Support and movement in animals

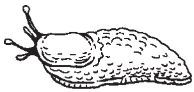
(Extension material for Level 2 Biology Study Guide, ISBN 978-1-927194-11-9, page 177)

NCEA Level 2 Biology material covered in this chapter includes material for Achievement Standard 91155 (Biology 2.3) 'Describe diversity in the structure and function of animals'. The chapter deals with:

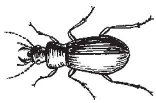
- The structure and function of the parts that provide support and allow movement – skeleton, muscles, joints.
- A description of how and where support is achieved in animals – hydrostatic skeleton (fluid), exoskeleton (chitin), endoskeleton (bones).
- A description of how and where movement is achieved in animals – muscle contraction, antagonistic muscles, tendons and ligaments, joints.
- Reasons for the differences in structure and function between different groups – these could relate to mobility and energy needs, size, habitat, life cycle, way of life.

Animals need support structures to hold their bodies together, keep them erect, and allow for movement. Aquatic animals need less support than terrestrial animals, as water provides buoyancy.

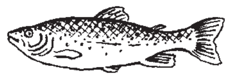
Essentially, there are three types of *support* system – **hydrostatic skeleton**, **exoskeleton**, **endoskeleton**. *Movement* is achieved by muscular contraction acting on the skeleton.



Hydrostatic skeletons
A *fluid-filled body cavity* (called a coelom) acts as an internal support system (e.g. molluscs, coelenterates and annelids).



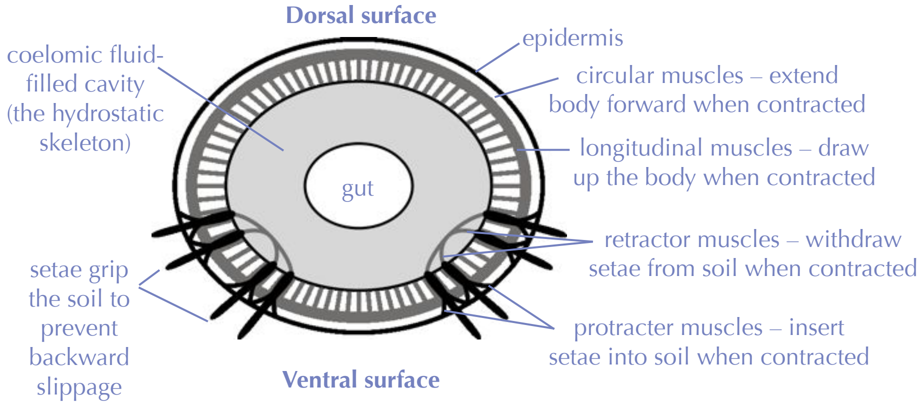
Exoskeletons
The *body wall* acts as an external support structure (e.g. arthropods).



Endoskeletons
An *internal skeleton* made of cartilage or bone is present (e.g. fish, mammals and birds).

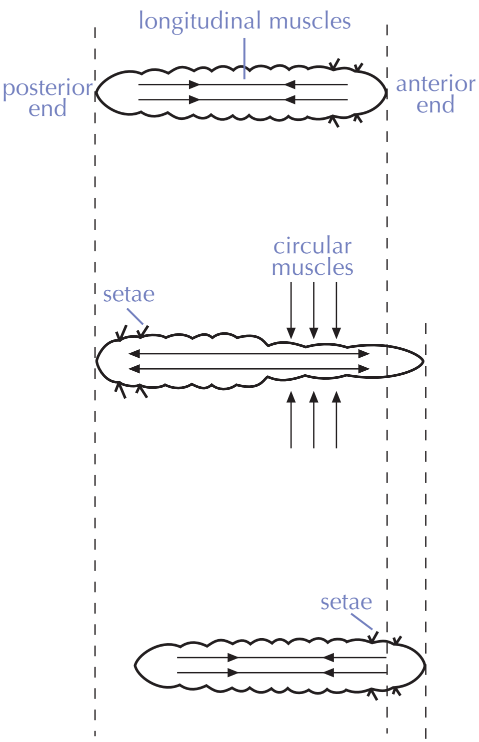
Hydrostatic skeleton of earthworms

The earthworm's skin encloses two layers of muscle (*circular* and *longitudinal*). Centrally placed and running the length of the body is the digestive tract. Between the muscles and the digestive tract is a fluid-filled cavity, the **coelom** (fluid is **coelomic fluid**). The coelomic fluid acts as a **hydrostatic skeleton**, as fluid is incompressible and so provides resistance to muscular contraction.



