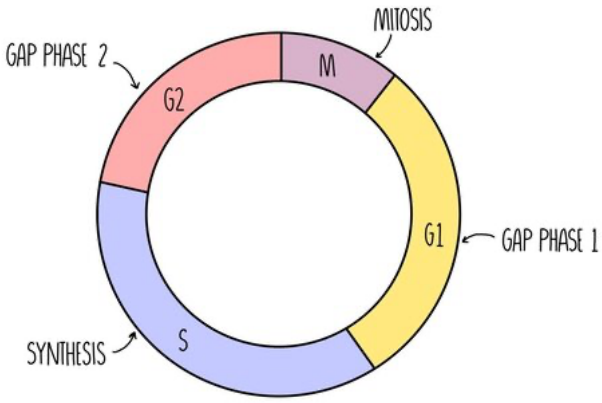
Module 2: Foundations in Biology

Cell Division

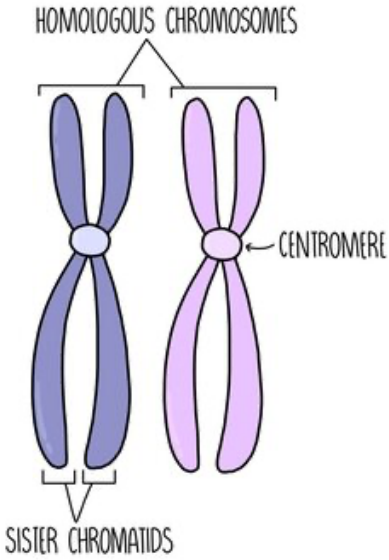
Mitosis and the Cell Cycle

Mitosis is a type of cell division where cells produce identical copies of themselves and is used for **growth and repair** and **asexual reproduction**. It differs from **meiosis**, which is the type of cell division used to produce **gametes**.

Mitosis occurs as part of the cell cycle which consists of four distinct phases. First, **interphase** takes place which is made up of three growth phases (called **G1** phase, **S** phase and **G2** phase), followed by **mitosis**.



- **Gap Phase 1 (G1)** - cell grows **bigger** and **replicates** its **organelles**. A high amount of **protein synthesis** is taking place in order to build new organelles.
- **Synthesis Phase (S)** - the cell **replicates** its **DNA**
- **Gap Phase 2 (G2)** - the cell **keeps growing** until all of the **organelles** have **duplicated**.



Once the DNA has replicated, each chromosome now consists of **two sister chromatids**, connected by a structure called the **centromere**. The **mitochondria** produce more **ATP** which will provide the energy for cell division and the ribosomes will be synthesising a high level of proteins to replicate organelles.

There are two **'checkpoints'** in the cell cycle - one before S phase and one straight after S phase. During these checkpoints, the cell is **checking its DNA** for **errors**. This minimises the chances of duplicating any mutated DNA into the replicated cell.

The Stages of Mitosis

Mitosis can be divided into a series of stages depending on what's going on with the chromosomes in the cell. You can use the acronym **PMAT** (pass me another tequila) to help you remember the order.

- **Prophase** - the **chromosomes condense** (they become shorter and fatter) and the **nuclear envelope disintegrates**. The **centrioles** move to opposite poles of the cell and form **spindle fibres**.
- **Metaphase** - the chromosomes line up along the **middle** of the cell. They **attach to the spindle fibre** by their **centromere**.
- **Anaphase** - the centromere splits and the **chromatids** are **pulled to opposite poles** of the cell.
- **Telophase & cytokinesis** - the two groups of chromsomes **decondense** (they become long and thin) and a **nuclear envelope reforms** around them, forming two new nuclei. The cytoplasm divides (**cytokinesis**) and the plasma membrane pinches off to form **two new, genetically-identical cells**.

Investigating mitosis in squashed root tips

You can see mitosis happening in root tip cells by **staining the chromosomes** and observing under the microscope. We use cells right from the tips of the roots because this is where mitosis is taking place (in the **meristem** tissue).

