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11.2 Movement

IB Biology - Revision Notes

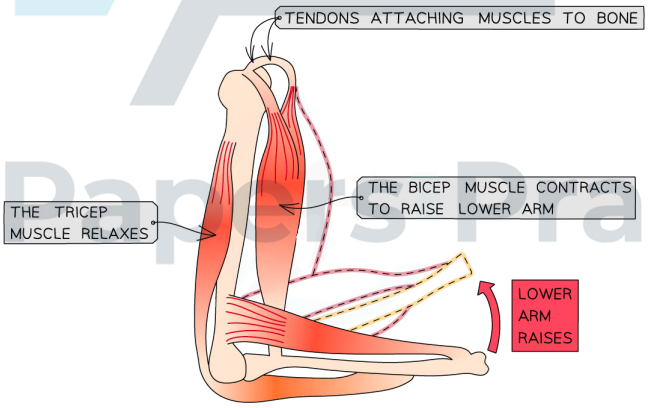
11.2.1 Requirements for Movement

Bones & Exoskeletons

- The effective movement of the human body requires both **muscle** and an **incompressible skeleton**
- Bones and exoskeletons provide **anchorage for muscles** and **act as levers**
- Mammals have **internal bones,** called an **endoskeleton,** to support their bodies from the inside with tissues surrounding the bone
- Many organisms have **external skeletons** called **exoskeletons** which are found on the **outside of the organism** to protect the internal tissues
- **Organisms that have exoskeletons** include:
  - Crustaceans
  - Insects
  - Arachnids
  - Centipedes and millipedes
  - Molluscs
- Key features of both exo and endo skeletons is that they **provide support for the body** of the organism whilst also **facilitating movement**
  - Exoskeletons also provide **protection** for the body's soft tissues within
- Muscles are anchored to the skeleton either on the inside (as with exoskeletons) or the outside (as with endoskeletons) and the presence of pivot points means that **skeletons act as levers** transferring the size and direction of force
  - Levers have a point of **effort**, a point of **load** and a **pivot point** called the fulcrum
  - These same three features are seen in skeletons

Antagonistic Pairs

- There are over 600 skeletal muscles in the human body
- Muscles are **effectors**, stimulated by nerve impulses from **motor neurones** (specialised cells adapted to rapidly carry electrical charges called nerve impulses from sensory neurones to the muscles to bring about movement)
- Lengths of strong connective tissue called **tendons**, connect muscles to bones
  - They are **flexible but do not stretch** when a muscle is contracting and pulling on a bone
- Muscles are only capable of **contracting** or **pulling**, they **cannot push**
- As a result of this limitation muscles generally **operate in pairs**
- One muscle pulls in one direction at a joint and the other muscle pulls in the opposite direction
- This is described as **antagonistic muscle action**
- An example of this can be seen in the **bicep and tricep** of the arm
  - To raise the lower arm
    - The bicep contracts and the tricep relaxes
    - As the bone can't be stretched the arm flexes around the joint
    - This brings the tricep into its full length so that it can contract again
  - To lower the lower arm
    - The tricep contracts and bicep relaxes
    - As the bone can't be stretched the arm flexes around the joint



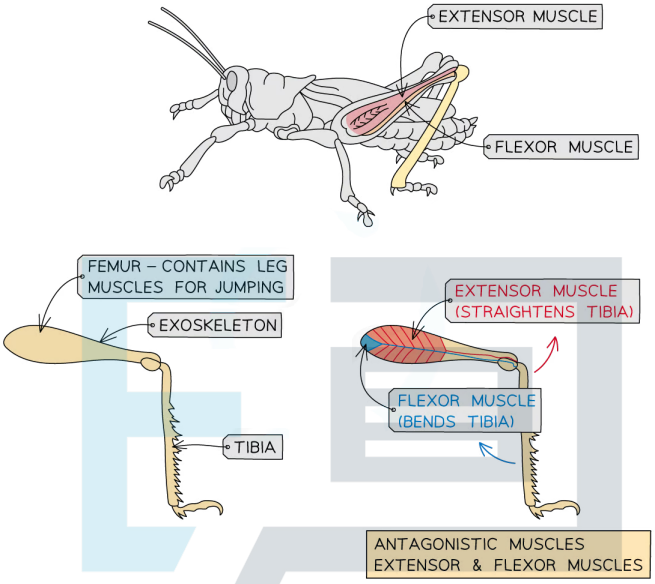
The two muscles work together by pulling in opposite directions

Antagonistic pairs of muscles in an insect leg

- **Antagonistic muscles** are also common in the **appendages of insects**
- Insects such as the praying mantis and the grasshopper have rear legs that are adapted to allow **jumping**
- These rear legs are separated into three sections
  - The **tarsus** is the lower leg

