HL IB Biology

Your notes

Cell & Nuclear Division

Contents

Cell Division


Your notes

Formation of New Cells

- According to the cell theory, new cells are produced from pre-existing ones
- The cells that make up a multicellular organism are the result of a single cell undergoing many cycles of **cell division**
  - This single cell will initially form embryonic stem cells which will **specialise** to form the organs and tissues of the organism
- A cell that divides is known as a **parent** (or 'mother') **cell**
  - Each parent cell will produce two **daughter cells** after cell division has occurred
- Two types of cell division exist
  - One results in daughter cells that are **genetically identical** to each other and to the parent cell
  - The other produces cells that are **genetically different** from each other and from the parent cell
    - This type of cell division is an important source of genetic variation within populations

Cytokinesis

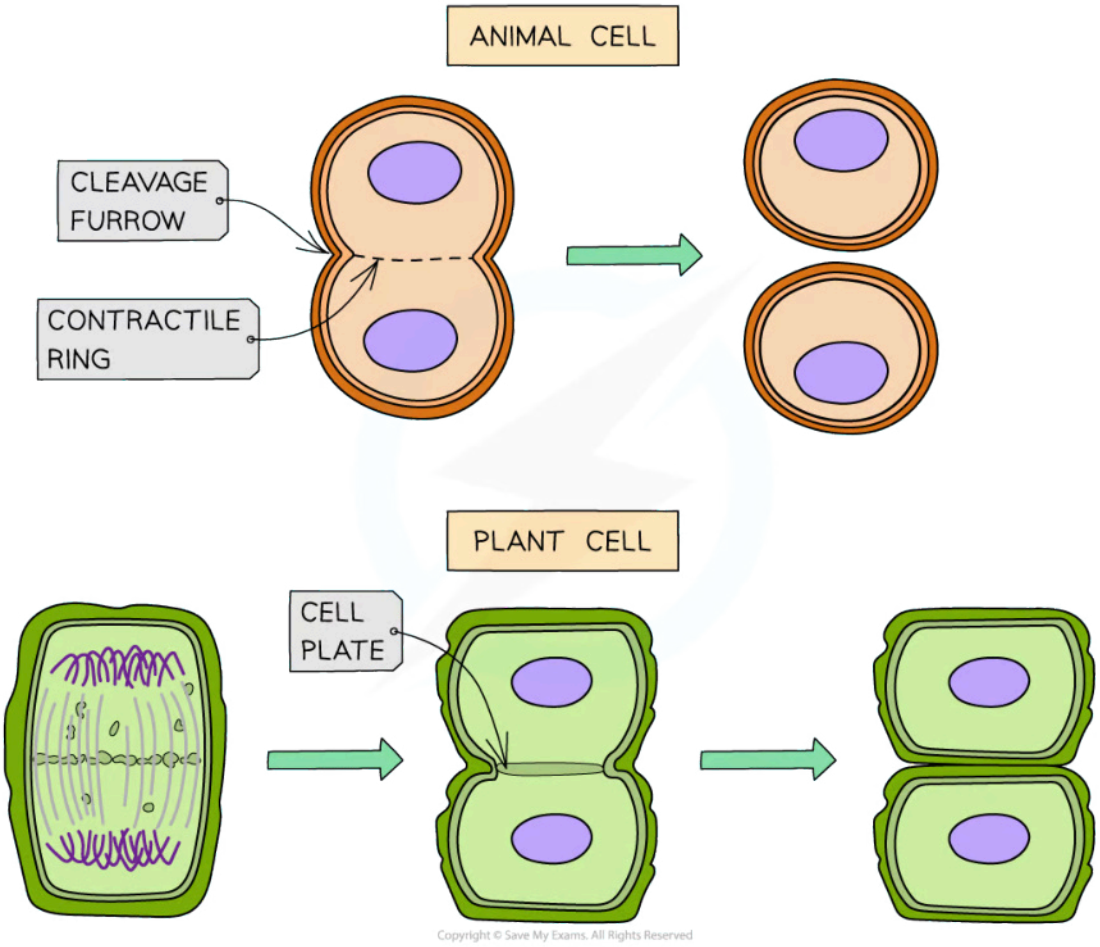

Your notes

- During cell division, the nucleus of the cell will divide first
  - This is known as **nuclear division**
- Once the nucleus has divided into two nuclei, the **cytoplasm divides in two** with one nucleus moving into each cell to **create two daughter cells**
  - The division of the cytoplasm is called **cytokinesis**

Cytokinesis in animal and plant cells

- The process differs slightly in animal and plant cells
- In **animal** cells:
  - A '**cleavage furrow**' forms and separates the daughter cells
  - The cleavage furrow forms when **actin and myosin** proteins form a **contractile ring** just under the plasma membrane
  - This ring is formed at the equator (centre) of the cell
  - As the proteins contract, they pull the plasma membrane towards the centre eventually separating the cell into two daughter cells
- In **plants** cells:
  - A '**cell plate**' (the precursor to a new cell wall) forms at the equator. Once the cell plate reaches the cell walls of the parent cell, new cell walls are produced, separating the new daughter cells
  - The cell plate is formed from **vesicles** carrying carbohydrates, lipids and proteins fusing together to create the **two plasma membranes**
  - After this other **vesicles, carrying pectin and cellulose,** deposit these substances by exocytosis in the gap between the two new membranes leading to the formation of **new cell walls**

Your notes



Cytokinesis in an animal cell and a plant cell

Examiner Tip

Remember that cytokinesis will only occur **after** nuclear division has happened.

Equal & Unequal Cytokinesis

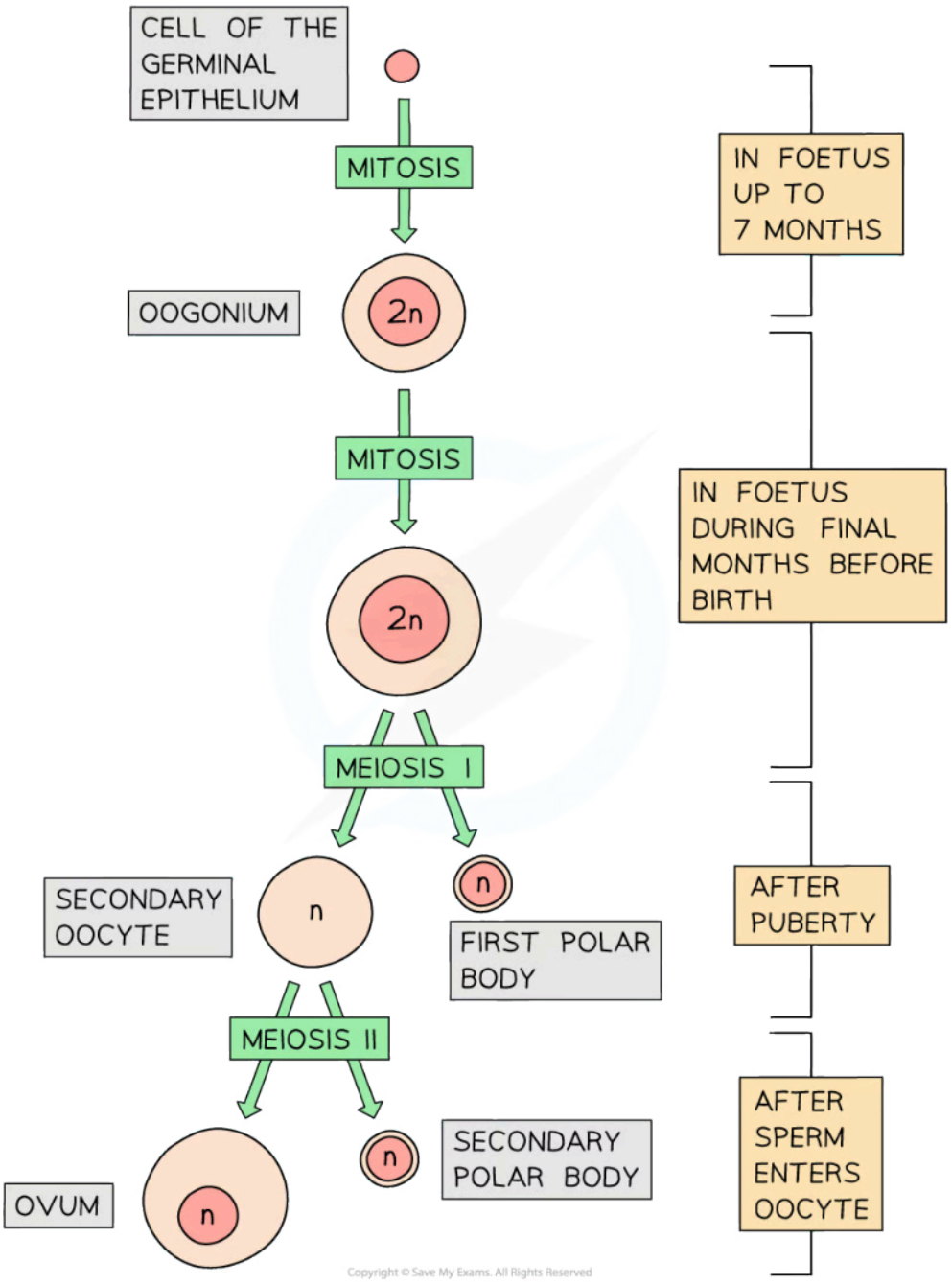

Your notes

- During cytokinesis, the division of the cytoplasm is **usually equal**
  - This produces daughter cells that are of a similar size
  - It is also important to ensure that each daughter cell receives at least one **mitochondrion** for cellular respiration
    - Plant cells would also need to receive at least one **chloroplast** in order to photosynthesise
  - These organelles can only be made by dividing a pre-existing structure
- There are however cases where the division of the cytoplasm is **not equal**, such as:
  - **Oogenesis** in humans
  - **Budding** in yeast

Oogenesis as an example of the unequal division of cytoplasm

- The production of ova begins in the ovaries of the female foetus **before birth**
  - Germinal epithelial cells will divide to form an immature ovum called a **primary oocyte**
- During puberty, the primary oocyte will divide to form a **secondary oocyte** and a smaller structure called a **polar body**
  - These structures are the result of the unequal division of cytoplasm
- The secondary oocyte will divide again to form an **ovum** and another **polar body**
  - The polar bodies will **degenerate** and form part of the final ovum

Your notes



Oogenesis is an example of unequal cytokinesis

Nuclear Division


Your notes

Role of Mitosis & Meiosis in Eukaryotes

- There are two processes by which the **nucleus** of a **eukaryotic cell** can **divide**. These are:
  - Mitosis
  - Meiosis
- It is important for the nucleus of a cell to divide before cell division to avoid the production of **anucleate** cells
  - An anucleate cell is one without a nucleus
- **Mitosis** gives rise to **genetically identical cells** and is the type of cell division used for **growth**, **repair** of damaged tissues, **replacement** of cells and **asexual reproduction**
  - Mitosis maintains the chromosome number and genome of cells
  - Cells produced during mitosis will often be diploid (2n)
- **Meiosis** gives rise to cells that are **genetically different** from each other and is the type of cell division used to produce gametes (sex cells)
  - This is because the daughter cells produced during meiosis will only have half the number of chromosomes of the parent cell
  - These cells are said to be haploid (n)
  - Meiosis is important for generating **genetic diversity**

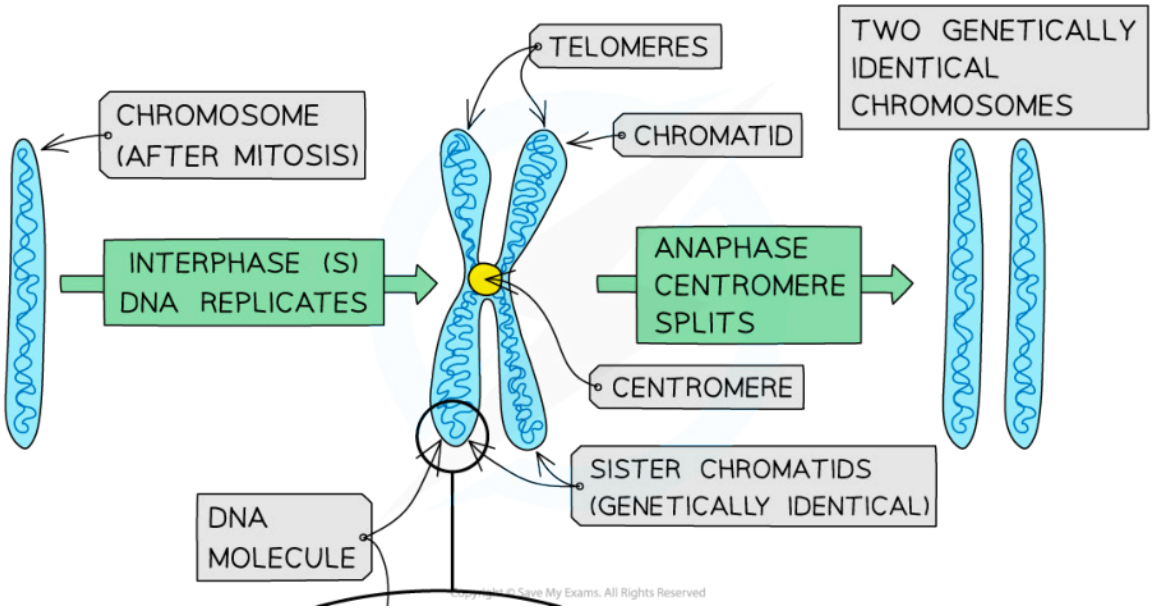
DNA Replication in Nuclear Division

Your notes

DNA replication as a prerequisite for mitosis and meiosis

- During **interphase** (the period before nuclear division) of the cell cycle, the DNA replicates to create **two identical strands of DNA called chromatids**
  - The chromatids are joined together by a narrow region called the **centromere**
- The two chromatids that make up the double structure of a chromosome are known as **'sister chromatids'**
  - During **anaphase**, one chromatid from each chromosomes ends up in one daughter cell while the other chromatid ends up in the other daughter cell
  - After the centromere is split apart at the start of anaphase, the chromatids are referred to as individual **chromosomes** again

