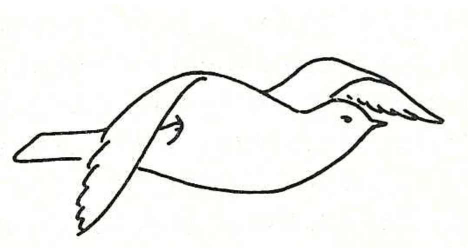
The angle of attack (AoA): the angle at which the leading edge of wing cuts into the forward airflow.
NB: It is erroneously thought that **AoA** is the angle of the aerofoil relative to the ground, yet it's the angle of the **wing** relative to **airflow**
●Increasing the angle of attack increases the volume of air diverted over the wing and leads to an increase in lift, but this is at the expense of drag which quickly increases.
●In a bird excessive **AoA** results in air turbulence / interruption of airflow **(eddy)** above the wing which causes a flight stall e.g., when taking off or landing.
● Air turbulence above the wing in birds is prevented by **(1)** the **alula** (bastard wings) and **(2)** end-feathers, both of which serve as sloths to smoothen the airflow above the wings. The alula is formed by 3 or 4 feathers attached to the first digit. **NB: Angle of attack decreases with increasing speed**



MECHANISM OF FLAPPING FLIGHT

Attachment of flight muscles in a bird's thoracic region



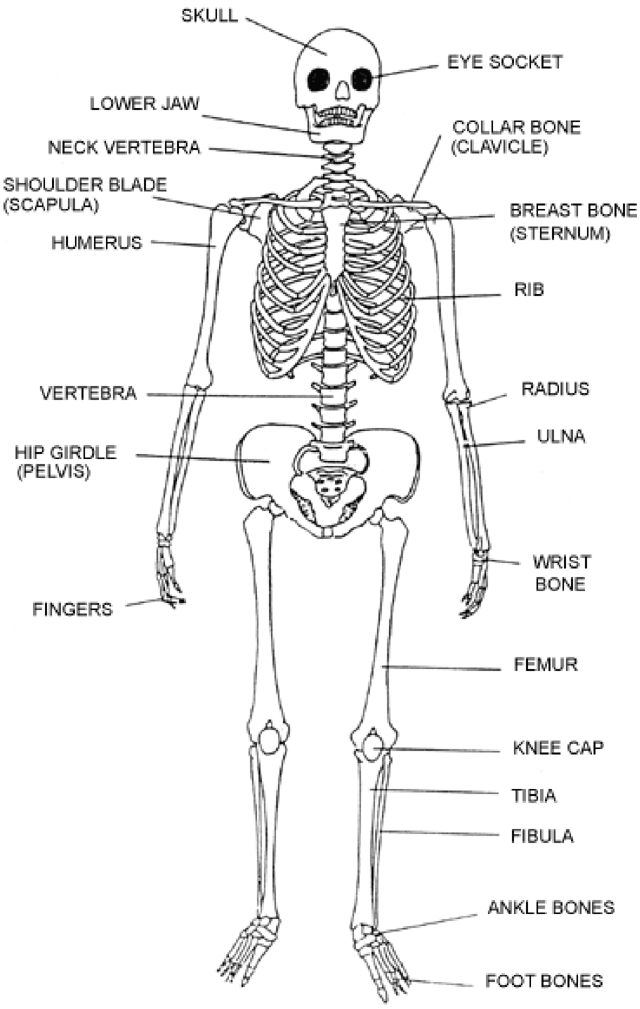
Downstroke  **1, 2** and **3** are successive stages of down stroke.	●**Downstroke** is marked by contraction of **pectoralis major** muscle and relaxation of **pectoralis minor** muscle (supracoracoideus) at the same time; abduction (elevation / raising) of humerus to a nearly vertical position and also retraction (pulling back) of wings to a horizontal position backwards; full extension of the elbow and wrist joints; **pronation** (dropping of leading edge relative to the trailing edge) and slight protraction (stretching out) slightly of humerus. This is followed by the downwards and forwards movement of wings until they lie parallel to and in front of the body. This is accomplished in part by protraction (stretching out) of the humerus.
Upstroke Flexed wrist reduces air resistance. 	The up-stroke of the wing is much more rapid than the down-stroke. ●During upstroke the pectoralis minor muscles (supracoracoideus) contract; the **pectoralis major** muscles relax at same time; the wings are first adducted(elevated/raised); bent at the wrist; the arm is rotated slightly so that the leading edge is higher than the trailing edge; thus reducing the air resistance and the rush of air lifts the wing. **NB: The secondary feathers provide much of the lifting force and the primaries most of the forward thrust.**

Why does the slower moving air generate more pressure on the wing than the faster moving air?
In calm air, the molecules are moving randomly in all directions. However, when air begins to move, most (but not all) molecules are moving in the same direction. The faster the air moves, the greater the number of air molecules moving in the same direction. So, air moving a bit slower will have more molecules moving in other directions. In the case of a wing, because air under the wing is moving a bit slower than air over the wing, more air molecules will be striking the bottom of the wing than will be striking the top of the wing.