Method:

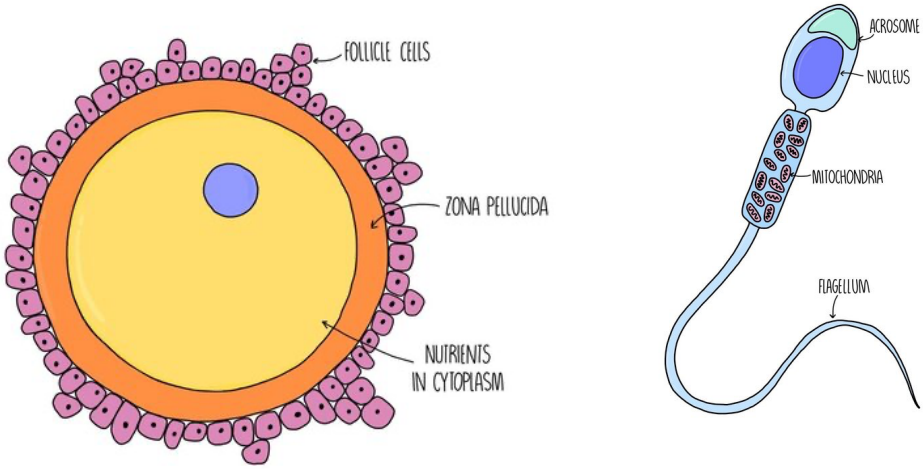
- Cut a **thin** section of tissue from the tip of a growing root.
- Pipette a set volume of 1M **hydrochloric acid** into a boiling tube and place in a 60^{o}C water bath.
- Place the plant tissue in the boiling tube and leave for five minutes.
- **Rinse** the root tip with cold water and **dry** using a paper towel.
- Cut the root tip so that you have a **thin layer of cells** (about 2 mm) and spread out onto a microscope slide using a mounted needle.

- Add a drop of **Toluidine blue O stain** to the tissue and place a cover slip on top. Push down on the cover slip to **squash** the cells and allow light to pass through. Be careful not to push sideways otherwise the chromosomes will become damaged.
- Use a light microscope to visualise the cells and identify the stages of mitosis. Any cells with **visible chromosomes** will be undergoing mitosis (as the chromosomes are condensed).

Gametes

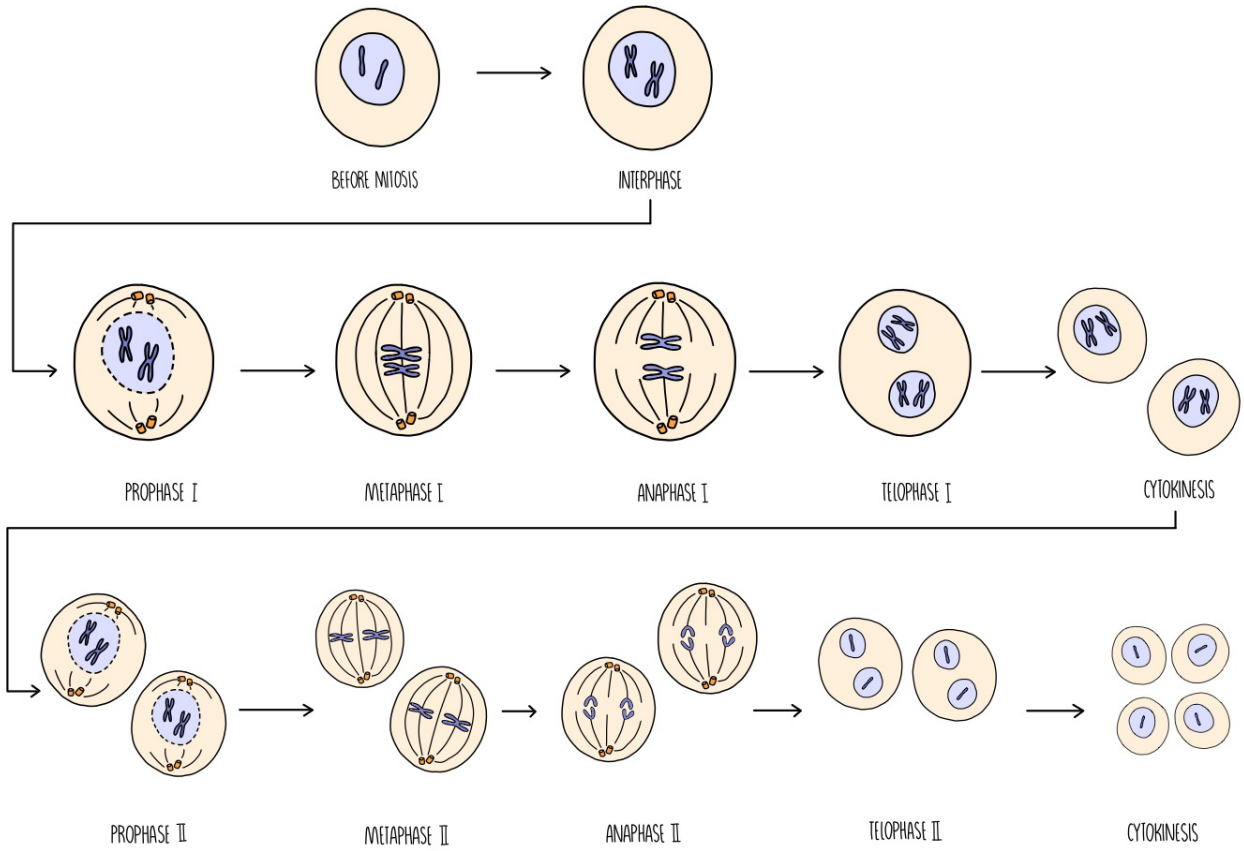
Gametes are **sex cells** (the sperm and egg in humans). Gametes are **haploid** which means they contain half the number of chromosomes as the rest of the cells which make up our body. This means that when two gametes fuse during sexual reproduction, the fertilised egg (called a **zygote**) contains the full number of chromosomes i.e. it is **diploid**. In humans, the diploid number of chromosomes is 46 (23 pairs), which means that gametes contain just 23 chromosomes.