Cross-section of an earthworm to show muscle layers, coelomic cavity, setae

The longitudinal muscles run the length of the body; the circular muscles run around each body segment (the segments are separated by a thin sheet of muscle). Like all muscles pairs, these circular and longitudinal muscles act as an **antagonistic pair** – one muscle contracts causing the other to relax.



- Circular muscles relax.
- Longitudinal muscles contract.
- **Setae** (or **chaetae**), small bristles, anchor anterior (front) part of the worm.

- Setae anchor posterior (back) part of worm.
- Longitudinal muscles relax.
- Circular muscles at the anterior (front) end contract, forcing the anterior end forward through the soil.

- Setae extend out to anchor the anterior end of the worm.
- Circular muscles relax.
- Longitudinal muscles contract, dragging the posterior (back) part of worm forwards.

The muscular contractions in each segment are slightly staggered, which results in a wave of contractions (known as **peristalsis**) from the head (anterior) to the tail (posterior) end. This is co-ordinated by the *ventral nerve cord*. Mucus secreted by cells in the skin *lubricates* the path through the soil.

Exoskeleton of insects

Arthropods have evolved an exoskeleton ('skeleton on the *outside*' – 'exo' means outside); the muscles are internal. In insects, the exoskeleton is a non-living cuticle made mainly of the polysaccharide **chitin** (similar to cellulose, but contains nitrogen) as well as of various proteins. The proteins typically become *tanned*, which makes the exoskeleton stiff (and dark). The outer surface of the cuticle is *waxy* for waterproofing. The cuticle remains un-tanned (thus soft) at joints, to allow for movement.

Adult insects are the reproductive stage and usually have wings. The formation of the exoskeleton divides insects into two major groups:

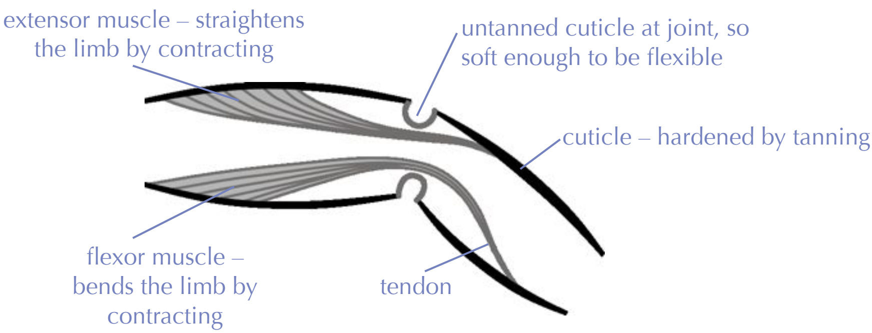
- Insects that grow in progressively bigger stages (called instars) from an egg to an adult (e.g. crickets). *Each instar has an exoskeleton* and looks like a slightly bigger version of the previous instar. These insects shed the cuticle at the end of each stage as the cuticle is *non-living* – it cannot allow for growth. For a short time after the previous cutide has been shed, the next cuticle is soft and so does not offer support or protection.
- Insects that emerge from an egg as a larva. The larva moults through three or more stages, then pupates to emerge as an adult (e.g. butterflies). *It is only the adult insects that have an exoskeleton*.

The exoskeleton is likely to be a main factor limiting the size of insects.

The cuticle is formed into plates which meet at *joints*. Antagonistic muscles (*extensors* and *flexors*) attach to the cuticle on the inside of joints and act as *levers* to produce movement.