QUESTIONS TO EXPLORE
(a) Compare gliding and flapping flights
(b) Compare the flight mechanism of insects and birds

Please read and summarise notes about joints of the mammalian skeleton

THE HUMAN SKELETON



HIGHLIGHTS OF THE HUMAN SKELETON

●Consists of **206 bones** at adulthood, about **300** at childhood.
●The **longest bone** in the human body is the **femur**; the **smallest** is **stirrup in the ear.**
● Males have slightly thicker and longer legs and arms; females have a wider pelvis and a larger space within the pelvis.
●It is divided into **axial** and **appendicular skeletons**

Axial skeleton is composed of **80 bones** divided into **five parts**; the **human skull,** the **ossicles** of the middle ear, the **hyoid bone** of the throat, the **rib cage,** and the **vertebral column.**
The word **Axial,** taken from the word axis refers to the fact that the bones are located close to or along the central axis of the body.

Appendicular skeleton is composed of **126 bones** divided into **six major** regions:
●Pectoral Girdles (4 bones) - Left and right **Clavicle** (2) and **Scapula** (2).
●Arm and Forearm (6 bones) - Left and right **Humerus** (2) (Arm), **Ulna** (2) and **Radius** (2) (Fore Arm).
●Hands (58 bones) - Left and right **Carpal** (16) (wrist), **Metacarpal** (10), Proximal phalanges (10), Middle phalanges (8), distal phalanges (10), and sesamoid (4).
●Pelvis (2 bones) - Left and right os coxae (2) (ilium).
●Thigh and leg (8 bones) **- Femur** (2) (thigh), **Tibia** (2), **Patella** (2) (knee), and **Fibula** (2) (leg).
●Feet (56 bones) - **Tarsals** (14) (ankle), **Metatarsals** (10), Proximal phalanges (10), middle phalanges (8), distal phalanges (10), and sesamoid (4).
The word **appendicular** is the adjective of the noun **appendage**, which itself means a part that is joined to something large.

FEATURES OF THE MAIN FORE AND HIND LIMB BONES

Main fore limb bones	***Hind limb bone***
HUMERUS ●It upper end bears a head which articulates with the **glenoid cavity** of the scapula to form **a ball and socket joint** at the shoulder. ●At its lower end is the **trochlea** which articulates with the fore arm to form **a hinge joint** at the elbow. **ULNA** ●Its upper end bears the **olecranon process** just after the elbow joint which when the arm is straightened prevents any further backward movement of the fore arm hence dislocation doesn't occur. **Therefore the olecranon process is considered to be the most important structure on the ulna bone.** ●It also bears a notch, the **sigmoid notch** close to the upper end which articulates with the **trochlea** of the humerus.	**FEMUR** ●At its upper end is a round head which articulates with the **acetabulum** of pelvic girdle to form a ball and socket joint at the hip. ●Three (3) **trochanter processes** protrude below the head and provide points of attachment for the thigh muscles. ●The lower end bears two (2) processes called **condyles** which articulate with tibia to form a **hinge joint** at the knee. A **patella groove** (where the **knee cap** is located) separates the femur's 2 condyles.

HIND LIMB OF A TYPICAL MAMMAL *Draw from:* **Michael Roberts, Pg. 423 fig. 24.8** ***left or*** **M.B.V. Roberts, functional approach**	**ILLUSTRATION OF THE HIND LIMB ACTION IN PROPULSION** *Draw from:* **Michael Roberts, Pg. 424 fig. 24.9A** ***left or*** **M.B.V. Roberts, functional approach**

BIPEDALISM [PROPULSION USING 2 REAR LEGS]