Chromosome structure and DNA replication diagram



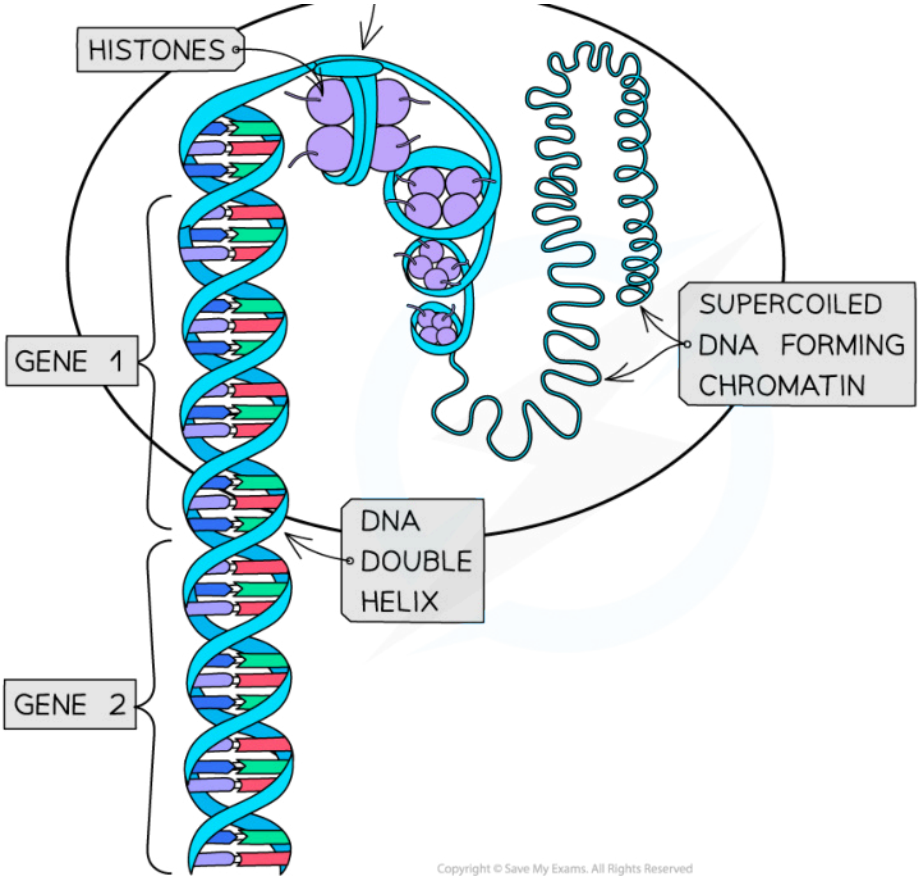


Diagram illustrating the structure of a chromosome at different stages of mitosis

Examiner Tip

It is important to distinguish between the terms chromatid, sister chromatids and chromosomes.

Your notes

Condensation & Movement of Chromosomes

Condensation of chromosomes

Your notes

- DNA molecules are **very long molecules** (human DNA can be more than 50,000 μm) that need to fit within much smaller nuclei (human nuclei average less than 5 μm)
- Prior to mitosis, the DNA molecules are loosely coiled (around histones in eukaryotic cells) to form a complex called **chromatin**
  - Histones package DNA into structures called **nucleosomes**
  - Each nucleosome consists of a strand of DNA coiled around eight histone proteins
- During **prophase**, the chromatin gets **condensed** by **supercoiling** to form **chromosomes**
- Condensation occurs by the repeated coiling of the DNA molecule (supercoiling)
- This supercoiling is aided in eukaryotic cells by the presence of histone proteins and enzymes

Supercoiling of DNA around histones diagram

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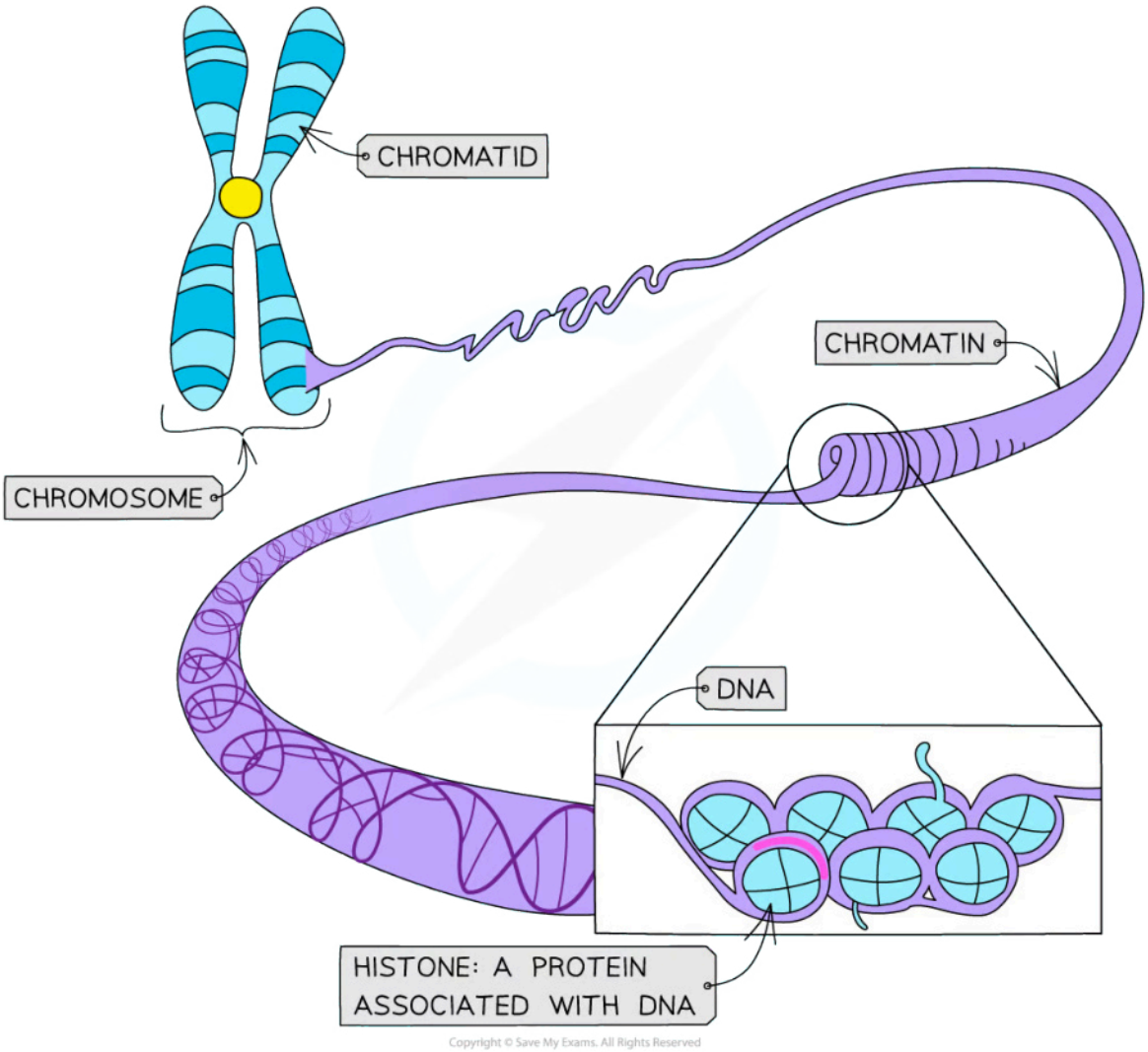

DNA is coiled around histone proteins to make chromatin

Movement of chromosomes

- **Microtubules** and **microtubule motors** are responsible for the movement of chromosomes during cell division
  - Microtubules are **tubulin** fibres that form part of the **cytoskeleton** of the cell
  - They are able to **lengthen and shorten** in order to enable chromosome movement
  - Two types of tubulin, α-tubulin and β-tubulin form **dimers** which can be added or removed at the ends of the microtubules to change the length of the tubule
    - A dimer is a compound made up of **two subunits**
- Chromosome movement is facilitated by **motor proteins**
  - These carry the chromosomes along the microtubules to the equator of the cell in preparation for nuclear division

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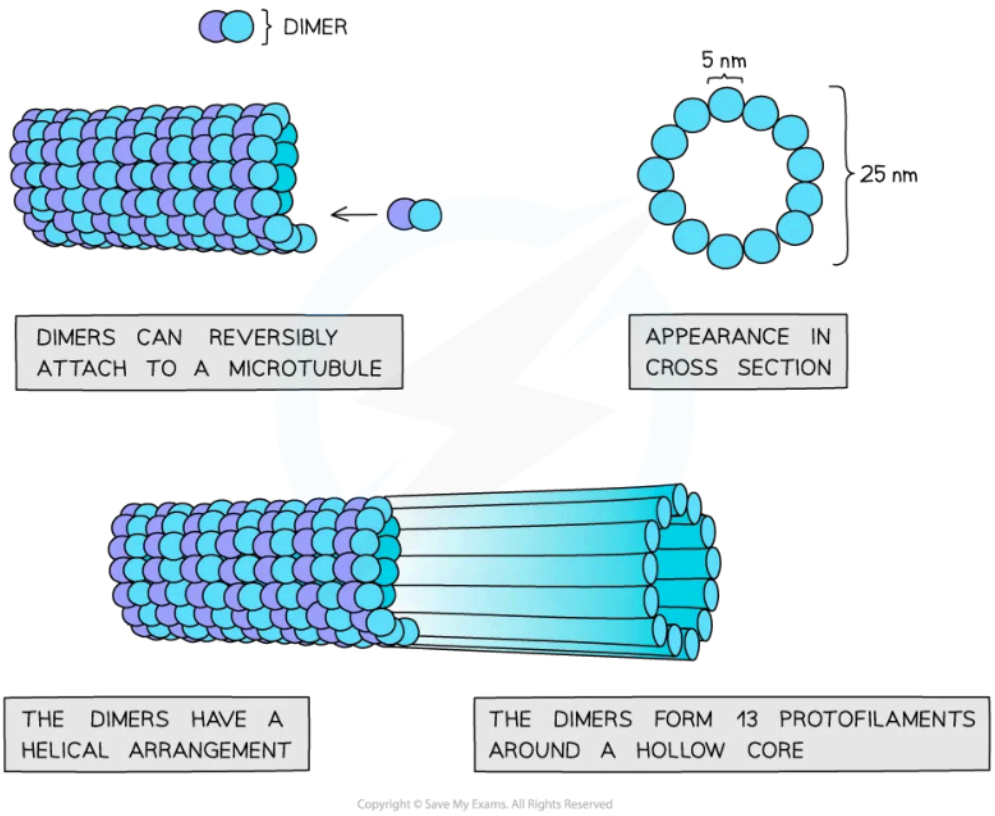
Microtubule formation diagram



Microtubules are responsible for the movement of chromosomes during cell division

Mitosis

Your notes

Phases of Mitosis

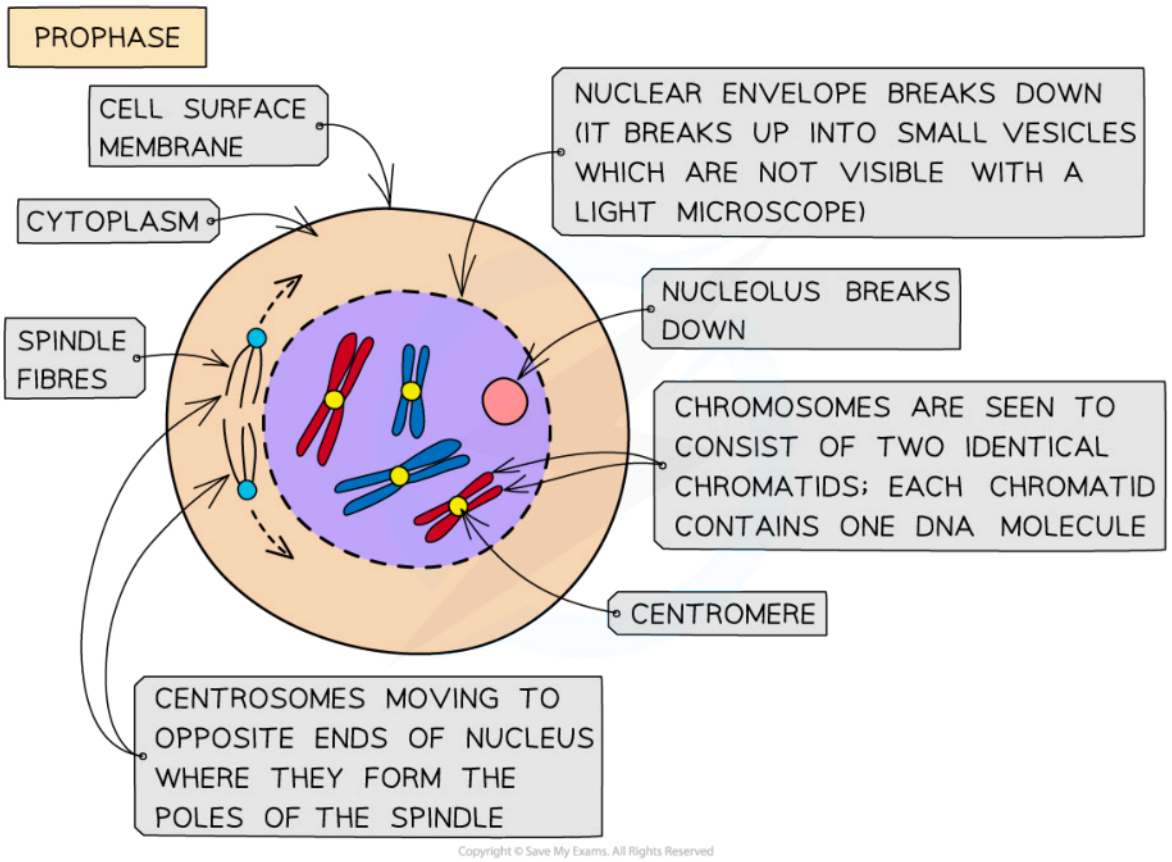
- Mitosis is the process of nuclear division by which **two genetically identical daughter nuclei** are produced that are also genetically identical to the parent cell nucleus (they have the same number of chromosomes as the parent cell)
- **Significance of mitosis**: mitosis occurs whenever the production of genetically identical nuclei are required in eukaryotic cells
  - E.g. during embryonic development, growth, tissue repair and asexual reproduction