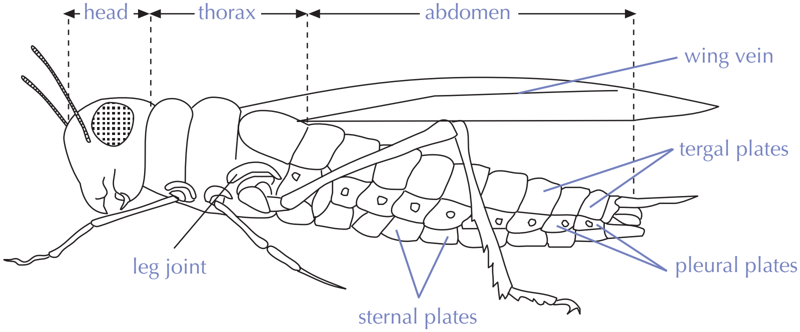
- Contraction of the extensor straightens the limb.
- Contraction of the flexor bends the limb.

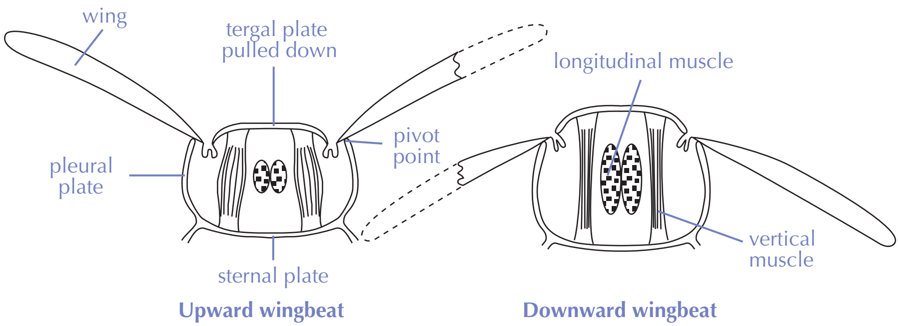
Leg joint of an insect



The muscles are attached to the inside of the exoskeleton

Insects' *wings* are strong and rigid, supported by inflexible veins. The wings (like the legs) attach to the abdomen and are operated by vertical and longitudinal muscles acting antagonistically on the tergal plate of the cuticle.





The pleural plate acts as a *fulcrum* (or pivot point) for the end of the wing, which is also attached to the tergal plate. The tergal plate is flexible, so that:

- When the *vertical* muscles contract (shorten), the tergal plate is pulled down, forcing the wing up.
- When the *longitudinal* muscles contract, they force the tergal plate up, pushing the wing down.

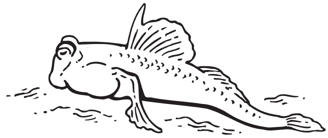
The flight muscles act as an antagonistic pair, and can contract and relax up to 1 000 times per second in rapidly flying insects such as midges.

Insects perform many movement functions besides flying, such as digging (dung beetle), hopping (grasshopper), jumping (springtail), running (silverfish), and swimming (water boatman). All these movements are achieved through rapidly contracting, antagonistic muscle pairs.

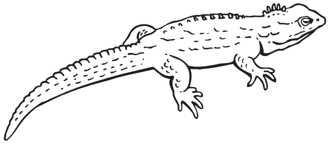
Endoskeleton of vertebrates

All vertebrates have an **endoskeleton** ('skeleton on the *inside*' – 'endo' means inside); which is made of bone and cartilage, both of which are *living* material which grow as the animal grows. Because of this, vertebrates can be much larger animals than invertebrates.

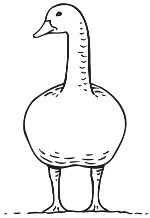
The first vertebrates to live on land supported their weight by lying on the ground. Their limbs served only to push them around. This type of locomotion is seen today in the mudskipper fish, which can drag itself around on land using its fins.



Gradual strengthening of the muscles and the hip and shoulder joints enabled vertebrates to lift their bodies vertically off the ground and so move more quickly. Modern reptiles still use this means of locomotion, but it is only efficient for quick bursts of movement over short distances.



The most successful land vertebrates – birds and mammals – sit their body weight *above* their limbs, so that their limb bones support the weight of the body. The limb muscles can then be specialised for movement.