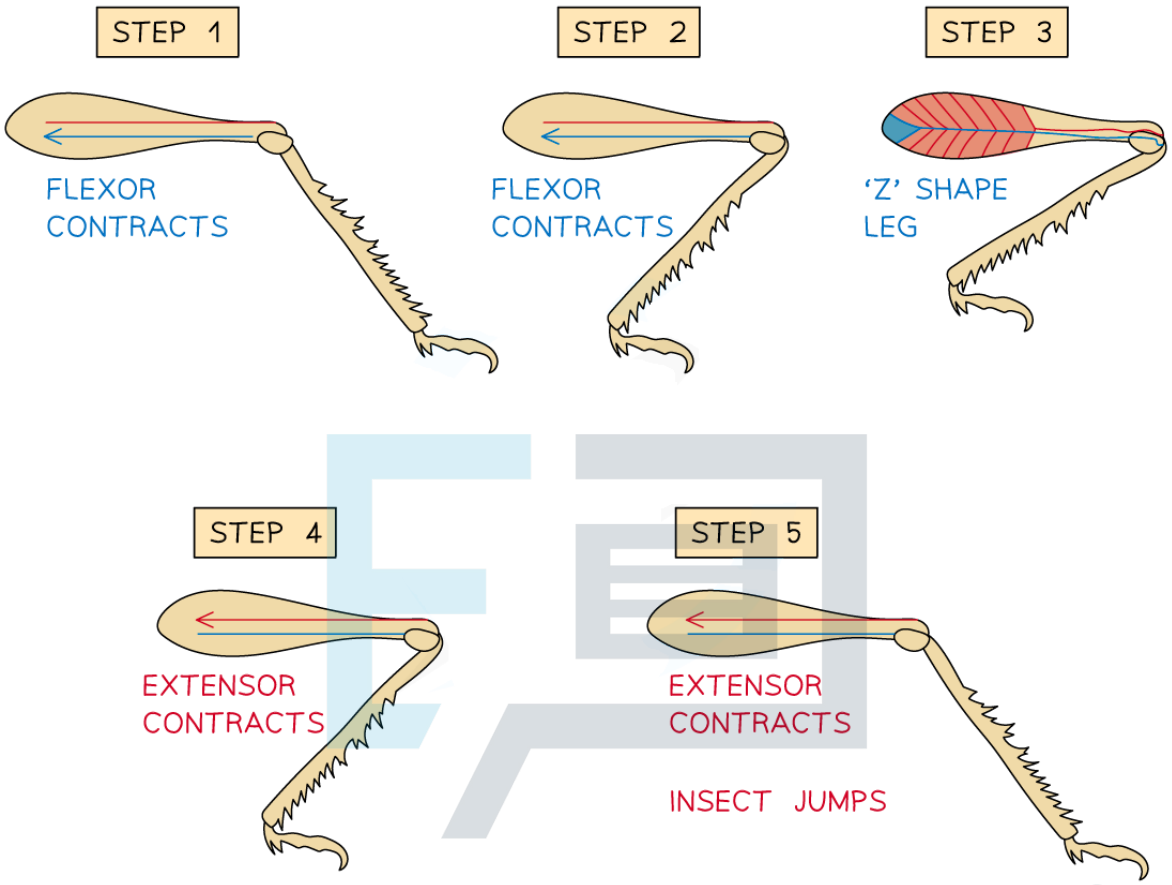
- The **tibia** is the middle part below the joint
- The **femur** is the upper leg

- Antagonistic muscles connect the tibia and femur
  - An **extensor** muscle
  - A **flexor** muscle



The structure of a grasshopper leg including antagonistic muscles

- When preparing to jump, the **flexor muscles contract** and the **extensor muscles relax**
  - This is called 'flexing'
  - The shape of the leg is 'Z' shaped as the tibia and femur are **brought closer together**
- To propel the insect into the air, the **extensor muscle then contract and flexor muscles relax**



Antagonistic muscles control the jumping movement of a grasshopper

Joints & Range of Movement

- **Synovial joints** are the most common type of joint in the human body
- They are characterised by a **joint cavity filled with a lubricating synovial fluid** which **reduces friction**
- The fluid is produced by the **synovial membrane**, which surrounds the joint
- Synovial joints are **capable of a variety of different movements** which depends on the structure within the joint including the joint type and the ligaments
- The movements possible at the joint are
  - Flexion
  - Extension
  - Rotation
  - Abduction (the movement of a limb away from the body)
  - Adduction (the movement of a limb towards the body)