Phases of Mitosis

- Although mitosis is, in reality, one continuous process, it can be divided into **four main stages or phases**
- These stages are:
  - **Prophase**
  - **Metaphase**
  - **Anaphase**
  - **Telophase**
- Most organisms contain many chromosomes in the nuclei of their cells (eg. humans have 46) but the diagrams below show mitosis of an animal cell with only four chromosomes, for simplicity
- The different colours of the chromosomes are just to show that half are from the female parent and half from the male parent

Prophase

- Chromosomes **condense** and are now visible when stained
- The chromosomes consist of **two identical chromatids** called **sister chromatids** (each containing one DNA molecule) that are joined together at the centromere
- The two centrosomes (replicated in the G_2 phase just before prophase) move towards **opposite poles** (opposite ends of the nucleus)
- **Spindle fibres** (protein **microtubules**) begin to emerge from the centrosomes (consists of two centrioles in animal cells)
- The **nuclear envelope** (nuclear membrane) **breaks down** into small vesicles
- The nucleolus disappears

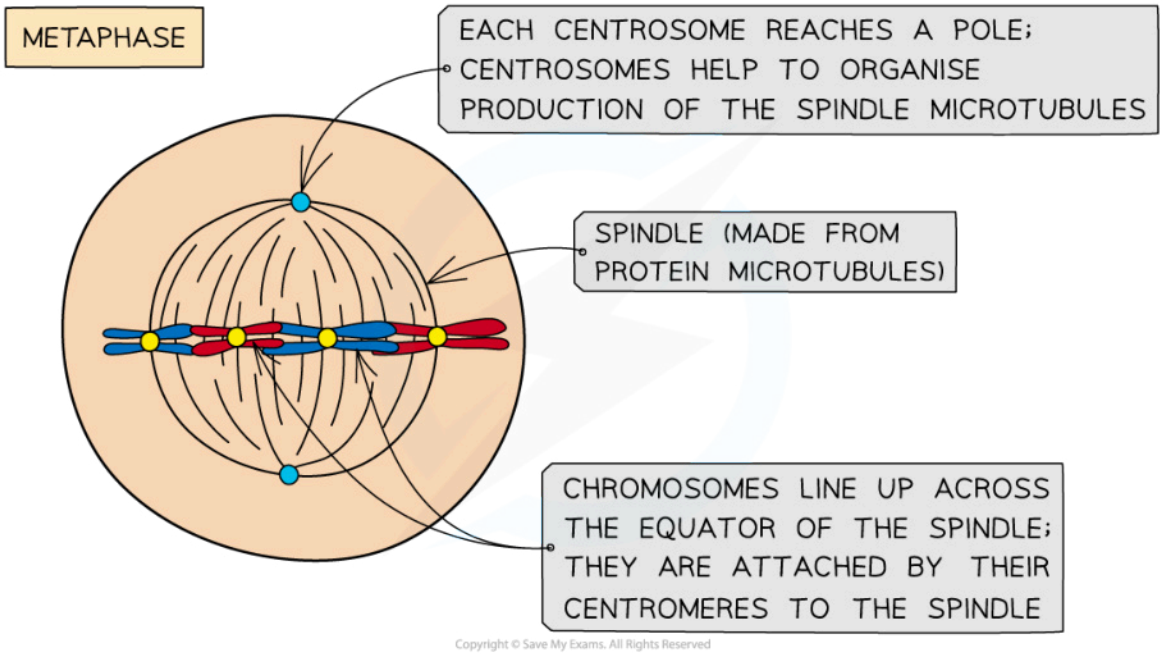


Prophase

Your notes

Metaphase

- **Centrosomes** reach **opposite poles**
- **Spindle fibres** (protein microtubules) continue to **extend from centrosomes**
- Chromosomes **line up at the equator** of the spindle (also known as the metaphase plate) so they are equidistant to the two centrosome poles
- Spindle fibres (protein microtubules) reach the chromosomes and **attach to the centromeres**
  - This attachment involves specific proteins called **kinetochores**
- Each **sister chromatid** is attached to a spindle fibre originating from **opposite poles**

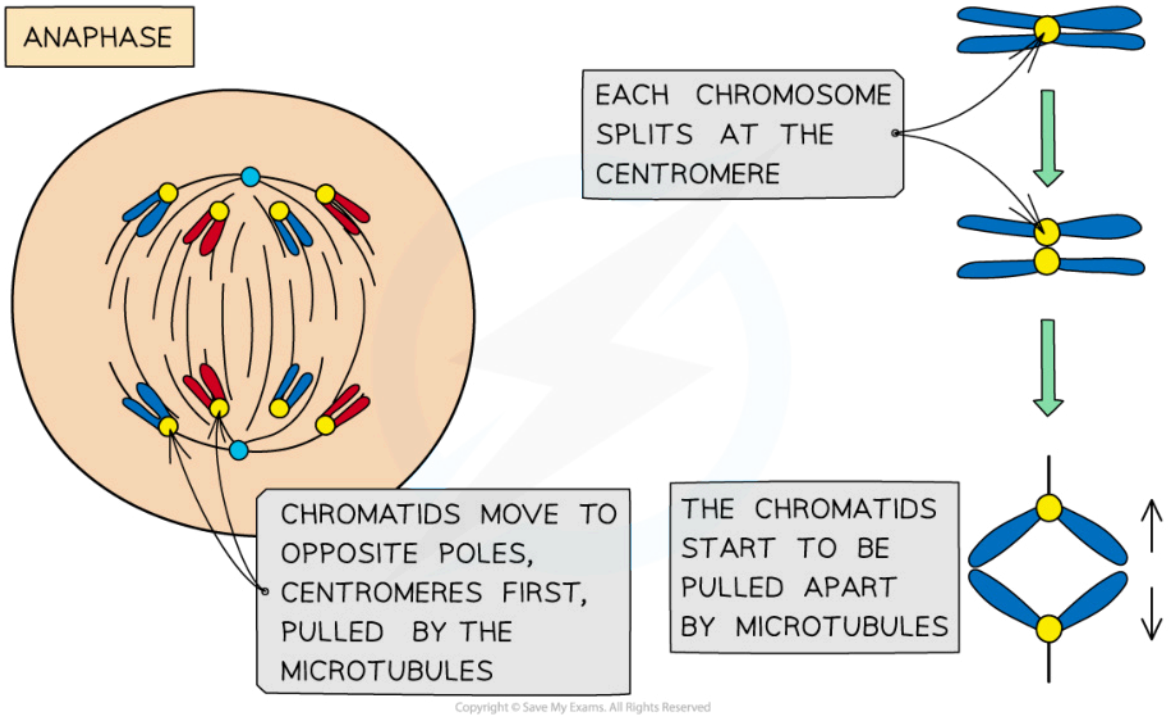


Metaphase

Anaphase

- The sister chromatids **separate at the centromere** (the centromere divides in two)
- Spindle fibres (protein microtubules) begin to **shorten**
- The separated sister chromatids (**now called chromosomes**) are **pulled to opposite poles** by the spindle fibres (protein microtubules)

Your notes

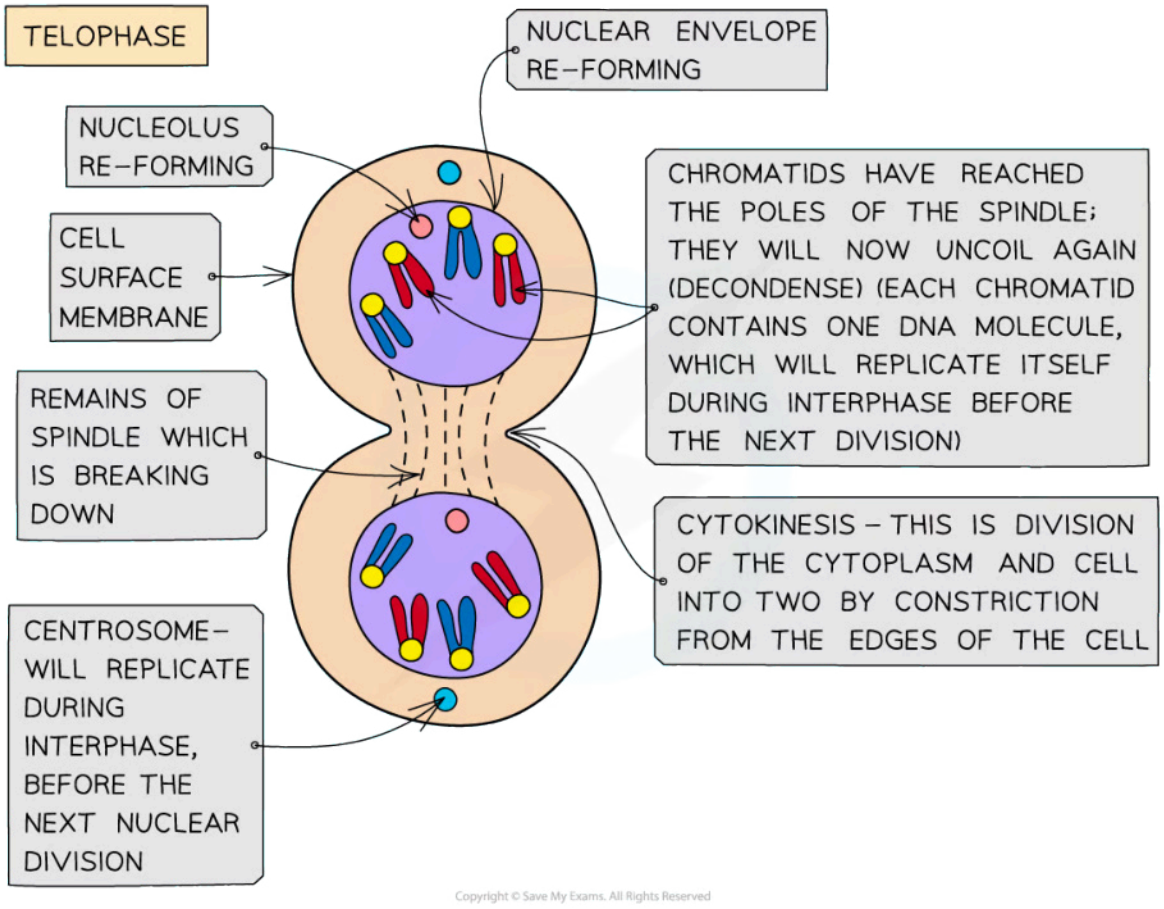


Anaphase

Telophase

- Chromosomes arrive at opposite poles and begin to **decondense**
- **Nuclear envelopes** (nuclear membranes) begin to **reform** around each set of chromosomes
- The **spindle fibres break down**
- New **nucleoli form** within each nucleus

Your notes



Telophase

Examiner Tip

Make sure you learn the four stages of mitosis and what is happening to the DNA molecules (one chromatid contains one DNA molecule) at each stage – learn **'PMAT'** (prophase, metaphase, anaphase, telophase) to help you remember the order of the stages!