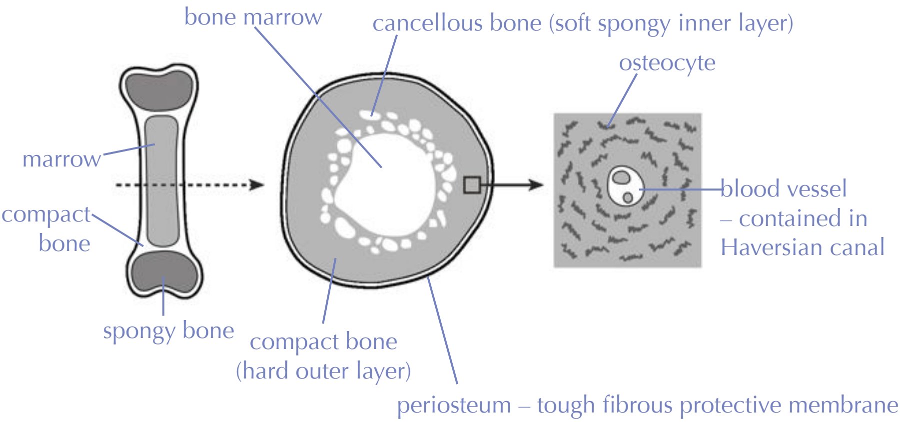


Bone

As bone is a living tissue; it can repair itself after being damaged or broken. The living cells of bones are called osteocytes, which are supplied with nutrients by blood vessels that pass through the bone. Bones:

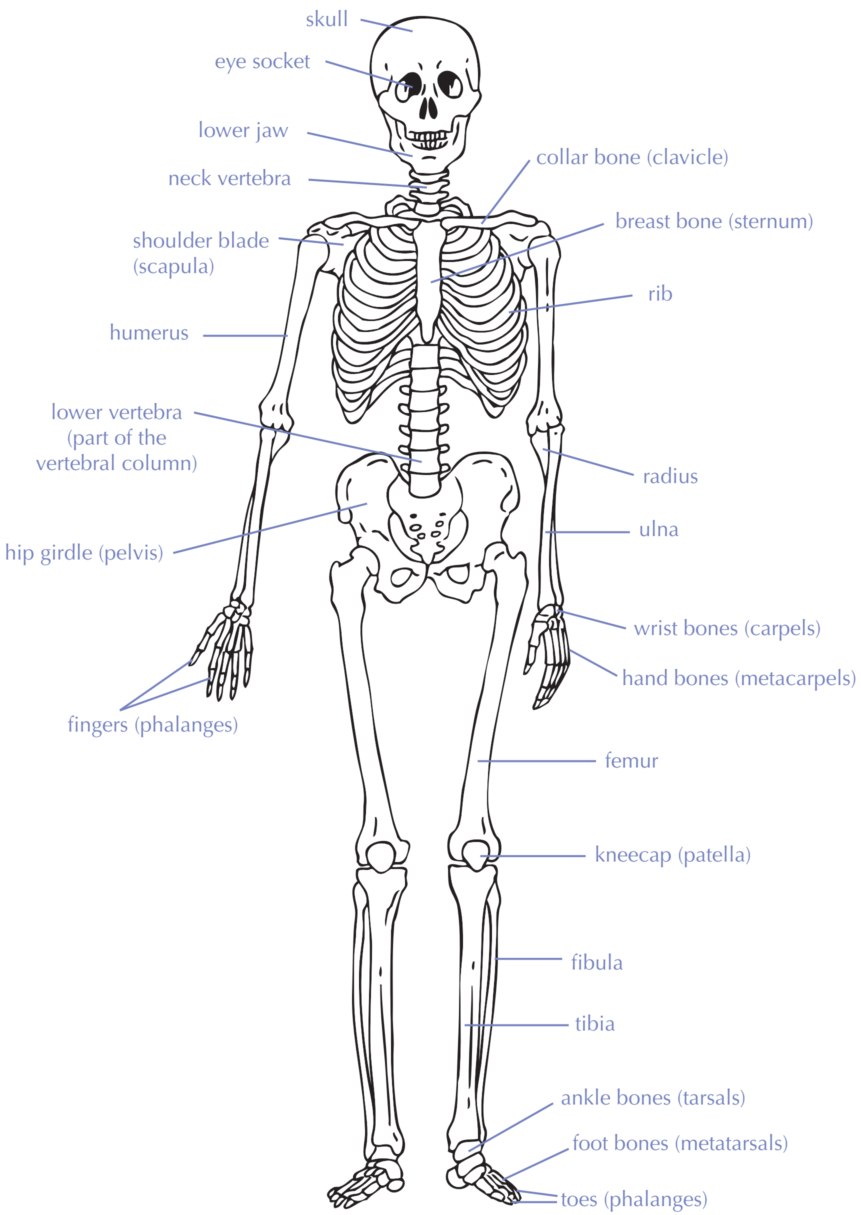
- *Support* surrounding tissue and *protect* vital organs (e.g. brain, heart and lungs).
- Allow *movement* by providing attachment for muscles.