Table to show some examples of different joint types and their associated movements

Joint	Movement
Knee (hinge)	Flexion and extension
Elbow (hinge)	Flexion and extension
Hip (ball and socket)	Flex, extend, rotate, sideways and back
Shoulder	Abduction and adduction, flexion and extension

11.2.2 Skeletal Muscle

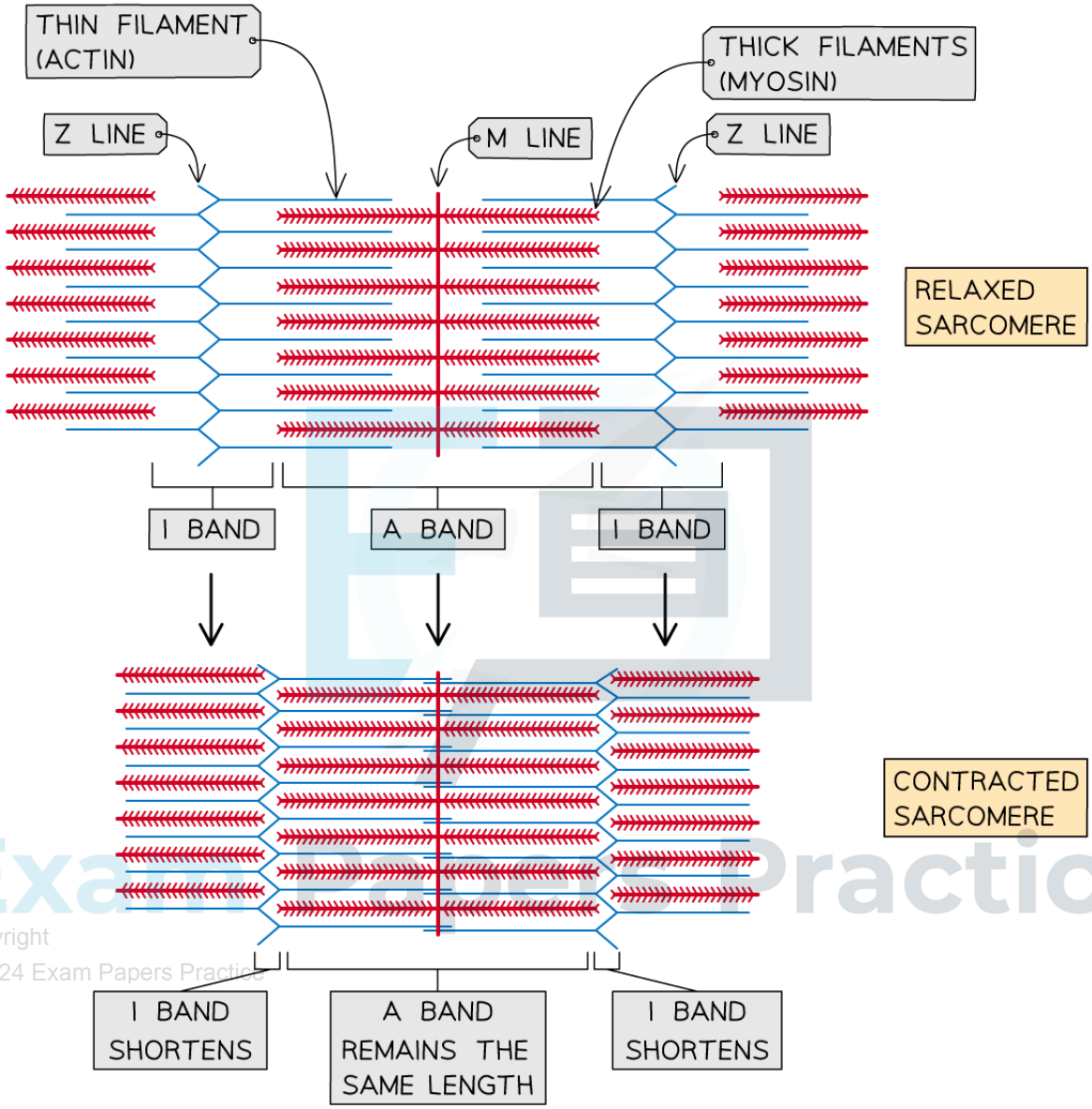
Skeletal Muscle Fibres: Structure

- Muscles in the body that are attached to the skeleton and aid movement are called **skeletal muscles**
- Other muscle types include:
  - **Cardiac muscle** which is found in the heart
  - **Smooth muscle** is found in the blood vessels and organs
- Skeletal muscle is **striated** as it has a stripy appearance when viewed under a microscope
- Striated muscle cells are bundled up into fibres which are surrounded by a single plasma membrane called the **sarcolemma**
- The fibres are highly specialised cell-like units
  - Each muscle fibre contains:
    - An organised arrangement of **contractile proteins** in the cytoplasm
    - **Many nuclei** – this is why muscle fibres are not usually referred to as cells
    - Specialised endoplasmic reticulum called the **sarcoplasmic reticulum** (SR) which stores calcium and conveys signals to all parts of the fibre at once using protein pumps in the membranes
    - Specialised cytoplasm called the **sarcoplasm** contains **mitochondria** and **myofibrils**
      - The mitochondria carry out **aerobic respiration** to generate the ATP required for muscle contraction
      - Myofibrils are bundles of **actin and myosin filaments**, which slide past each other during muscle contraction