During sexual reproduction, the nucleus of the sperm cell fuses with the nucleus of the egg cell - this fusion of nuclei is called **fertilisation**.



Meiosis

Meiosis is the type of cell division which produces **gametes** for **sexual reproduction**. Unlike mitosis, the daughter cells are **genetically different** from the parent cell and contain just **half** the number of chromosomes (i.e. they are **haploid**). When two haploid gametes join during fertilisation, a **diploid** cell called a **zygote** is formed. Meiosis involves **two rounds** of cell division which are referred to as **meiosis I** and **meiosis II**.



It takes place in the following stages:

Meiosis I

- **Interphase**: the **DNA replicates** so there are now **two identical copies** of each chromosome (referred to as **chromatids**).
- **Prophase I**: chromatids **condense** and arrange themselves into **homologous pairs** (called bivalents). **Crossing over** occurs (see below). The **nuclear envelope disintegrates** and **spindle fibres form**.
- **Metaphase I**: homologous chromosomes line up along the **equator** and **attach to the spindle fibre** by their centromeres.
- **Anaphase I**: homologous chromosomes are **separated**
- **Telophase I**: chromosomes reach **opposite poles** of the cell. **Nuclear envelope reforms** around the chromosomes. **Cytokinesis** results in the formation of two daughter cells.

Meiosis II

- **Prophase II**: chromosomes **condense**, **nuclear envelope disintegrates** and **spindle fibres form**.

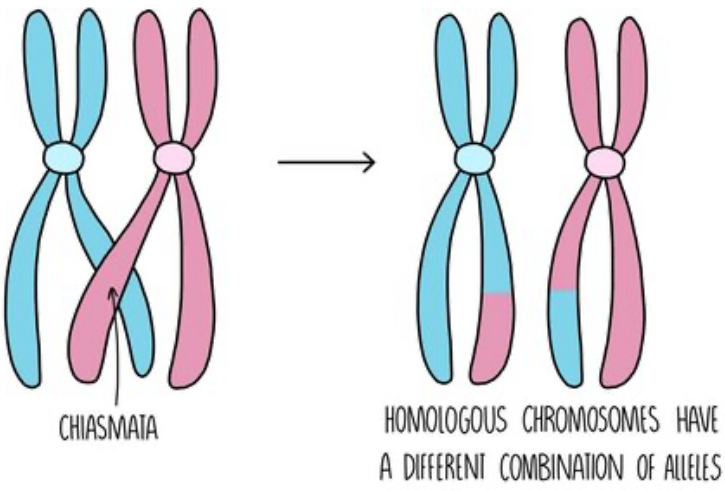
- **Metaphase II**: chromosomes **attach to the spindle fibre** by their centromeres.
- **Anaphase II**: sister chromatids are **separated**.
- **Telophase II**: chromatids reach **opposite poles** of the cell. **Nuclear envelope reforms** and **cytokinesis** takes places. **Four genetically unique daughter cells** are produced.