Your notes

Mitosis: Skills

Your notes

Identifying Phases of Mitosis

- Cells undergoing different stages of the cell cycle can be identified using photomicrographs taken from microscope slides
- Cells undergoing certain stages of the cell cycle have distinctive appearances

Interphase

- As cells spend the majority of the cell cycle in this stage then most cells will be in this stage
- The **chromatin** is **visible** (however **chromosomes** are not) so the nuclei have a dark appearance

Prophase

- Chromosomes are **visible**
- The nuclear envelope is breaking down

Metaphase

- **Chromosomes** are lined up along the **middle** of the cell

Anaphase

- **Chromosomes are moving away** from the middle of the cell, towards opposite poles
- As they are pulled from the centromere through the cytoplasm, the chromosomes tend to have a characteristic **'V' shape**

Telophase

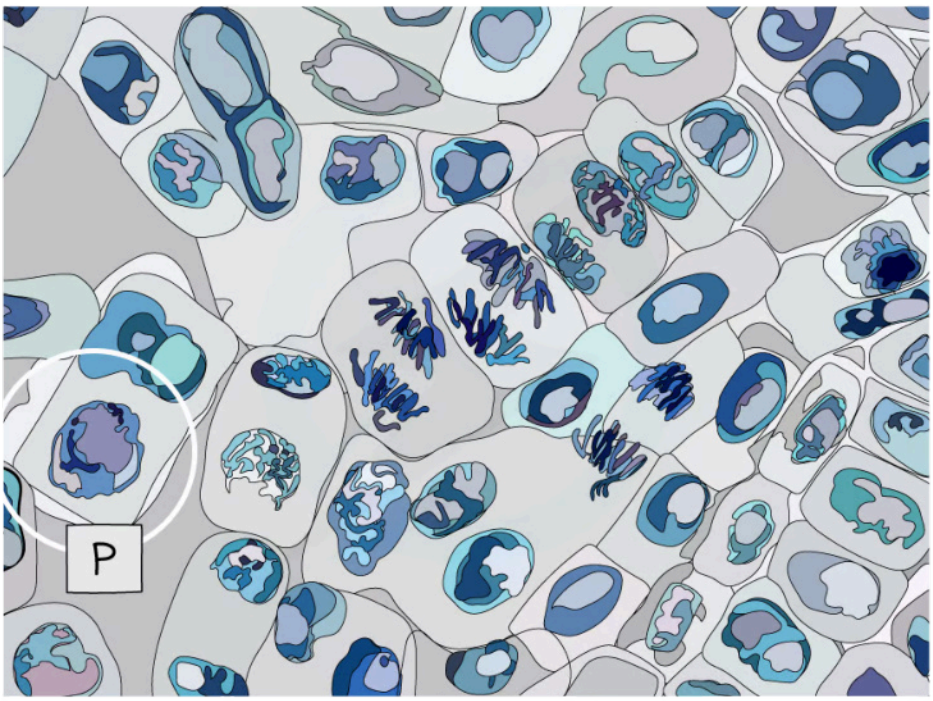
- Chromosomes have arrived at **opposite poles** of the cell
- Chromosomes begin to **uncoil** (are no longer condensed)
- The nuclear envelope is reforming

Cytokinesis

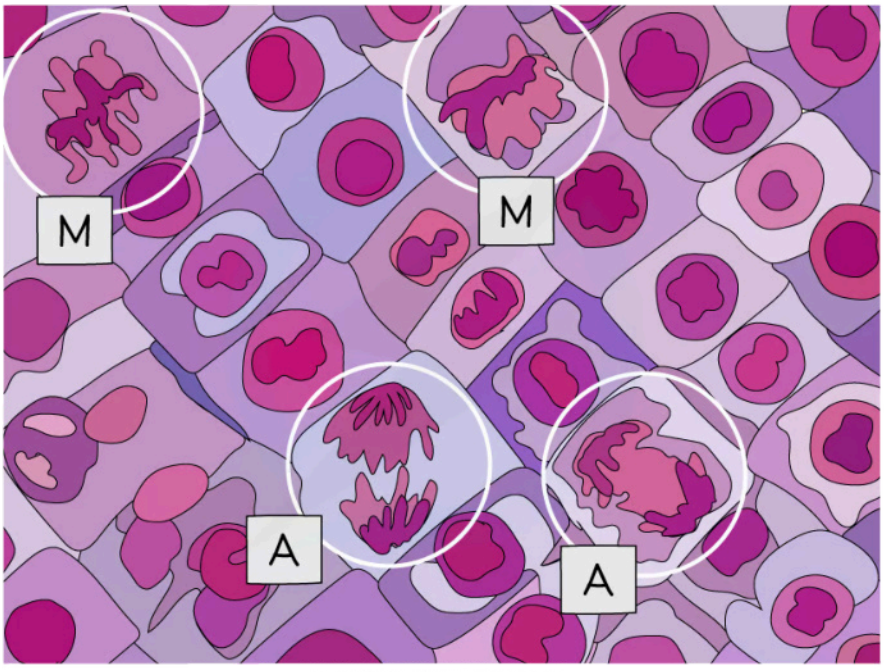
- Animal cells: a **cleavage furrow** forms and separates the daughter cells
- Plant cells: a **cell plate** forms at the site of the metaphase plate and expands towards the cell wall of the parent cell, separating the daughter cells

Identification of phases

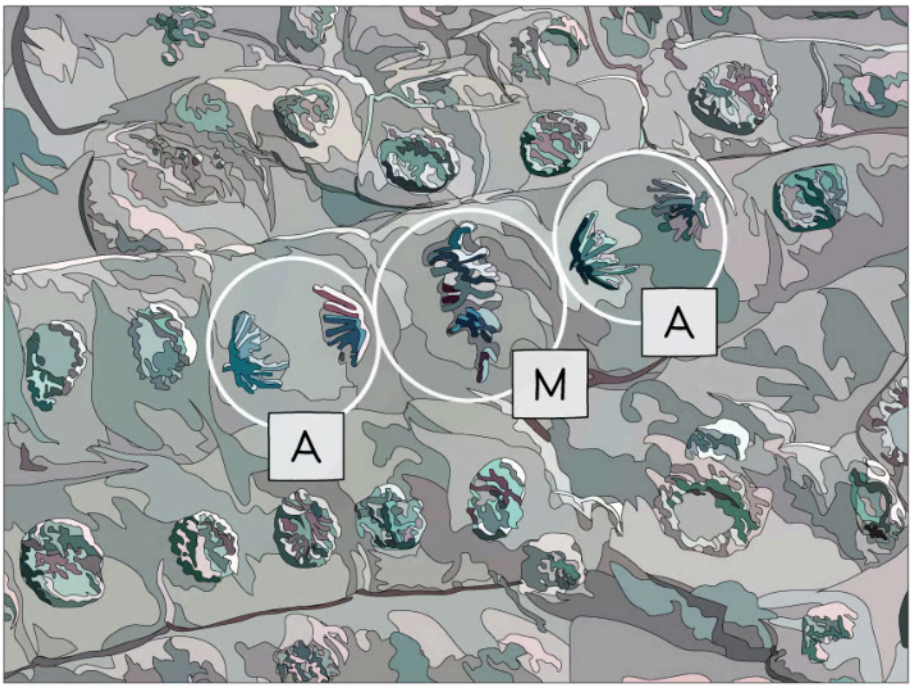
Your notes



Micrograph showing a cell undergoing prophase (P)

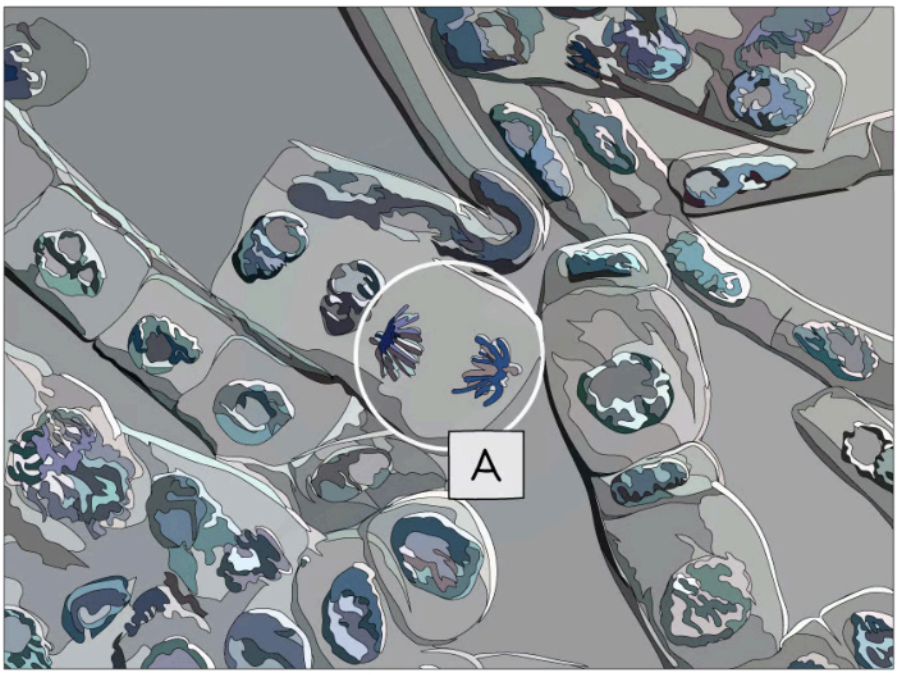


Micrograph showing cells undergoing metaphase (M) and anaphase (A)



Micrograph showing cells undergoing metaphase (M) and anaphase (A)

Your notes



Micrograph showing a cell undergoing anaphase (A)

Examiner Tip

It is important to be able to recognise each mitotic stage from electron micrographs and to be able to explain why that cell is in the stage you have selected. It can be difficult to tell prophase and telophase apart in some photomicrographs. In prophase, there is only one group of chromosomes in the cell while in telophase there are two groups, one at each pole.

Your notes

Meiosis

Your notes

Meiosis as Reduction Division

- There are two processes by which the **nucleus** of a **eukaryotic cell** can **divide**. These are:
  - Mitosis
  - Meiosis
- **Mitosis** gives rise to **genetically identical cells** and is the type of cell division used for **growth**, **repair** of damaged tissues, **replacement** of cells and **asexual reproduction**
- **Meiosis** gives rise to cells that are **genetically different** from each other and is the type of cell division used to produce gametes (sex cells)
- During meiosis, the nucleus of the original 'parent' cell undergoes **two rounds of division**. These are:
  - **Meiosis I**
  - **Meiosis II**

Meiosis I

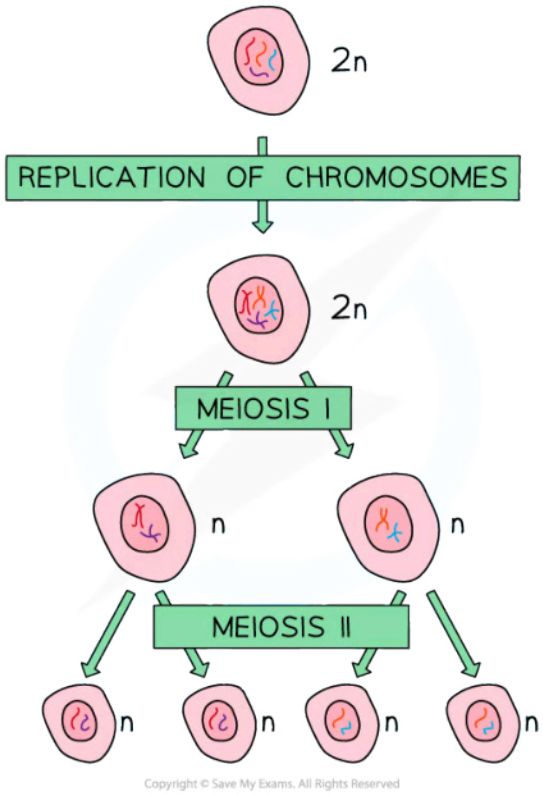
- The nucleus of the original 'parent' cell is diploid (**2n**) i.e. it contains **two sets of chromosomes**
- Before meiosis I, these chromosomes **replicate**
- During meiosis I, the homologous pairs of chromosomes are **split up**, to produce **two** haploid (**n**) nuclei
  - At this point, each chromosome still consists of **two chromatids**
- Note that the **chromosome number halves** (from 2n to n) in the **first division** of meiosis (**meiosis I**), not the second division (meiosis II)
  - This is why the first division of meiosis is also known as **reduction division**
- During prophase I of meiosis homologous chromosomes pair up and are in very close proximity to each other
  - A pair of homologous chromosomes can be referred to as a **bivalent**
  - At this point, there can be an exchange of genetic material **(alleles)** between **non-sister chromatids** in the bivalent
    - The crossing points are called **chiasmata**
  - This results in a **new combination of alleles on the two chromosomes** (these can be referred to as **recombinant chromosomes**)
  - This exchange of genetic material is known as **crossing over**
- **Spindle fibres** attach to the centromeres of the bivalents which pulls the homologous chromosomes to the opposite poles of the cell
  - The individual chromatids of each chromosome are still attached by their centromeres
- Between meiosis I and II there is no replication of the chromosomes

Meiosis II

- During meiosis II, the **chromatids** that make up each chromosome **separate** to produce **four haploid** (**n**) nuclei
  - At this point, each chromosome now consists of a **single chromatid**

Meiosis overview diagram

Your notes



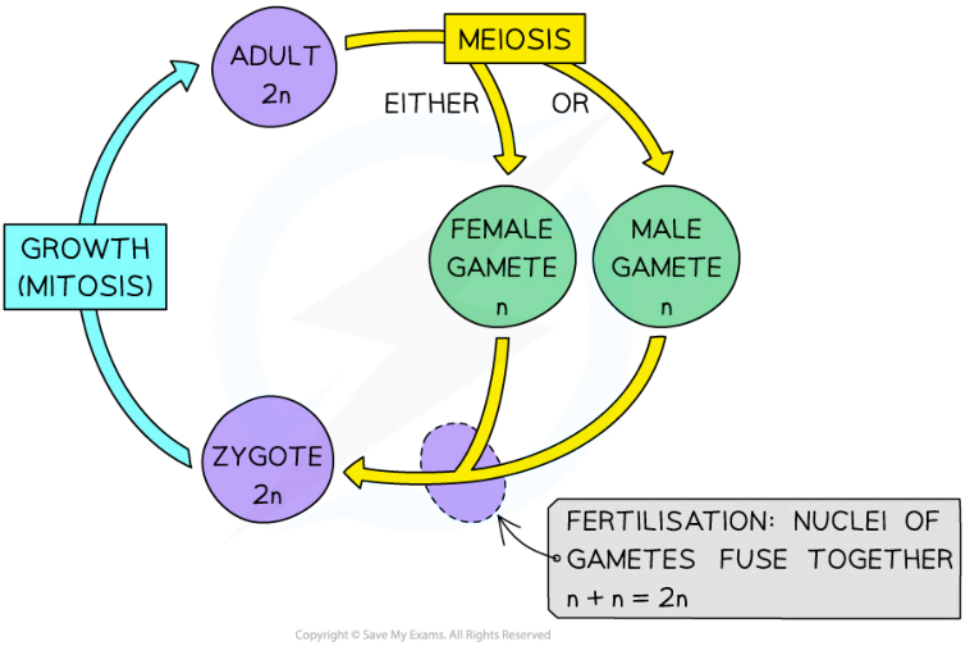
One diploid nucleus divides by meiosis to produce four haploid nuclei