- The **sarcolemma** (muscle fibre membrane) has many deep tube-like projections that fold in from its outer surface
  - These are known as **transverse system tubules** or **T-tubules**
  - These run close to the SR

11.2.3 Mechanism of Muscle Contraction

Sliding Filament Model

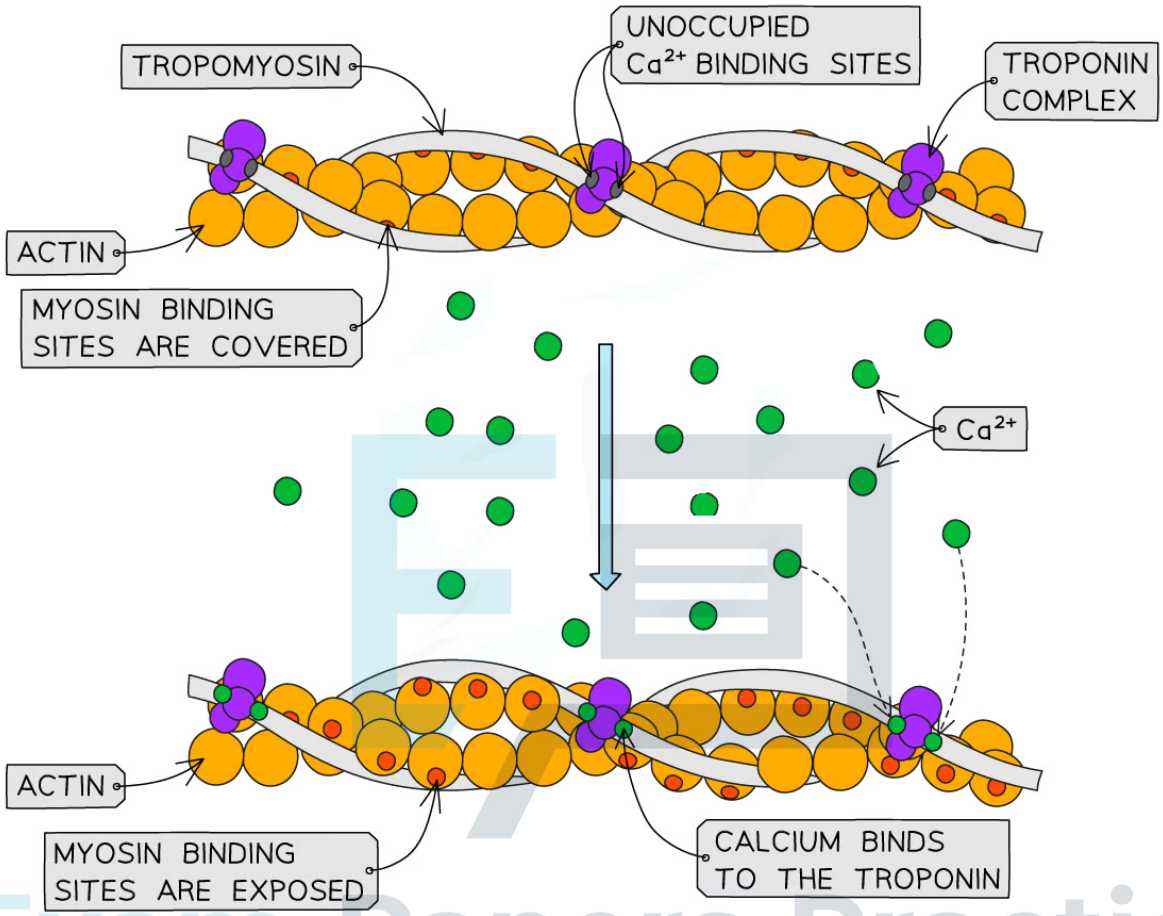
- The **thick filaments** within a myofibril are made up of **myosin** molecules
  - These are **fibrous protein** molecules with a **globular head**
  - The fibrous part of the myosin molecule **anchors** the molecule into the thick filament
  - In the thick filament, many myosin molecules lie next to each other with their globular heads **all pointing away from the M line**
- The **thin filaments** within a myofibril are made up of **actin** molecules
  - These are **globular protein** molecules
  - Many actin molecules link together to form a **chain**
  - **Two actin chains** twist together to form **one thin filament**
  - A fibrous protein known as **tropomyosin** is twisted around the two actin chains
  - Another protein known as **troponin** is attached to the actin chains at regular intervals
- Muscles cause movement by contracting
  - During muscle contraction, **myosin heads form cross-bridges** by binding with sites on the actin filaments
  - The myosin heads then **change orientation** which **pulls the actin filaments** so that they **slide** next to the myosin.
  - This is called a **power stroke**
- **Sarcomeres** within myofibrils **shorten** as the Z lines are pulled closer together