Bone hardness comes from the minerals *calcium carbonate*, $CaCO_3$, and *calcium phosphate*, $Ca_3(PO_4)_2$; their strength comes from the fibrous protein *collagen*. The outer layer of bone is **compact bone** (which is very hard), while the inner layer is **spongy bone**. Spongy bone contains spaces that are filled with fat or marrow. Because of this, spongy bone is not as heavy or hard as compact bone. The ends of bones are thickened and strengthened, as they bear the greatest stresses.



The embryonic skeleton is made of cartilage, which provides the framework for the bones to develop in. Bone marrow manufactures blood cells.

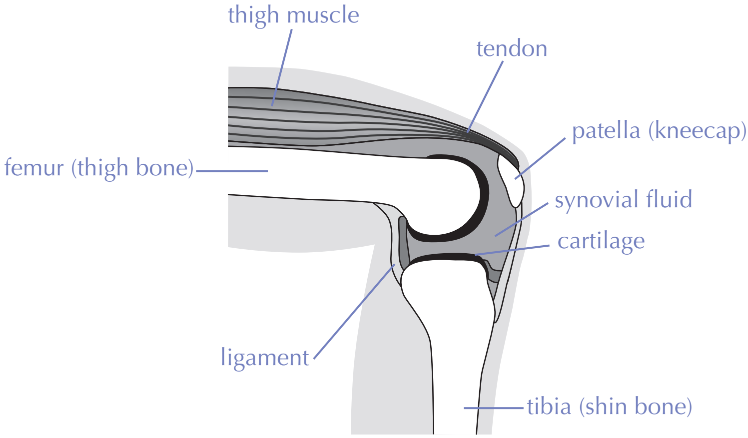
The human skeleton has 206 bones.



The skull, vertebral column, and ribs, compose the *axial skeleton*; the shoulder and hip girdles, together with their limbs, compose the *appendicular skeleton*. The long bones (e.g. femur, tibia) are hollow – a hollow structure is stiffer than a similar solid one, and gives a significant saving in weight.

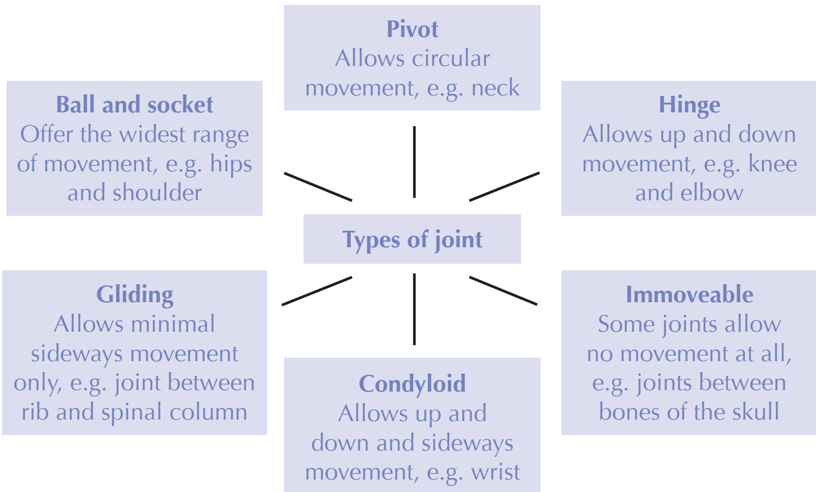
Joints

Bones meet at **joints**. The joints bear weight and allow movement between bones. The knee is an example of a complex synovial joint.