The need for meiosis in a sexual life cycle

- The life cycles of organisms can be **sexual** or **asexual** (some organisms are capable of both)
  - In an **asexual** life cycle, the **offspring are genetically identical to the parent** (they have exactly the same chromosomes)
  - In a **sexual** life cycle, the **offspring are genetically distinct from each other and from each of the parents** (their chromosomes are different, causing them to be genetically distinct)
- The **halving of the chromosome number** during meiosis is very important for a **sexual life cycle** as it allows for the **fusion of gametes**
- Sexual reproduction is a process involving the **fusion** of the nuclei of two gametes to form a **zygote** (fertilised egg cell) and the production of offspring that are genetically distinct from each other
- This **fusion of gamete nuclei** is known as **fertilisation**
  - Fertilisation **doubles** the number of chromosomes each time it occurs
  - This is why it is essential that the chromosome number is also **halved** at some stage in organisms with a **sexual life cycle**, otherwise the chromosome number would keep doubling every generation
  - This halving of the chromosome number occurs during **meiosis**
  - In animals, this halving occurs during the **creation of gametes**

Sexual lifecycle overview diagram

Your notes



Sexual life cycle

Down Syndrome & Non-Disjunction

Your notes

- **Non-disjunction** occurs when chromosomes fail to separate correctly during **meiosis**
- This can occur in either anaphase I or anaphase II, leading to **gametes** forming with an **abnormal number of chromosomes**
  - The gametes may end up with **one extra copy** of a particular chromosome or **no copies** of a particular chromosome
  - These gametes will have a different number of chromosomes compared to the normal haploid number
- If the abnormal gametes are fertilized, then a **chromosome abnormality** occurs as the diploid cell (**zygote**) will have the incorrect number of chromosomes

Diagram showing non-disjunction compared to normal chromosome separation

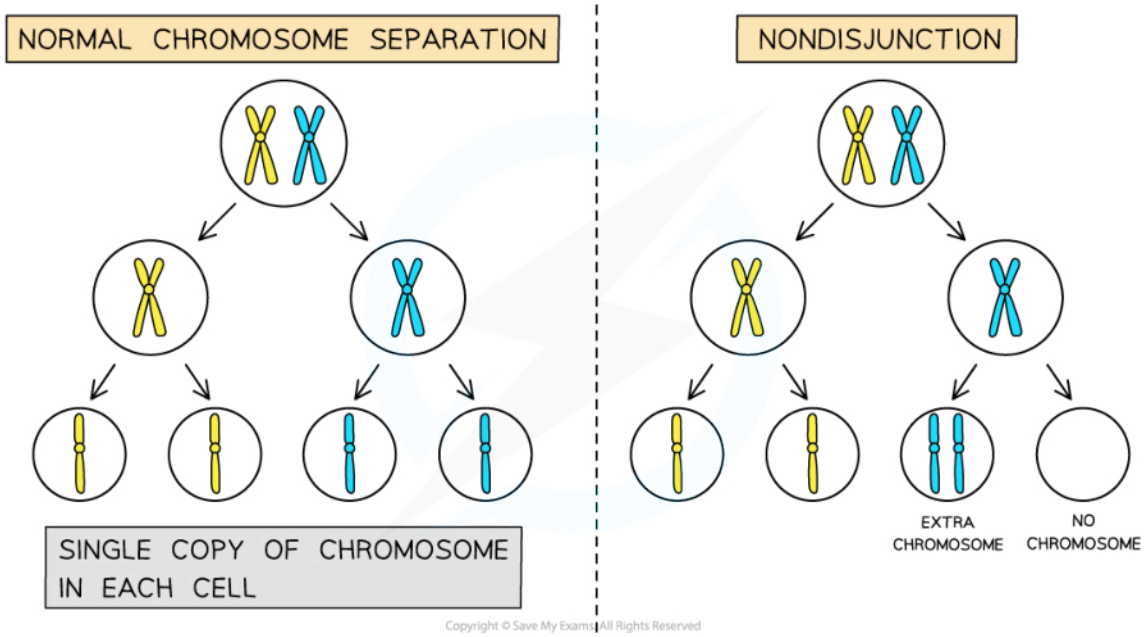


Image showing how chromosomes failing to separate properly during meiosis can result in gametes with the incorrect number of chromosomes

Down Syndrome

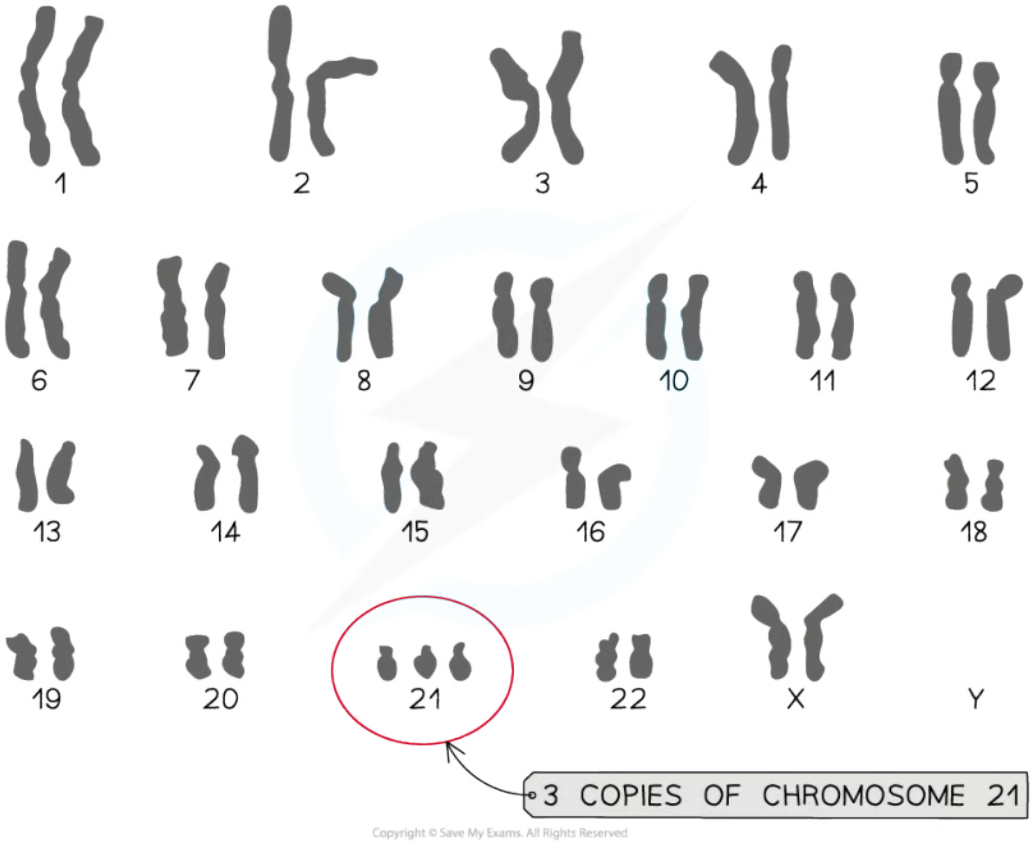
- A key example of a non-disjunction chromosome abnormality is Down syndrome, also called **Trisomy 21**
- Non-disjunction occurs during anaphase I (in this case) and the 21st pair of homologous chromosomes fail to separate
- Individuals with this syndrome have a total of 47 chromosomes in their cells as they have three copies of **chromosome 21**
- The impact of trisomy 21 can vary between individuals, but some common features of the syndrome are **physical growth delays** and **reduced intellectual ability.** Individuals can also suffer from issues with

Your notes

sight or **hearing**

- There are other examples of non-disjunction which result in trisomy
  - **Patau syndrome** (trisomy 13) and **Edwards syndrome** (trisomy 18) are very serious syndromes which result in many physical disabilities and developmental difficulties
- The risk of chromosomal abnormalities **increases significantly** with age
  - The age of the mother is particularly important in the case of Down Syndrome as non-disjunction is more likely to happen in older ova
- **Karyotyping** of the chromosomes in foetal cells can be used to identify chromosomal abnormalities
  - Foetal cells may be obtained by performing an amniocentesis or by chorionic villus sampling

Down syndrome karyotype diagram



A karyogram showing the karyotype of an individual with Down syndrome

Meiosis as Source of Variation

Your notes

Crossing over and random orientation promote genetic variation

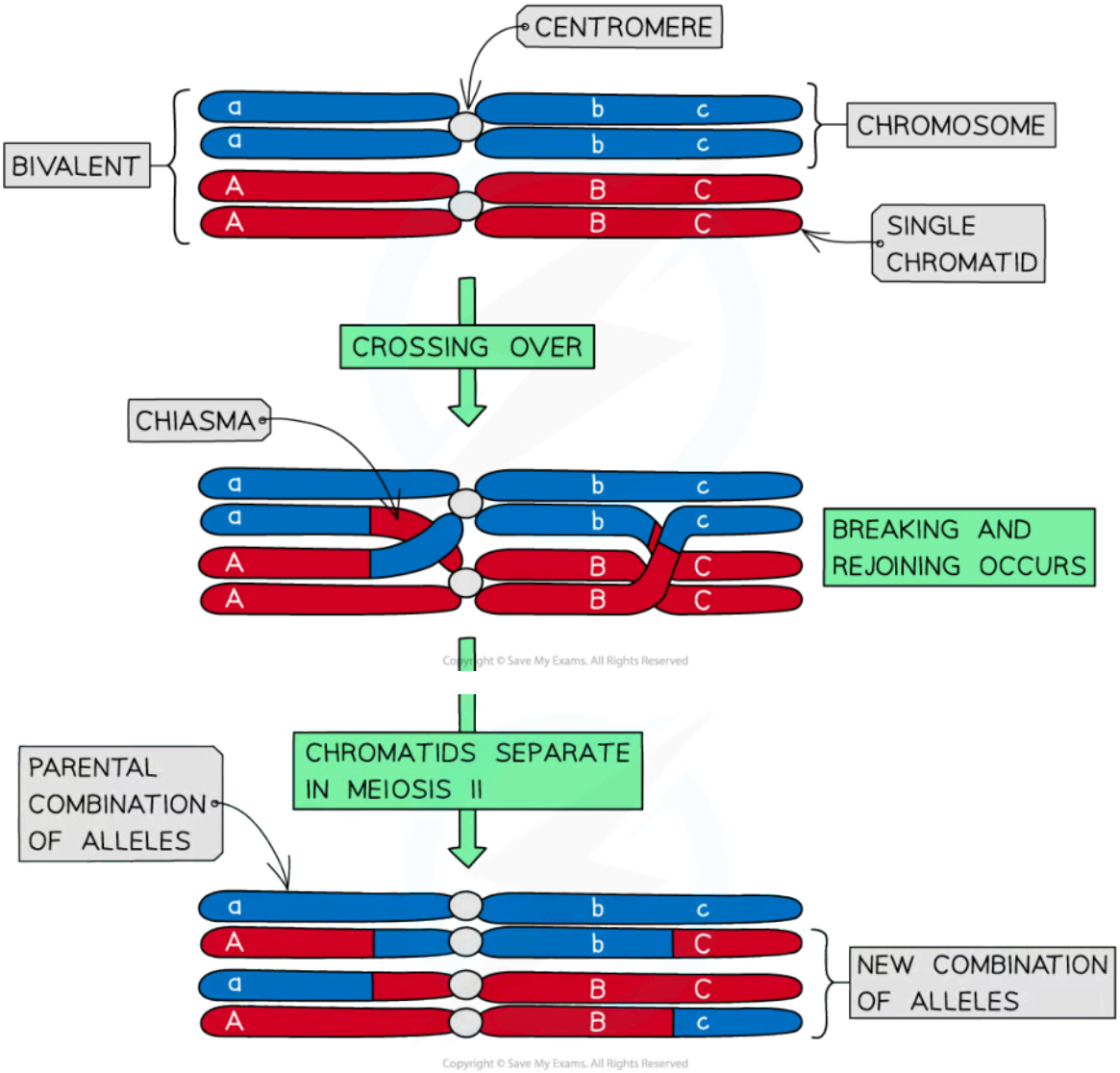
- Having **genetically different offspring** can be **advantageous** for natural selection and therefore increase the survival chances of a species
- **Meiosis** has several mechanisms that **increase the genetic variation of gametes** produced
- Both **crossing over** and **random orientation** result in **different combinations of alleles** in gametes

Crossing over

- At the start of meiosis, homologous chromosomes **pair up** with each other
  - As DNA replication has already occurred, each chromosome is made up of **two sister chromatids**
  - This means that a pair of homologous chromosomes is made up of **four DNA molecules**
- A pair of homologous chromosomes is known as a **bivalent**
  - Each pair consists of a maternal and paternal chromosome
- The pairing process resulting in the formation of a bivalent is known as **synapsis**
- After synapsis has occurred, a process known as **crossing over** may occur
- During crossing over, two **non-sister chromatids** (i.e. one chromatid from each of the homologous chromosomes) form a **junction**
- At this junction, the two chromatids **break** and **rejoin** with each other
- As these crossover events occur at exactly the same position on the two non-sister chromatids, this allows **genes** to **exchange** between the chromatids
- Non-sister chromatids are **homologous** but are **not genetically identical** and this means that some of the **alleles** of the exchanged genes will be **different**
- This process, therefore, produces chromatids with **completely new combinations of alleles** (that were not previously present in the DNA of the 'parent' cell)
  - This is because genetic material was exchanged between the maternal and paternal chromosomes
- As these chromatids will eventually be split up into **different gametes**, crossing over is of great **importance** because it is a significant source of **genetic variation** between gametes
  - This ensures there is genetic variation in **populations** of **sexually-reproducing species**, which is key to a species' ability to **evolve** and **adapt** to changes in its environment over time