When the muscle contracts, the sarcomere shortens due to the sliding of the actin and myosin filaments.

Role of ATP and Calcium Ions in Muscle Contraction

- The **sliding of the filaments**, which facilitate muscle contraction, is dependent on a series of protein molecules as well as **calcium** and **ATP**
- **Calcium** drives the process in the following way:
  - An **action potential** arrives at the **neuromuscular junction**
  - **Calcium ions** are released from the **sarcoplasmic reticulum** (SR)
  - **Calcium ions** bind to **troponin molecules** (found on the actin filaments), stimulating them to **change shape**
  - This causes **tropomyosin proteins** to change position on the **actin** (thin) filaments
  - Myosin **binding sites are exposed** on the **actin** molecules
  - The globular **heads of the myosin molecules bind with these sites**, forming **cross-bridges** between the two types of filament
  - The formation of the cross-bridges causes the **myosin heads to spontaneously bend** (releasing ADP and inorganic phosphate), **pulling the actin** filaments towards the centre of the sarcomere
    - This is the **power stroke**
  - This causes the muscle to **contract** a very small distance



Calcium binds to the troponin resulting in a change in shape of tropomyosin

- Effective muscle contraction occurs when many power strokes occur in quick succession; for this to take place, **ATP** is required
  - **ATP binds to the myosin heads** producing a change in shape that causes the **myosin heads to release from the actin filaments**
  - The enzyme **ATP hydrolase** hydrolyses ATP into ADP and inorganic phosphate which causes the **myosin heads to move back to their original positions**
    - This is known as cocking of the myosin head or the **recovery stroke**
  - The myosin heads are then able to **bind to new binding sites** on the actin filaments, **closer to the Z disc**
  - The myosin heads move again, pulling the actin filaments even closer the centre of the **sarcomere**, causing the **sarcomere to shorten** once more and pulling the Z discs closer together
  - ATP binds to the myosin heads once more in order for them to detach again

    - As long as **troponin** and **tropomyosin** are not blocking the myosin-binding sites and the muscle has a supply of ATP, this process repeats until the muscle is fully contracted
- When the motor neurone stops sending impulses to the muscle fibre, **calcium ions are actively pumped back into the sarcoplasmic reticulum** and the **tropomyosin moves back** to cover the binding sites on the actin
- The muscle is now relaxed

Exam Tip

The sliding filament model can be difficult to visualise fully with diagrams. To help you more clearly understand the steps involved, try to find some animations or videos of the sliding filament model online to see the **movement of the myosin heads and thin (actin) filaments** during muscle contraction!

Be sure to use the term calcium ***ions***, rather than just calcium.