The knee has several ligaments connecting femur and tibia

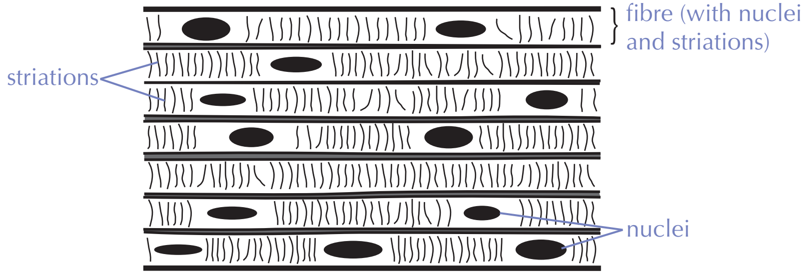
Tough, elastic **ligaments** hold the bones together, strengthening the joint and helping prevent incorrect movement. **Cartilage** forms at the ends of the bones to give a smooth surface for articulation, by reducing friction (if the cartilage wears away, the bones grind together and friction occurs, causing pain, swelling, stiffness – a condition called *osteoarthritis*). **Synovial fluid**, contained in the joint capsule, lubricates and nourishes the cartilage, reducing friction.



Muscles

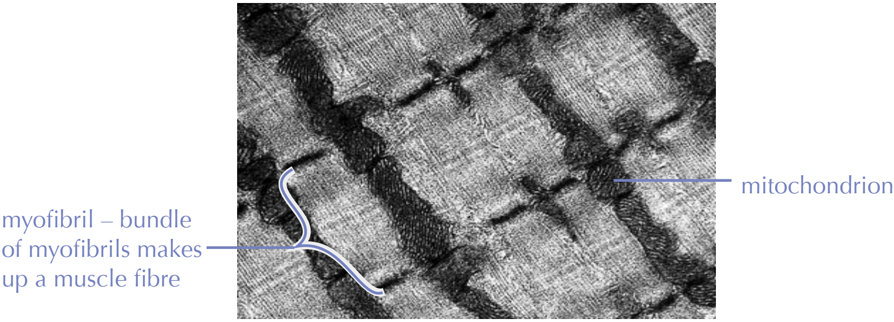
Muscles attach to the bones by tough fibrous **tendons**, mainly made of collagen (as are ligaments).

Muscles which move the limbs are the *skeletal* muscles – the other two types of muscle are *cardiac* (found in the heart), and *smooth* (found in the internal organs). Skeletal muscles are under the voluntary (or conscious) control of the brain, and able to contract rapidly; they appear striped (striated) when viewed under the microscope. The stripes/striations are the light and dark bands from overlapping (myo)filaments.



Bundle of seven fibres of skeletal muscle

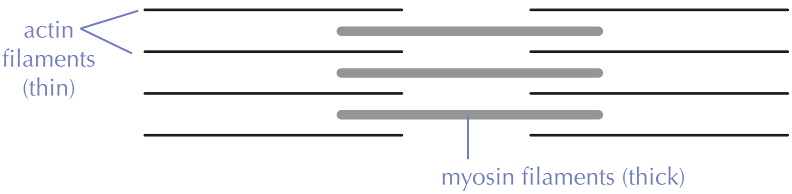
Fibres are made up of bundles of *myofibrils*. As muscles need large amounts of energy to contract, their cells have large quantities of **mitochondria**.



SEM picture (× 21 200) of striated muscle fibres from rat leg

Myofibrils are made of long filaments (*myofilaments*) of two proteins – **actin** and **myosin** (where these two overlap, the muscle fibres look darker). When a muscle contracts, these two filaments slide past each other, shortening the muscle. This exerts a pull on the bone that the muscle is attached to, so the bone moves.