Diagram showing crossing over

Your notes



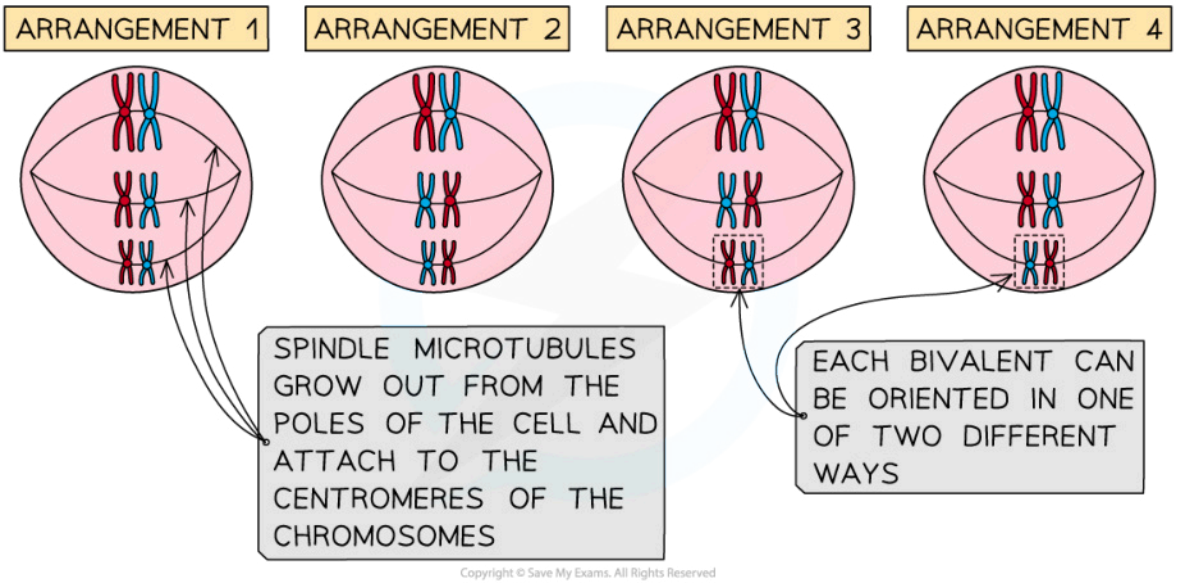
Crossing over of non-sister chromatids leading to the exchange of genetic material

Random orientation of bivalents

- At metaphase, during meiosis I, **bivalents line up at the cell equator** as they prepare to **separate**
- **Spindle microtubules** grow out from the **poles** of the cell and attach to the **centromeres** of the chromosomes
- Each of the two homologous chromosomes in a bivalent is attached to a **different pole**
- The **orientation of the bivalents** when they line up at the cell equator determines which pole each chromosome gets attached to (and eventually pulled towards)
- The orientation of the bivalents is **completely random**
- In addition, the bivalents also **assort independently of one another** (i.e. the orientation of one bivalent never affects the orientation of another)

Your notes

Diagram showing random orientation



The orientation of bivalents lining up at the cell equator is random

The different combinations of chromosomes following meiosis

- The number of possible chromosomal combinations resulting from random assortment is equal to $\mathbf{2^n}$
  - *n* is the number of homologous chromosome pairs or haploid number
- For humans: the number of chromosomes is 46 meaning the number of homologous chromosome pairs is 23 so the calculation would be:
  - 2^{23} = 8,388,608 possible chromosomal combinations

Cell Cycle (HL)

Your notes

Cell Proliferation in Organisms

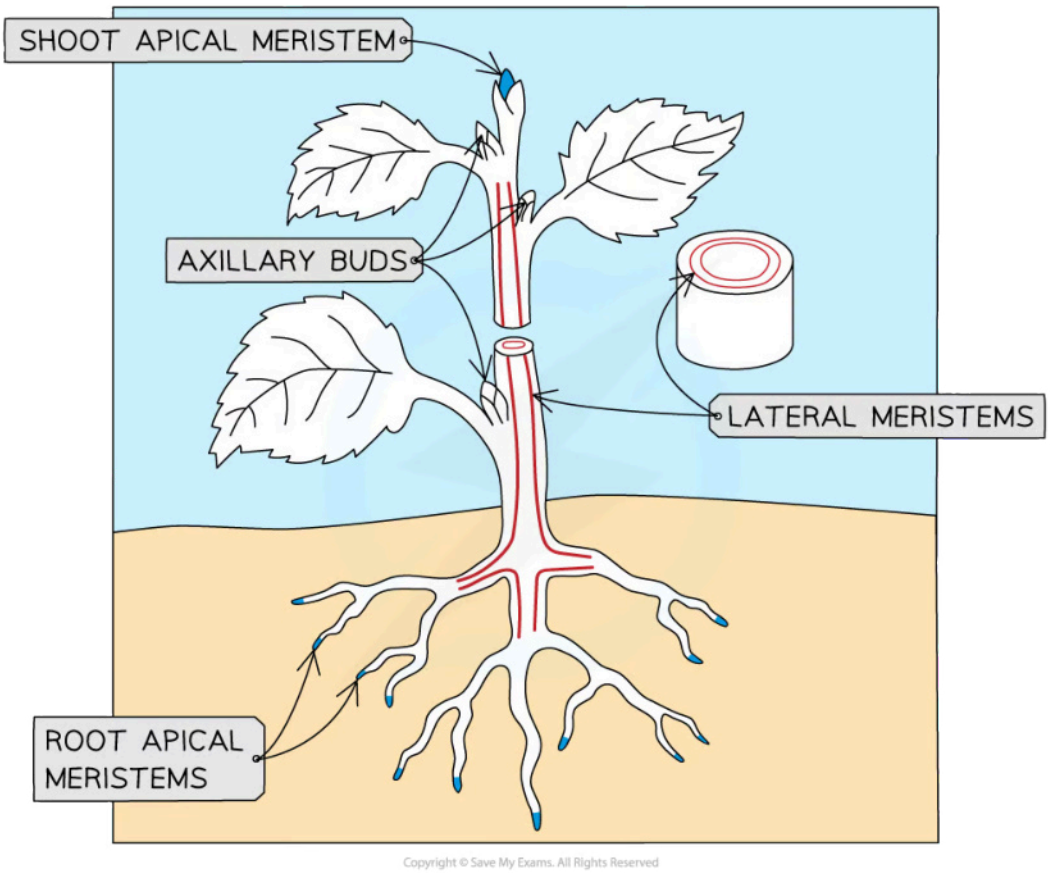
- Plants and animals originate from a zygote which will divide repeatedly to form an embryo
  - During this stage of development, there is a **rapid increase** in the number of cells which allows the embryo to grow
    - This rapid increase in cell number is known as **proliferation**
    - Proliferation for growth occur within **early-stage animal embryos**, as well as growth regions in plants known as **meristems**

Plant meristems

- Plant growth occurs in regions known as **meristems**
  - The cells in these regions are known as **meristem cells**
- Meristem cells are **undifferentiated**; they actively divide by mitosis to produce **new plant tissue**
- Meristems can be found in the **growing tips of plant roots and shoots**
  - A meristem at the tip of a shoot is a **shoot apical meristem**
  - A meristem at the tip of a root is a **root apical meristem**
  - Meristem tissue with the potential to form **new side branches** from the main plant stem can be found in regions known as **axillary buds**
- Meristems can also be found **parallel to the sides of a stem** e.g. within the **vascular bundles** that contain the xylem vessels and the phloem
  - These are known as **lateral meristems** and enable plant stems to **grow in diameter**
  - Lateral means 'from the side'
- The regions of meristem tissue in the **vascular bundles** are known as **cambium**

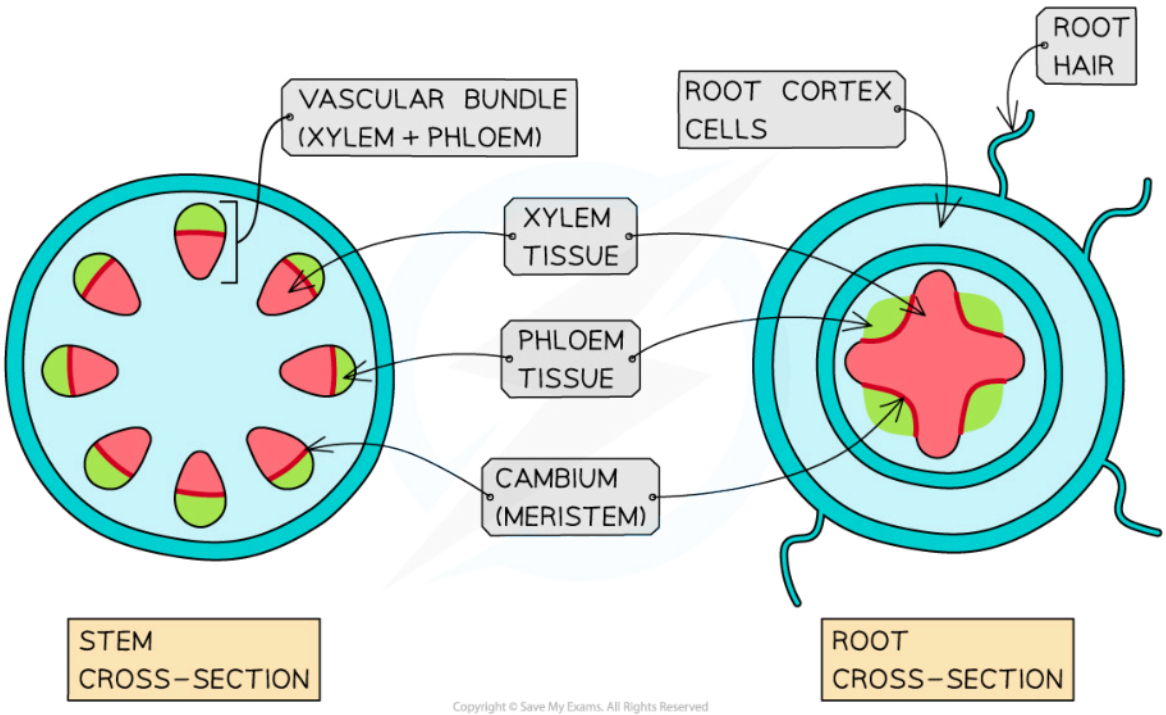
Diagram to show the location of plant meristems

Your notes



The growing parts of plants are known as meristems, and can be found in the shoot apex (shoot apical meristem), the root apex (root apical meristem), and the sides of the stem (lateral meristem)

Diagram to show the location of the cambium meristem tissue



Lateral meristem tissue is known as cambium. It can be found between the xylem and phloem in stems and roots.

Early-stage animal embryos

- Following human fertilisation, the newly **fertilised ovum divides by mitosis** to form **two diploid nuclei** (i.e. each nucleus contains two sets of chromosomes) and the cytoplasm divides equally to form a two-cell embryo
- Mitosis continues to form a four-cell embryo and this process continues until eventually, the embryo takes the shape of a hollow ball called a **blastocyst** (with an internal group of cells called **blastomeres**)
  - Blastomeres will eventually develop into the **foetus**
  - These cells are undifferentiated and could develop into any type of specialised cell at this point