Using Fluorescence to Study Muscle Contractions

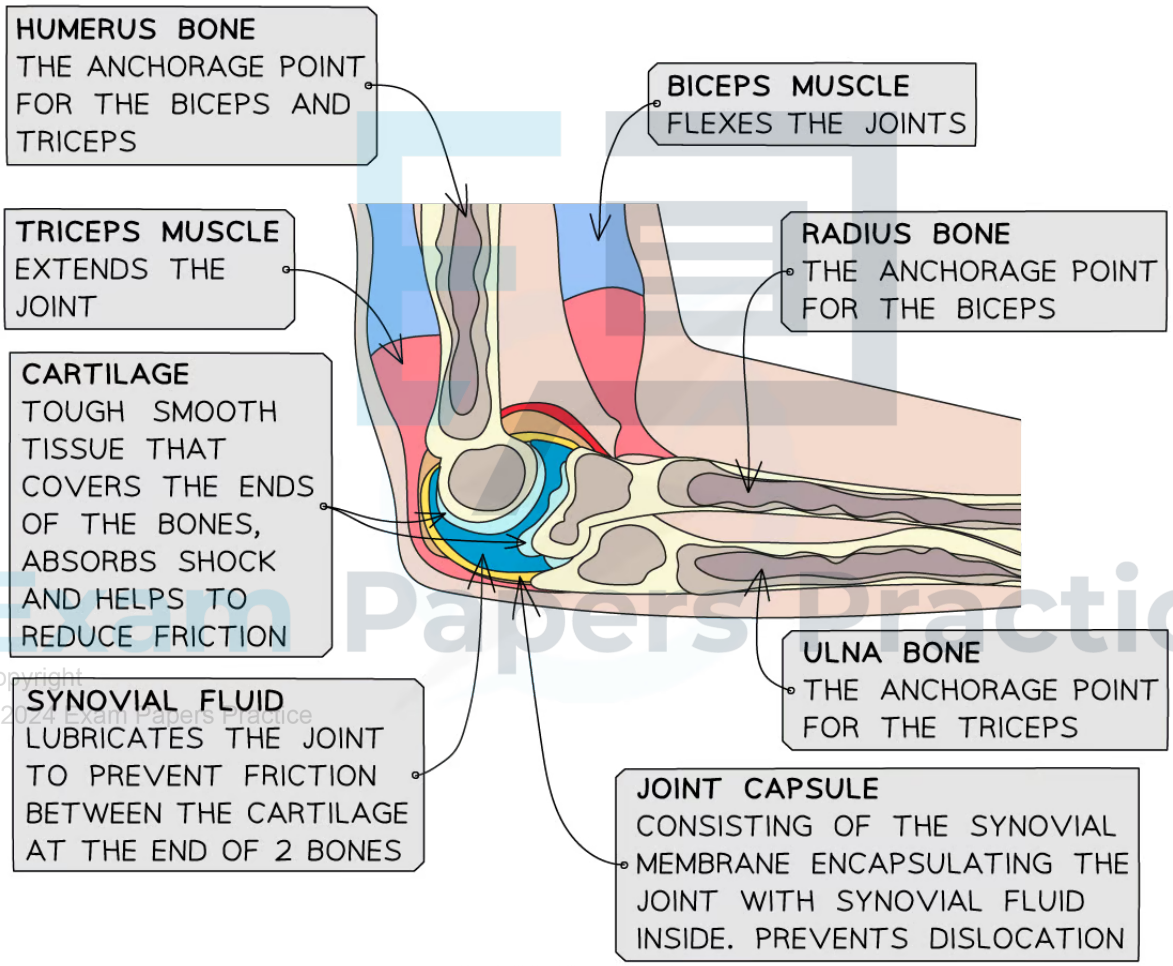
NOS: Developments in scientific research follow improvements in apparatus – Fluorescence was used to study the cyclic interactions in muscle contraction

- **Fluorescence** is the **emission of electromagnetic radiation** after the substance has been exposed to a different wavelength of radiation
- Fluorescence has been used historically to **study muscle contraction** in organisms under the microscope by injecting them with **fluorescent proteins**, called **aequorins**, extracted from a jellyfish species, *Aequorea victoria*
- Aequorins are **calcium sensitive** and so react with Ca^{2+} ions released during the muscle contraction
    - The interaction can be viewed under a microscope
- **Autoradiography** can also be used to show the presence of **calcium isotope**, calcium-45 during muscle contraction
    - Calcium is present in the overlapping regions of the actin and myosin
    - Here it binds to the troponin causing a change in the shape of tropomyosin, allowing the myosin to bind to the actin
- In a study of *Nitella axillaris* (a species of algae) cells, the mechanism of the sliding filament theory has been demonstrated by attaching a fluorescent dye to the end of myosin fibres
    - Under microscope, the **myosin** was shown to **'walk' along the actin fibres** during contraction
- This same method was also used to demonstrate the effect of **ATP levels on the speed of the contraction** and therefore show the dependence of the sliding filament theory on the availability of ATP
    - When **more ATP** was present, the fibres moved at a **faster speed** than when there was less ATP present