Bipedal locomotion is **walking, running,** and **standing** on two rear limbs.
●During walking, **the calf muscle** of the right limb c**ontracts** to raise the right heel; causing the **ball of foot** to exert a contact force on the ground; generating the **ground reaction force** (**GRF**) which thrusts the body forward and slightly upwards.
●The weight of the body shifts to the left foot which is still in contact with the ground to provide support.
●Extension of the right limb results in its heel touching the ground first to bear the body weight transferred to it from the left side.
●Further forward movement of the body exerts backward pressure against the ground through the right big toe.
●As the right leg bears the body weight, the left heel is raised and the whole sequence repeats.
●This sequence in which the right leg alternates with the left, heel-and-toe action continues until walking ceases.
●The **GRF** is composed of the lift force which thrusts the body off the ground and the forward force that propels the body forward - the magnitude of which depends on the angle between the ground and the main axis of the limb.
●A large angle between the ground and the main axis of the limb (e.g. 90^0) results in large lift force which thrusts the body vertically upwards with no forward force, a small angle causes a relatively bigger forward force and small upward lift.
NB: The ball of the foot is where the toes join with the rest of the foot.

WHY MAN STANDS ON SOLES BUT GENERALLY SPRINTS ON TOES

●Standing on soles increases the surface area for supporting the body weight in a balanced posture.
●Sprinting on toes increases the effective length of limbs; enabling taking longer strides that propel the body forward over a greater distance and at a faster pace even if the speed of limb movement remains the same.

WHY SPRINTERS CROUCH (BEND DOWN) BEFORE TAKEOFF

Crouching creates a small angle between the ground and the main axis of the limb; resulting in maximum forward thrust rather than upward lift; hence propelling the body a greater distance forward.

QUADRUPEDALISM [PROPULSION USING FOUR LEGS]

Quadruped: an animal especially a mammal, having four limbs all specialized for walking, except humans and the birds.

Tetrapod: a vertebrate animal having four limbs e.g. amphibians, reptiles, birds and mammals.
NB: A Tetrapod may use only two limbs for walking

●**Contraction of extensor muscle** causes each limb to act as a lever by extending and exerting a backward force that presses the foot against the ground thus thrusting the animal forward and slightly upwards; because an equal and opposite force called **reaction force** is transmitted along the length of the limb against the body while **contraction of flexor muscle** pulls the limb forward and lifts it off the ground.
●During **walking**, only one limb is raised at a time; the other three remain anchored to the ground to provide tripod support / stability in a sequence of leg movement as follows**: left forelimb; right hindlimb; right forelimb; left hindlimb** *[N.P.O. Green; etal, Biol Sc]* **or LH; LF; RH; RF** *[Michael Roberts Pg 426& FA]*
●During **slow running**, tripod support is lost because the two forelimbs are moved together followed by the two hind limbs in the sequence of: **left forelimb; right forelimb; right hindlimb; left hindlimb.**
● During **maximum speed running,** a dog uses its back to attain speed. All the four legs may be lifted off the ground at the same time, with alternate upward arching of the back coupled with rear feet extension in front of the front feet and the front feet extension behind the rear feet, and full extension of the vertebral column coupled with full extension of front legs forward and rear legs rearward to increase stride length.

SUCCESSIVE STAGES IN THE DIAGONAL LOCOMOTORY PATTERN OF A WALKING TETRAPOD
Draw from: **Michael Roberts, etal Page 426 fig. 24.11B (walking)** ***or*** **M.B.V. Roberts, functional approach**

TASK
Summarize the importance of centre of gravity
Check: **Michael Roberts,** etal Page 426

PLANTIGRADE, DIGITIGRADE AND UNGULIGRADE LOCOMOTION

●**Plantigrade locomotion:** walking with the podials and metatarsals flat on the ground e.g. humans, raccoons, opossums, bears, rabbits, kangaroo, mice, pandas, rats and hedgehogs.
●**Digitigrade locomotion:** walking on the toes with the heel and wrist permanently raised e.g. birds, wolf, dog, coyote, cat, lion, elephant (semi-digitigrade)
●**Unguligrade locomotion:** walking on the nail or nails of the toes (the hoof) with the heel/wrist and the digits permanently raised. **Ungulates** include horse, zebra, donkey, cattle, bison, rhinoceros, camel, hippopotamus, goat, pig, sheep, giraffe, okapi, moose, deer, antelope, and gazelle.

Advantage of a plantigrade foot: because of a large surface area, it offers stability and able to bear much weight.
Disadvantage of a plantigrade foot: locomotion is
of slow speed because of many bones and joints in the foot making the leg heavier at the far end.
Advantage of digitigrades: They are generally faster and quieter than other types of animals

QUESTION
Explain why in terrestrial tetrapods it is advantageous to have limbs below and parallel to the sides of the body e.g. in mammals rather than lateral to the body e.g. in amphibians
Consult with: **Clegg and Mackean,** Adv. Biol Princ. & Applic. Page 495