Cell proliferation for cell replacement and tissue repair

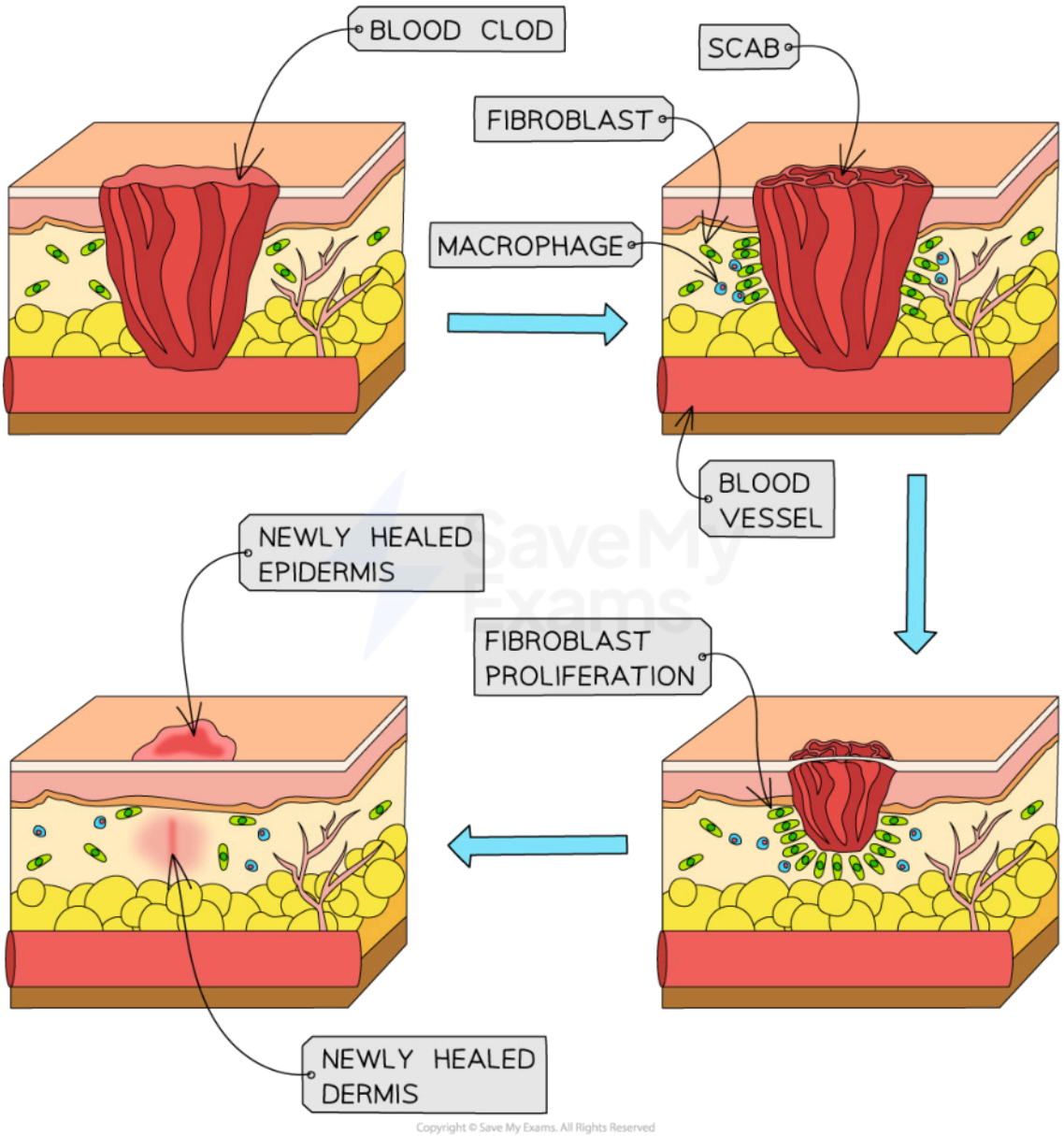
- Cells, such as those that form part of skin and blood, need to be constantly replaced
  - This is achieved by the process of **cell proliferation** whereby cells divide by **mitosis**
- Skin cells that form part of the **epidermis** (outer layer of the skin) are lost on a daily basis and will be replaced multiple times during a lifetime
  - This is achieved by the **proliferation of the stem cells** found in the basal (bottom) layer of the epidermis
  - These newly formed daughter cells will form new layers in the epidermis to replace the top layers lost through wear and tear
- Tissue repair during **wound healing** is another example of the importance of cell proliferation

Your notes

- Once the wound is sealed by a blood clot, the blood vessels will dilate to increase blood flow to the damaged area
- This enables **fibroblasts** and white blood cells called **macrophages** to reach the wound
  - Macrophages will engulf any pathogen that entered through the broken skin while the fibroblasts will proliferate to facilitate the closure of the wound
  - The fibroblasts achieve this by breaking down the fibrin in the blood clot while producing a new matrix of collagen fibres to help close the wound and support new skin cells

Your notes

Wound healing diagram



The proliferation of fibroblasts will speed up the process of wound healing

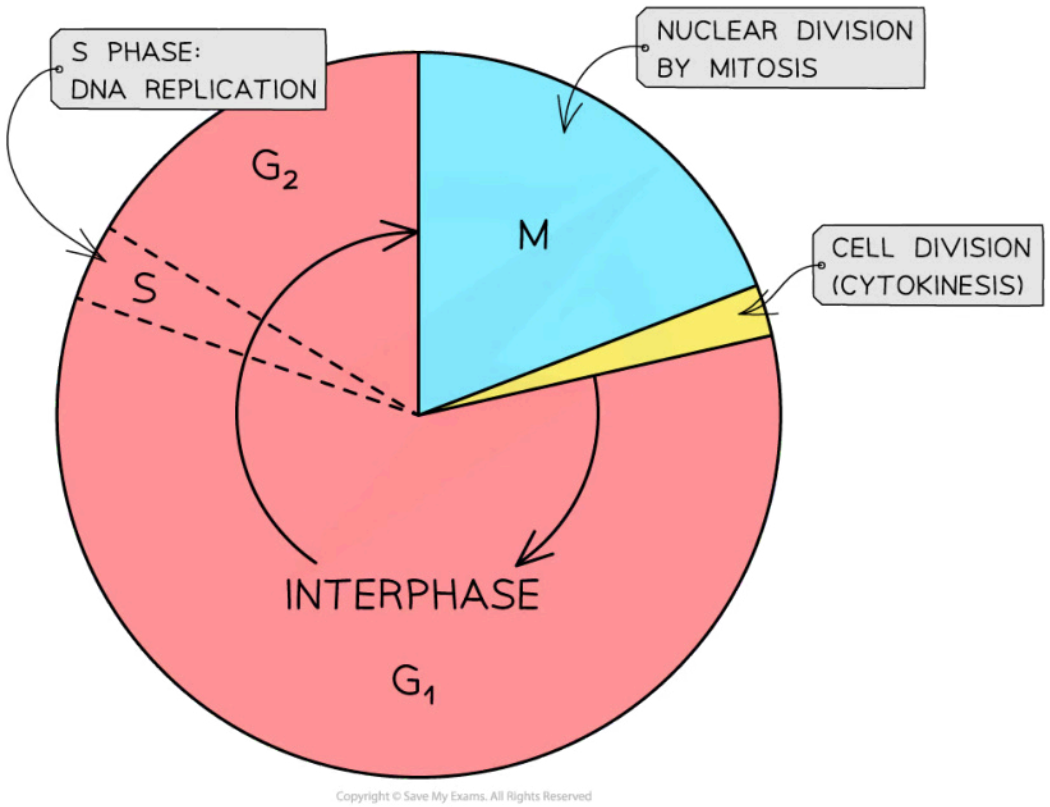
Your notes

Phases of the Cell Cycle

Your notes

- **Mitosis** is part of a **precisely controlled process** known as the **cell cycle**
  - Cell proliferation is achieved using the cell cycle
- The cell cycle is the **regulated sequence of events** that occurs **between one cell division and the next**
- The cell cycle has three phases occurring in the following order:
  - **interphase**
    - This includes the G_1, S and G_2 phases
  - **nuclear division (mitosis)**
  - **cell division (cytokinesis)**
- The length of the cell cycle varies depending on:
  - The environmental conditions, the cell type and the organism
  - For example, onion root tip cells divide once every 20 hours (roughly) but human intestine epithelial cells divide once every 10 hours (roughly)
- The movement from one phase to another is triggered by chemical signals called **cyclins**

Cell cycle diagram



The cell cycle

S = synthesis (of DNA); G = growth; M = mitosis

Examiner Tip

Make sure you know the order of the phases of the cell cycle but also what specifically occurs during the different phases.

Your notes

Interphase


Your notes

- **Interphase** is the **longest** and **most active phase** of the **cell cycle**
- During interphase, the cell:
  - **Increases** in **mass** and **size**
  - Carries out many cellular functions in the nucleus and cytoplasm e.g. **synthesising proteins** and **replicating its DNA** ready for mitosis (these only occur during interphase)
  - **Increases** the number of **mitochondria**
  - **Increases** the number of **chloroplasts** (if they are a plant or algae cell)

The phases of interphase

- Interphase consists of **three** phases:
  - **G_1 phase**
  - **S phase**
  - **G_2 phase**
- The gap between the previous cell division and the S phase is called the **G_1 phase** – **G** stands for **growth**
  - Cells make the **RNA, enzymes and other proteins required for growth** during the G_1 phase
- It is at some point during the G_1 phase a **signal** is received telling the cell to **divide** again (although some cells do not receive this signal and will **never divide;** they enter the **G_0 phase**)
- After the G_1 phase of interphase the cell enters the next phase of the cell cycle, the **S phase** – **S** stands for **synthesis** (of DNA)
  - The S phase is relatively short
  - The **DNA in the nucleus replicates,** resulting in each chromosome consisting of two identical sister chromatids
- Between the S phase and next cell division event the **G_2 phase** occurs
  - During the G_2 phase, the **cell continues to grow and the new DNA that has been synthesised is checked** and any errors are usually repaired
  - Other preparations for cell division are made (eg. production of tubulin protein, which is used to make microtubules for the mitotic spindle)
- **Interphase = G_1 + S + G_2**

Examiner Tip

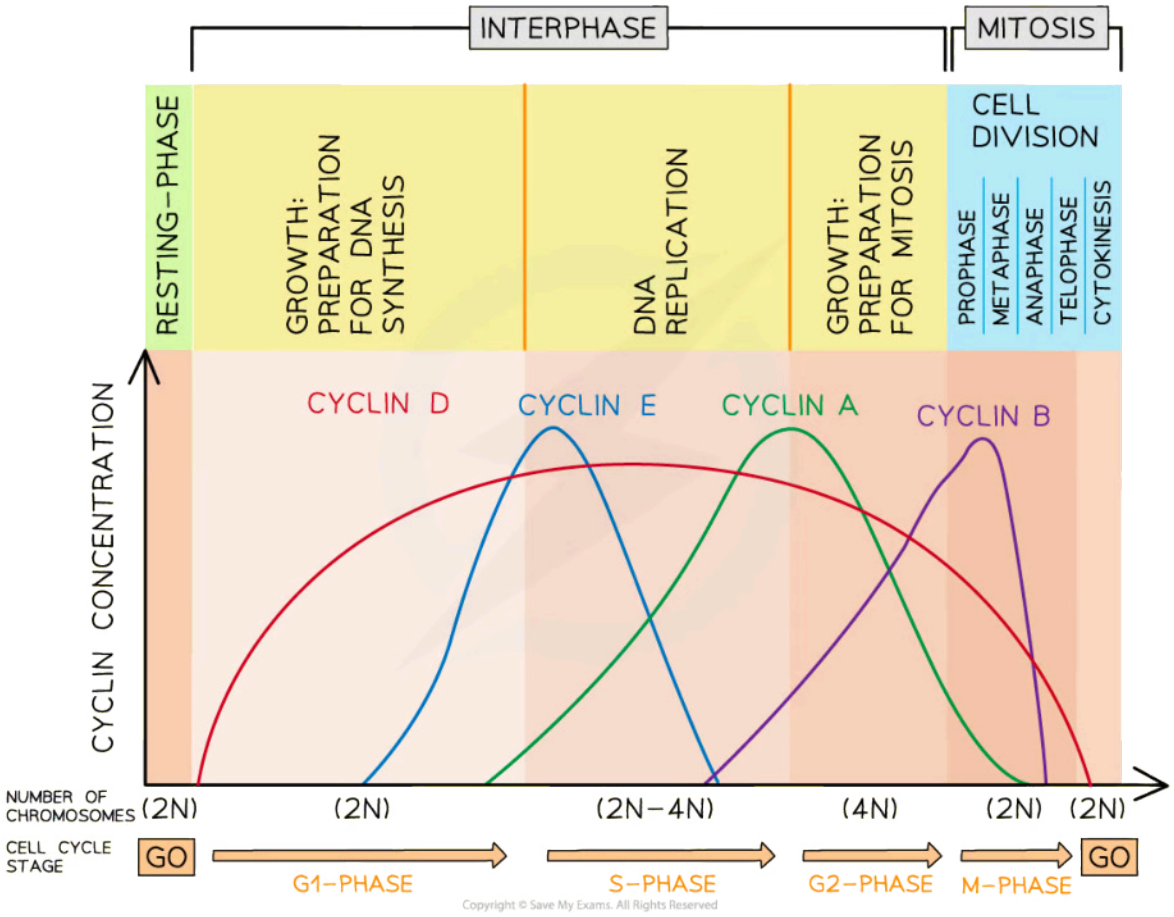
Don't forget, interphase is itself made up of three distinct stages (G_1, S and G_2) and you need to know what happens during each of these. For example, an exam question might ask you to identify the stage of the cell cycle during which a cell would be producing the most mRNA molecules and explain why. The correct answer would be the G_1 phase, as this is when protein synthesis is occurring and the production of mRNA occurs during transcription (the first part of protein synthesis).