11.2.4 Skills: The Human Elbow & Sarcomeres

Annotating the Human Elbow

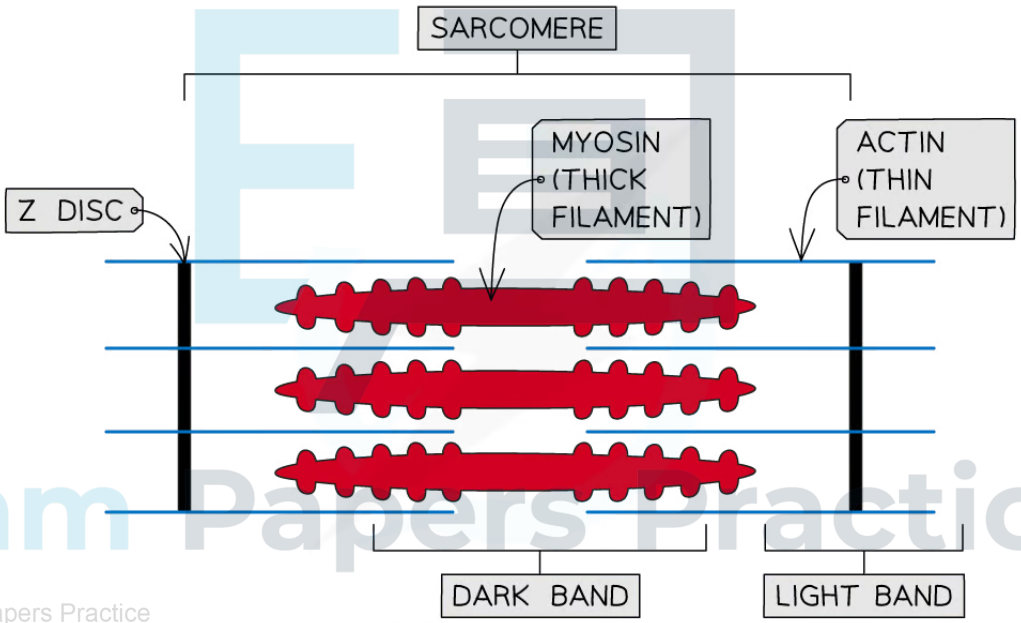
- The human elbow is an **articulated synovial joint** which means that it is a **junction where two moving bones meet encapsulated in synovial fluid**
- It consists of several components which can be labelled on a diagram and annotated with descriptions of each structure in the following way:



The human elbow joint

Drawing a Sarcomere

- An accurate drawing of the sarcomere is a good way to demonstrate the **relative movement of the muscle fibres** during muscle contraction
- It also allows us to understand the **visible bands** seen in the images of muscle tissue in micrographs
- Some important considerations are as follows:
  - **Z-lines** mark either end of a sarcomere
  - **Actin** must be adjoined clearly to the z-lines and is thinner than the myosin
  - **Myosin** should be shown with the crossheads visible and should be thicker than actin
  - **Light bands** (around the z line) and **dark bands** (where the 2 filament types overlap) should be labelled