Contractile proteins actin and myosin found in the myofibrils of muscle fibres



When the muscle contracts, the actin filaments slide towards each other, shortening the muscle ('bunching it up'), which then pulls against the skeleton.

A *motor unit* is a group of muscle fibres all supplied by the same bundle of nerve cells. When the nerve cells are stimulated by a nervous impulse, all the muscle fibres the nerve cells are associated with contract together.

Increasing the degree of movement of a muscle involves stimulation of greater numbers of nerve cells. If a muscle is stimulated continuously, it may build up lactic acid and become fatigued. A fatigued muscle will be unable to contract until the lactic acid is removed.

Limb movement

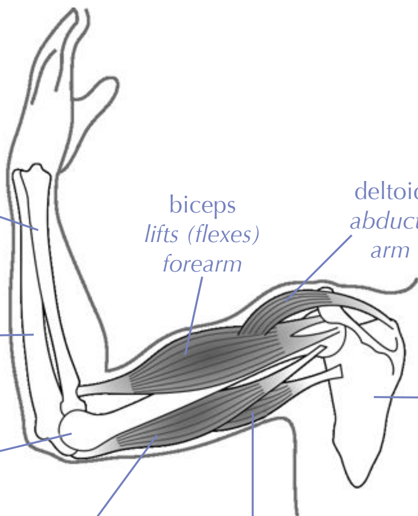
Muscles which bend a limb when they contract at a joint are called **flexors**. Muscles which straighten or extend a limb at a joint are called **extensors**.

Abductor muscles move limbs away from the body; muscles that return limbs to the body are called **adductors**.

Flexors and extensors, abductors and adductors, act as *antagonistic pairs*.

The distance that muscles move when they contract is quite limited, so muscles are usually attached close to the limb (pivot point).

The four muscles (two antagonistic pairs) used in arm movement in humans



The arm has been raised by contraction of the *biceps* and *deltoid* muscles; their opposing muscles, the *triceps* and *teres major*, are relaxed.

The limb pivot point is the elbow for the biceps and the triceps muscles, the shoulder is the pivot point for the deltoid and teres major muscles.

Activity A: Support and movement in animals

1. Explain why animals need a skeleton.
2. Explain why:
   a. The skeleton in earthworms is called a hydrostatic skeleton.
   b. The skeleton in insects is called an exoskeleton.
   c. The skeleton in mammals is called an endoskeleton.
3. Explain why muscles occur as antagonistic pairs.
4. Distinguish between the following pairs of terms:
   a. Chitin and bone.
   b. Ligaments and tendons.
   c. Extensors and flexors.
   d. Abductors and adductors.
5. Explain why virtually all large animals have a skeleton made of bone.
6. Explain how and why:
   a. Endoskeletons in humans are hardened.
   b. Exoskeletons in insects are hardened.
7. Compare and contrast how exoskeletons and endoskeletons provide support and movement.
8. Select three different taxonomic or functional groups, and, using named animals as examples, discuss the structure of their support and movement systems and the reasons for their differences. In your answer:
   - Describe the system for each of the named animals.
   - Explain how each of these systems operates.
   - Explain the differences in the systems in relation to the different ways of life of the three animals.