Meiosis increases genetic variation

From an evolutionary point of view, it is important that organisms produce offspring that show as much **genetic variation** as possible. Imagine if a mother duck gave birth to a group of ducklings that were all had very similar genes - these ducklings will all be **equally vulnerable** to the same diseases and other threats to their survival. Meiosis increases genetic variation in two ways - **crossing over** and **independent assortment**.

Crossing Over

During prophase I of meiosis, a process called crossing over occurs. This is when the **homologous chromosomes** move towards each other and **exchange genetic material**. A chromatid from the maternal chromosome becomes twisted around the paternal chromosome and they connect through a structure called the **chiasmata**. Pieces of chromosomes are **exchanged** and the chromatids separate, forming chromosomes with **different combinations of alleles**.

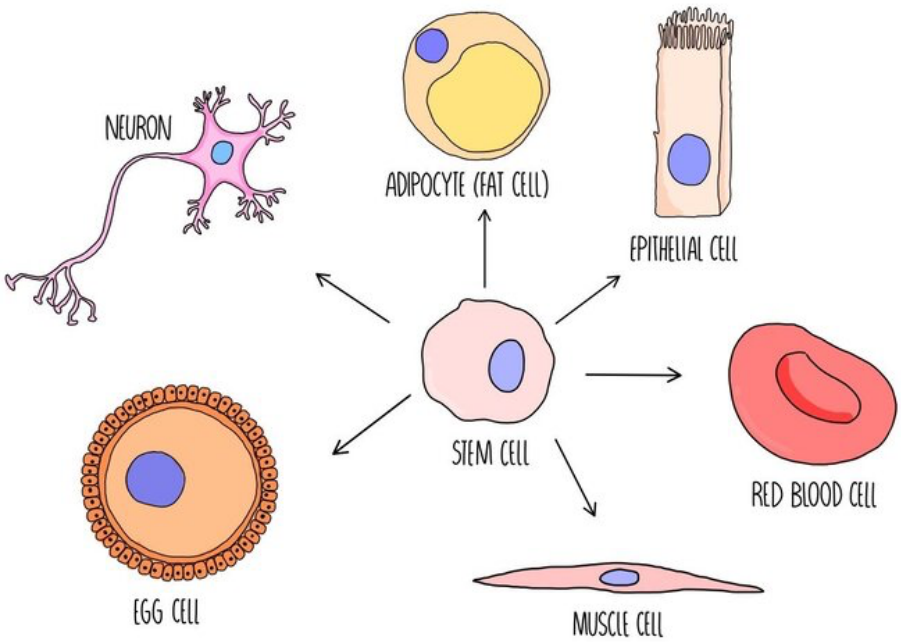


Independent assortment

Depending on the **order** in which chromosomes line up along the **equator** of the cell during **metaphase**, **different combinations** of chromosomes will end up in each gamete. The way in which the chromosomes align themselves on the spindle fibre is completely **random**, resulting in a huge number of possibilities of chromosomal combinations in the gametes.

Stem Cells and Potency

Stem cells are **unspecialised** cells which have the ability to become specialised cells, such as heart cells or neurons. The process by which a stem cell is converted from an unspecialised cell to a specialised cell is called **cell differentiation**. Stem cells have an **unlimited capacity** to **divide** and can produce lots more stem cells by **mitosis**.



The ability of stem cells to undergo differentiation is referred to as **potency** - there are different levels of potency:

- **Totipotent** - totipotent cells have the ability to divide into **any type of cell** (including the extraembryonic cells which make up the placenta and umbilical cord).
- **Pluripotent** - pluripotent cells can divide into **any type** of cell **except the extraembryonic cells**.
- **Multipotent** - these cells can divide into a **handfu**l of different cell types
- **Unipotent** - these cells can only divide into **one** type of cell

Adult **bone marrow** contains multipotent adult stem cells which can divide and differentiate to replace old **blood cells**. They are responsible for forming all the different types of red and white blood cells. In plants, stem cells are present in regions called **meristems**, found at the tip of the shoot and roots. These have greater potency than adult stem cells, and can divide to form almost any kind of cell.