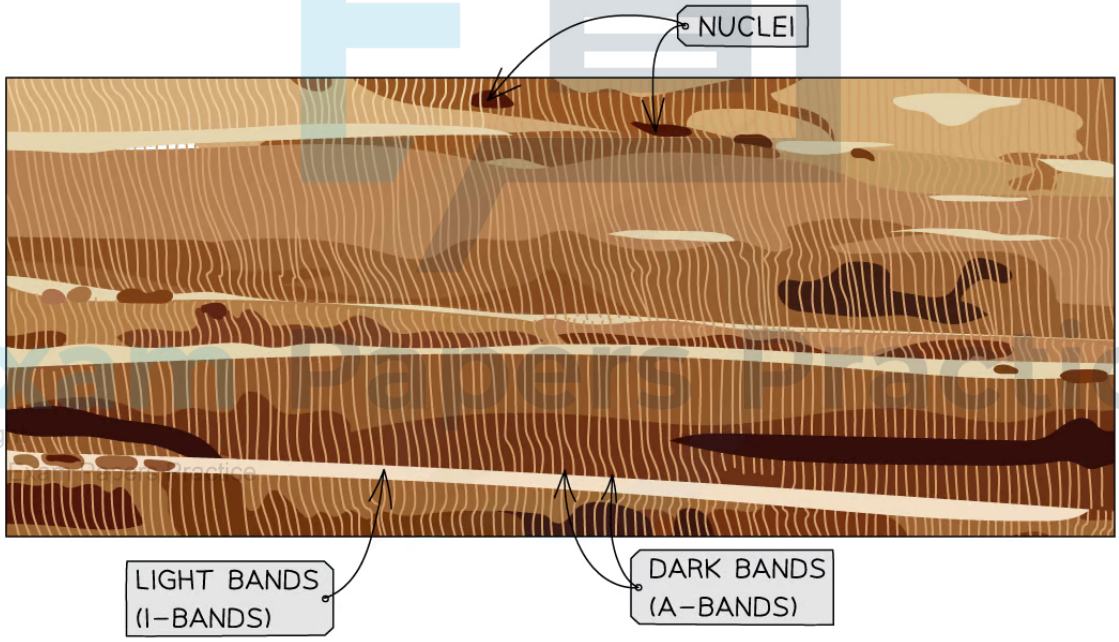


The sarcomere

11.2.5 Skills: Analysing Muscle Contractions in Electron Micrographs

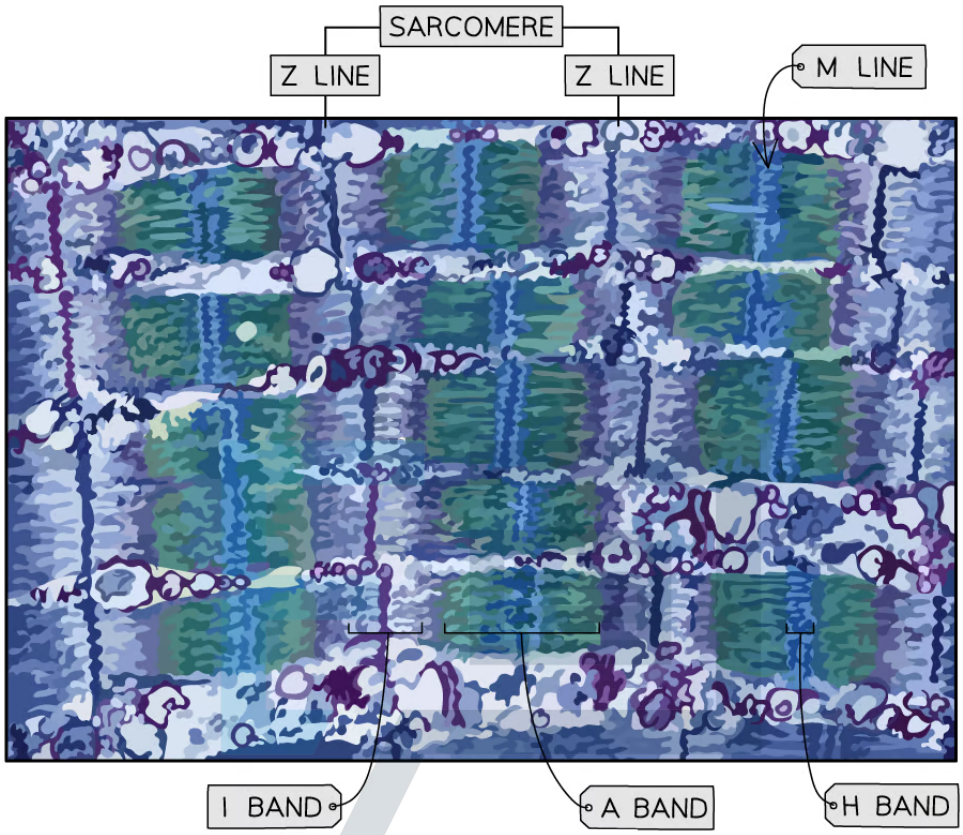
Analysing Muscle Contractions in Electron Micrographs

- Many biological structures are **too small to be seen by the naked eye**
- **Optical microscopes** are an invaluable tool for scientists as they allow for tissues, cells and organelles to be seen and studied
- **Electron microscopes** provide a much higher magnification and resolution so sub-cellular details can be studied
- Using microscopes to calculate the size of specimens requires the use of an **eyepiece graticule** which should be calibrated to the microscope
- However, it can be very difficult to make out the features of skeletal muscle fibres using an **optical microscope**
- Only the banding is visible, this is why it is referred to as **striated muscle**



The dark bands produce a characteristic striped appearance under an optical microscope

- Electron microscopes are often used to see muscle fibres in more detail
- They reveal the structure of **myofibrils**



KEY
I BAND = ACTIN FILAMENTS ONLY
A BAND = ACTIN FILAMENTS AND MYOSIN FILAMENTS
H BAND = MYOSIN FILAMENTS ONLY

The detailed structures of the muscle fibres are visible due to the much stronger magnification of the electron microscope.

In a relaxed sarcomere:

- There will be **visible dark lines** where the **Z-lines are** at either end of the sarcomere
- There will also be a **darker band in the middle** of the sarcomere where the thicker myosin fibres are positioned and in the very centre of that is the M line
- Around the Z-line, **lighter bands are seen where the thinner actin fibres** are positioned

In a contracted sarcomere:

- The **Z-lines and M-lines are still visible** with a **shorter distance** between the two z-lines
- The **lighter bands** around the z-line will be **smaller** or **not visible**
- The **darker band will be the same size** (although may appear a bit darker).