1. A skeleton is needed to hold the body *together and upright* / *support* the organs / allow the animal to *move*. This is because the skeleton provides a place for the connective tissue and muscles to *attach* and provides *resistance* against the contraction of muscles – this results in movement.
2. **a.** The skeleton in earthworms is hydrostatic because it is a *fluid* skeleton. The fluid gives support to the body/organs and provides resistance to the contracting muscles, because it *can't be compressed*. 'Hydro' = water; 'static' = not moving/stationary.
   b. The insect's skeleton is an external one; because it is on the outside of the body/muscles. 'Exo' = external/outside.
   c. The mammal's skeleton is an internal one; because it is on the inside of the body/muscles. 'Endo' = internal/inside.
3. Muscles occur as antagonistic pairs as one muscle contracts to move the limb while the other relaxes, and vice versa. The alternate contractions of the paired muscles cause opposite movements of the limb (e.g. bending and straightening). Muscles *can only contract*, and when they contract they pull on the skeleton, so causing movement. A muscle can only become relaxed when another muscle contracts – this is the antagonistic pair.
4. **a.** Chitin is a polysaccharide component of the cuticle (which is the exoskeleton of insects). It is non-living. Bone is living material, which makes the endoskeletons of vertebrates. Bone is made of cells called osteocytes, the protein collagen, and the hard minerals calcium phosphate and calcium carbonate.
   b. Both ligaments and tendons are made of the protein collagen, but tendons are the tough fibres that connect skeletal *muscles to bones*, while ligaments are the tough elastic fibres that *hold bones together in joints*.
   c. Extensors are muscles that *straighten* a limb when they contract, flexors *bend* a limb when they contract.
   d. Abductors are muscles that move limbs *away from the body* when they contract, adductors are muscles that move *limbs towards the body* when they contract.
5. Large animals have a skeleton of bone as bone is a *living* tissue and *grows as the animal grows*. The exoskeletons of arthropods (e.g. insects) restrict size, as they are non-living and have to be *shed to allow growth*. When shed, an exoskeleton allows a growth spurt, because the cuticle is soft for a short period of time. However, during this time, a soft cuticle does not offer either support or protection to the animal. As the animal increases in size, this inability to provide support during this time will eventually mean that the animal would collapse under its own weight. Therefore, the animal must remain small to survive.
6. **a.** Endoskeletons are hardened to provide *support and protection* to the body and the organs, and to provide *resistance* to muscular contraction, so allowing movement. This is done by the deposition of the minerals calcium carbonate and calcium phosphate in the outer layer of compact bone.

b. Exoskeletons are hardened to provide support and protection to the body and the organs and to provide resistance to muscular contraction, so allowing movement. This is done by a process called tanning, in which the proteins of the cuticle become hardened (and much darker). This occurs all over the body, except at the joints (allows for movement).

7. *Comparisons* of the two systems could include:

- Both support body/organs.
- Both allow for movement via joints.
- Movement is effected through the contraction of muscles working in antagonistic pairs – flexors/extensors, abductors/adductors.
- Large quantities of energy needed for movement (muscle cells rich in mitochondria; need for respiration).

Contrasts of the two systems could include:

- Detailed description of structure and composition of the two skeletons (non-living cuticle of chitin and protein versus a living bone and cartilage endoskeleton); joint structure.
- Synovial joints in endoskeleton.
- Different types of movement, e.g. flight in insects versus flight in bats and birds.
- Exoskeleton animals always small; endoskeleton animals can be large.
- Limitations of exoskeleton versus endoskeleton.

Correct terms should be used in all answers (e.g. cartilage, synovial fluid, coelomic fluid, cuticle, antagonistic muscles).

Answers could be enhanced by clear, labelled, annotated diagrams – annotations could be descriptions.

8. Three clearly different taxonomic (e.g. earthworms, insects, mammals) or functional groups (e.g. hydrostatic skeleton, exoskeleton, endoskeleton) need to be selected.

For *each* group, the *structures* associated with the *support and movement* need to be *described fully and carefully, using correct terms*, e.g.:

- *Detailed* descriptions of structure of hydrostatic skeleton, exoskeleton, endoskeleton (e.g. coelom/coelomic fluid; cuticle, chitin; bone, cartilage) and their location.
- *Detailed* description of muscles, connective tissue, antagonistic pairs and their location.
- The need for joints, their location, their structure – e.g. synovial joints, tendons, ligaments.

For *each* group, *how* these structures perform their particular function needs to be *explained*, e.g.:

- How the skeleton supports the body (e.g. organ support and protection), hardening of the skeleton, connective tissue.
- How movement is achieved – muscular contraction, antagonistic pairs, flexors and extensors, adductors and abductors, ligaments and tendons, actin and myosin energy requirements.

For *each* group, reasons for *differences* between the groups needs to be *explained* in relation to differences in:

- Habitat – e.g. aquatic or terrestrial (water supports body more than air).
- Activity levels of the animals (high or low), types of activity (walking, hopping, flying).
- Size and complexity of the animals (large or small, upright or horizontal, presence of segments, restrictions on size).
- Ecological niches (specific adaptations to their habitat and lifestyle).