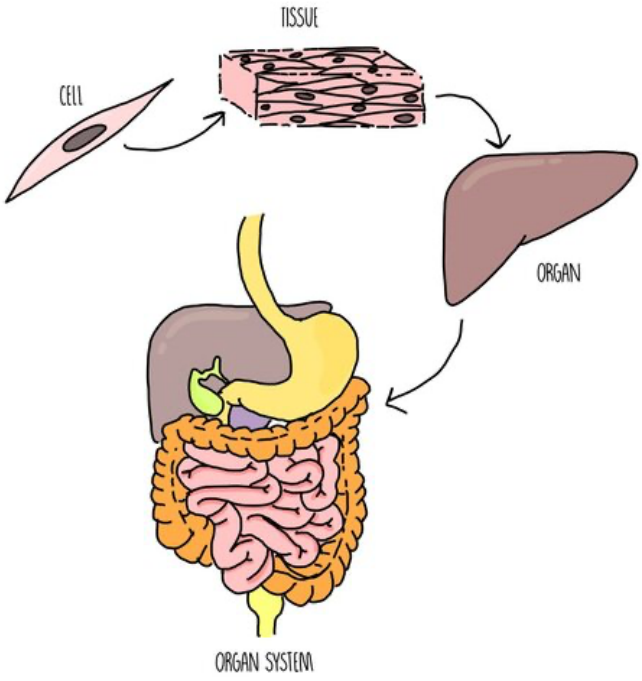
Stem cells in medicine

Stem cells are being used as a treatment for certain diseases:

- **Stem cell transplants** are given to patients with leukaemia - leukaemia is a type of cancer which destroys stem cells so bone marrow transplants are used to replace the lost stem cells.
- **Research** is being carried out to develop ways of **growing whole organs** from stem cells. The organs can then be **transplanted** into the patient to replace organs that have been damaged or are diseased e.g. pancreatic transplants can be given to people with diabetes. This approach will help those who currently have to wait years for an organ donation.

Levels of organisation

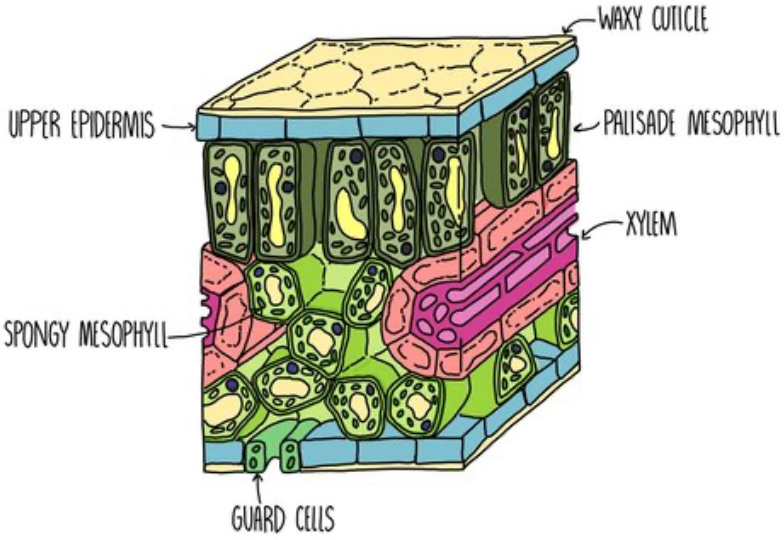
The cell is the 'basic building block of life' and is the smallest functioning part of an organism. A group of cells working together is called a **tissue** and a collection of tissues all performing a specific function is called an **organ**. Multiple organs which are connected together are referred to as an **organ system**.



Examples of organs include the heart and lungs (in animals) and leaves and roots (in plants).

The **leaf** is an example of a plant organ and is made up of the following tissues:

- **Upper epidermis** – covered in a waterproof waxy cuticle to reduce transpiration.
- **Palisade mesophyll** – tightly packed cells filled with mitochondria, located towards the top of the leaf to absorb as much light as possible. This is where most photosynthesis takes place.
- **Spongy mesophyll** – loosely arranged cells. Air spaces allow circulation of gases for gas exchange.
- **Phloem** – transport of sugars and amino acids (translocation).
- **Xylem** – transport of water and mineral ions (transpiration).
- **Lower epidermis** – contains stomata which open and close to allow gas exchange to take place.



The **lungs** are an example of an organ found in animals and is made up of the following tissues:

- **Endothelium** – forms the capillary walls which supply alveoli with oxygen and nutrients.
- **Fibrous connective tissue** – helps to push air out of the lungs during exhalation.
- **Squamous epithelial tissue** – makes up the walls of the alveoli.

Examples of organ systems include the respiratory system, circulatory system, reproductive system and digestive system.