Control of the Cell Cycle

Your notes

- The **cell cycle** is a sequence of stages including **interphase** (G_1, S & G_2), **mitosis** (M) and **cytokinesis** (C)
- There are **three checkpoints** in the cell cycle which must be overridden before the next stage can begin
  - These checkpoints are located at G_1, G_2 and M
- The cycle is **controlled** by **cyclins** (a group of proteins) and **kinases** (enzymes)
- There are **four different cyclins** (**D, E, A & B**) whose concentrations rise and fall over the cycle:
  - Each of these will trigger specific events in the cell cycle to occur

Cyclin control of the cell cycle diagram



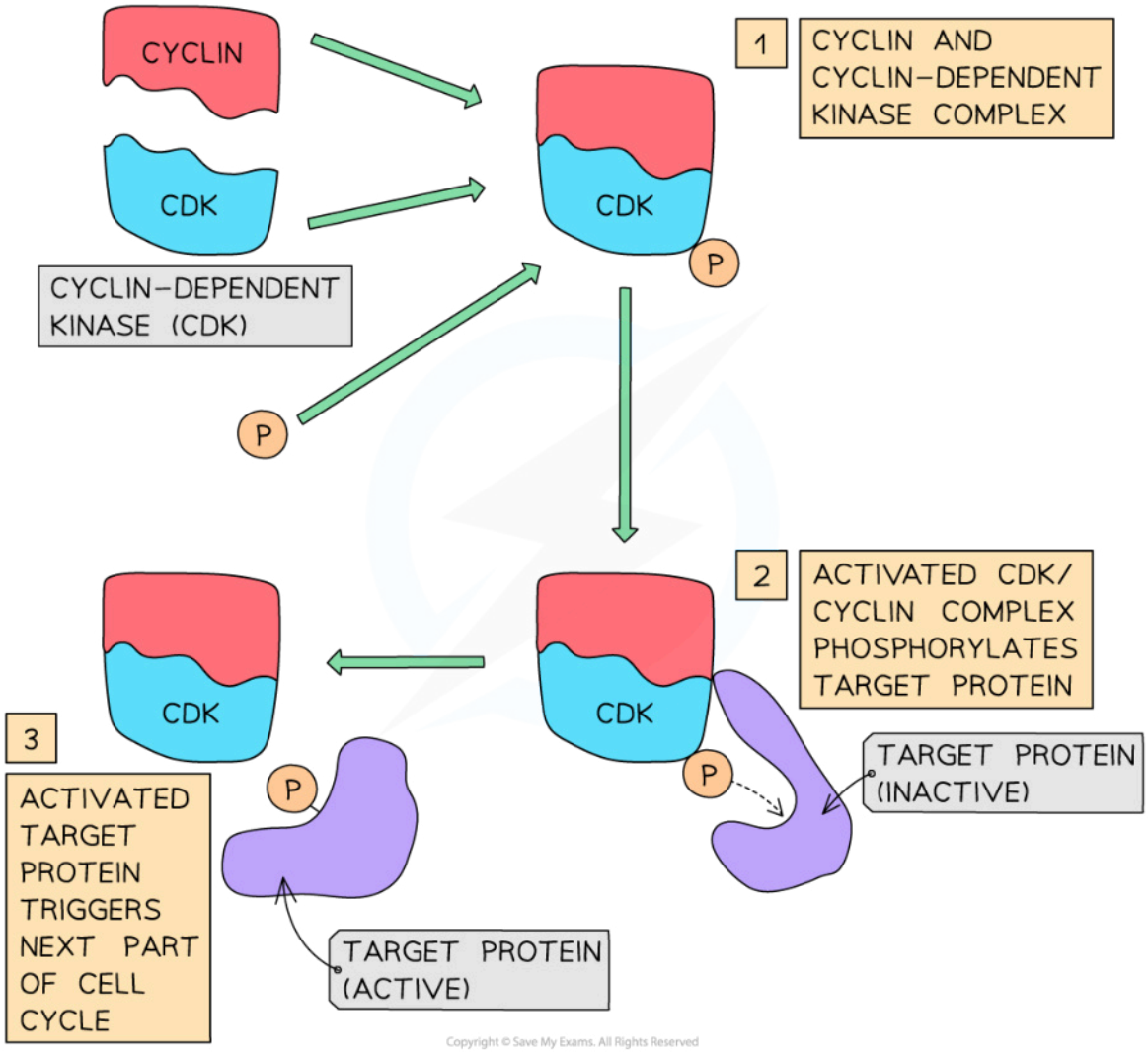
Cyclins control the cell cycle. The presence of certain cyclins triggers a specific stage of the cell cycle.

- When each of the different **cyclins** reach a **certain concentration** (or threshold level) they **trigger the next stage** of the cell cycle
- This ensures **key processes** (e.g. DNA replication, organelle multiplication and protein synthesis) **occur** at the **correct time**

- When a specific cyclin has reached a certain concentration it will **bind** with another group of proteins (**cyclin-dependent kinases**) forming a **complex** which is **activated**
- This complex **phosphorylates** (attaches a phosphate) a **target protein** which **activates it,** causing it to trigger **specific functions** (e.g. DNA replication)
- Once the specific function is complete the phosphate is released, the cyclin breaks down and the cyclin-dependent kinases become inactive

Your notes

Mechanism of cyclin action diagram



The mechanism for cell cycle control by cyclins

Examiner Tip

Note that you are not required to know details of the roles of specific cyclins for exam purposes.

Your notes

Uncontrolled Cell Division & Tumour Formation (HL)


Your notes

Mutations in Genes Controlling Cell Cycle

- Mutations of the genes that control the cell cycle may lead to cancer
- Two types of genes are typically involved with the development of cancer:
  - **Proto-oncogenes** code for proteins which stimulate normal cell division
    - These genes are converted to oncogenes once they mutate
    - This results in an **increase** in the protein product produced or proteins which are **permanently activated**
    - Leading to uncontrolled cell division which may result in cancer
  - **Tumour-suppressor genes** code for proteins which inhibit cell division or promote controlled cell death (known as apoptosis) should the nucleus contain damaged DNA
    - Mutations in these genes may result in **no or reduced** protein product or proteins which are **permanently deactivated**
    - Leading to uncontrolled cell division and possibly cancer

Types of Tumours

Your notes

- Cancers demonstrate how important it is that **cell division** is **precisely controlled**, as cancers arise due to **uncontrolled mitosis**
- Cancerous cells divide repeatedly and uncontrollably, forming a **tumour** (an irregular mass of cells)
- A typical tumour contains around a thousand million cancerous cells by the time it is detected

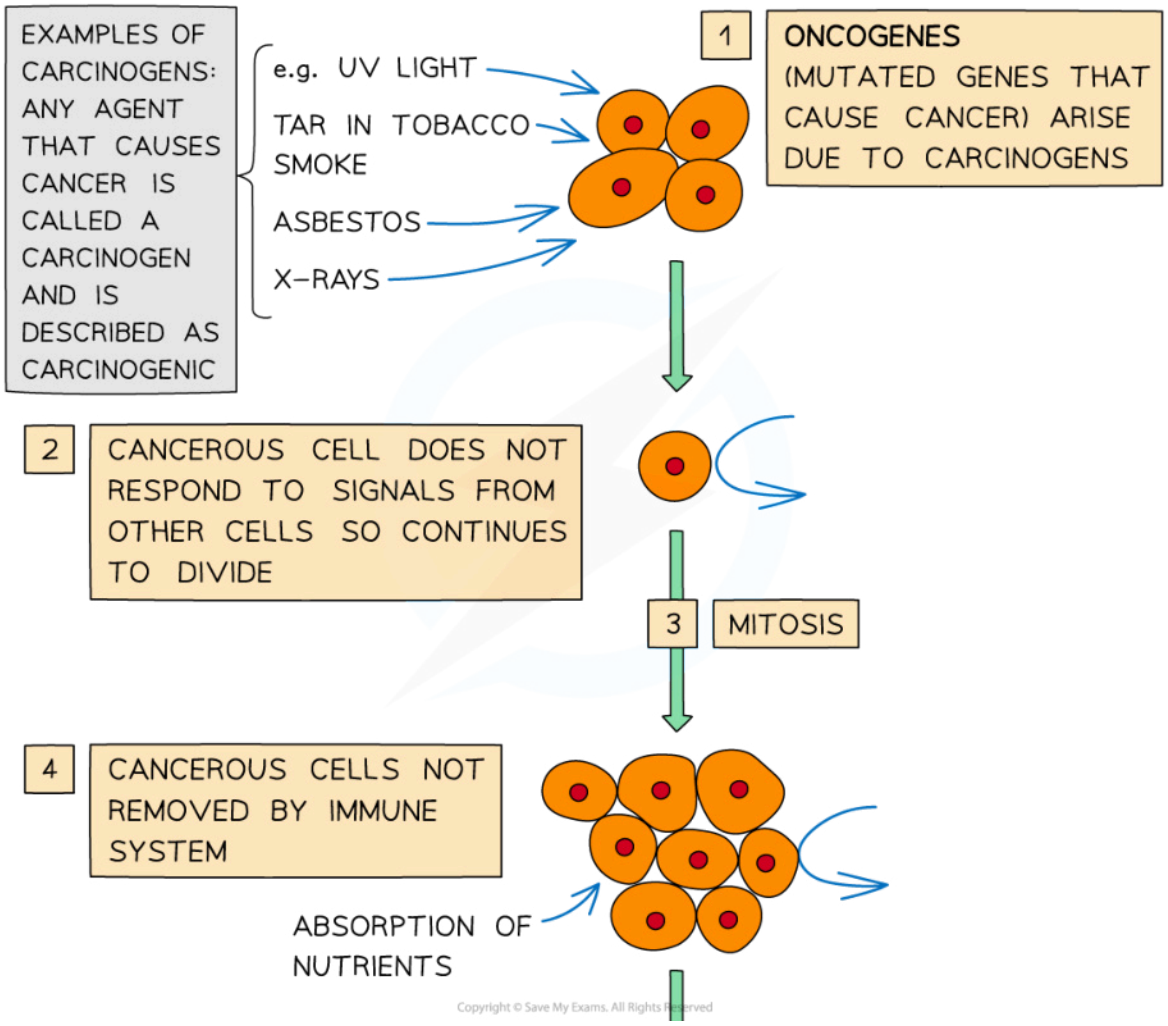
Types of tumour

- **Tumours** have different characteristics depending on whether they are cancerous (**malignant**) or non-cancerous (**benign**)
- All tumours may cause harm to the body by:
  - Damaging the organ in which the tumour is located
  - Causing blockages or obstructions
  - Damaging other organs by exerting pressure

Malignant tumours

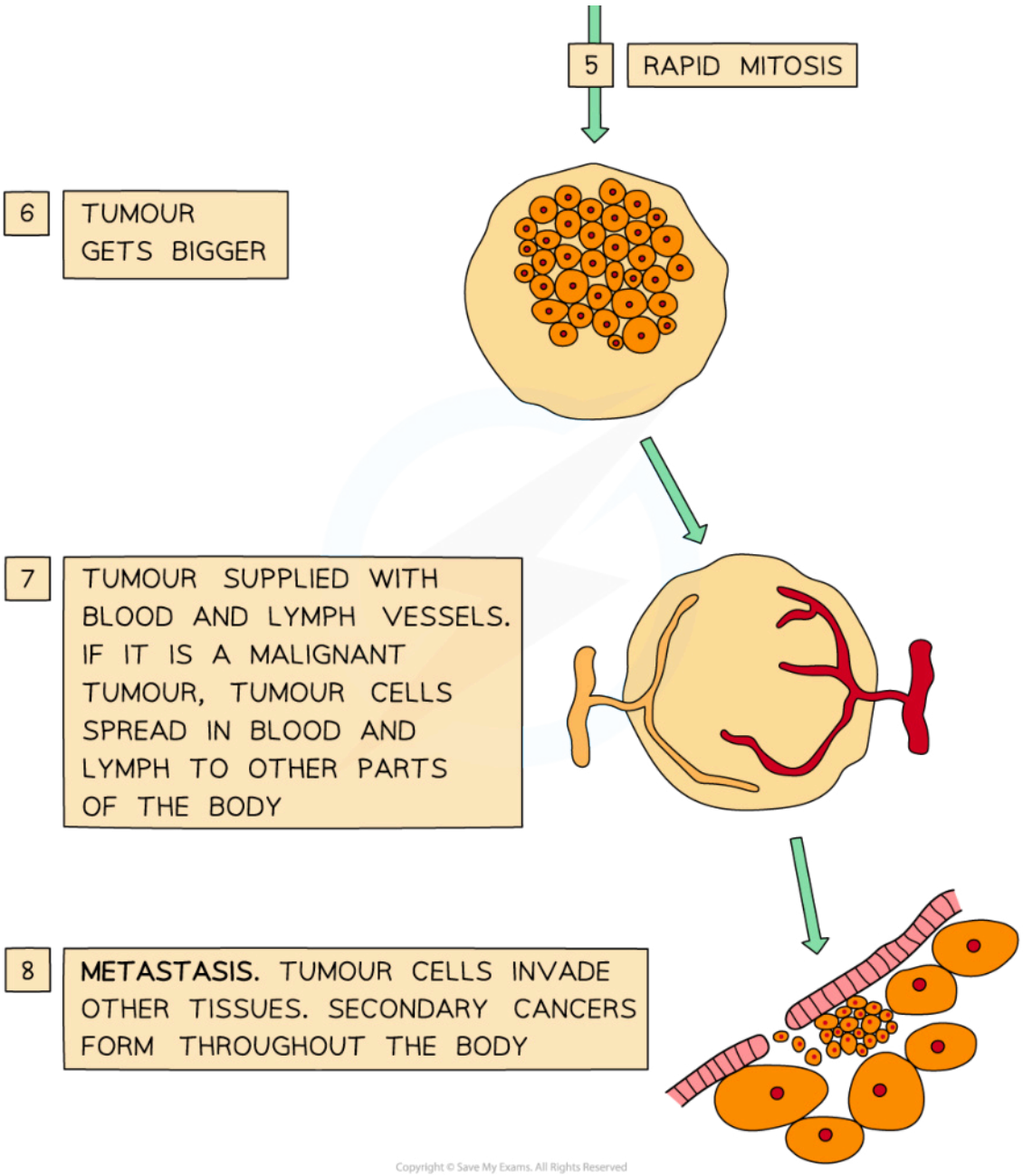
- Malignant tumours are **cancerous**
- Malignant tumours cause cancer by **growing rapidly**, then **invading and destroying surrounding tissues**
  - Cells within malignant tumours secret chemicals that cause the formation of blood vessels to supply the tumour with nutrients, growth factors and oxygen
  - These tumours are known as **primary tumours** and this is where cancer starts to develop
- Cells can break off these primary tumours and spread to other parts of the body through the bloodstream or lymphatic system, this is called **metastasis**
  - Metastasis causes the spread of tumours to other places in the body, affecting multiple organs
  - Tumours that develop from cells that broke off the primary tumour are known as **secondary tumours**
  - When removed through surgery, malignant secondary tumours can still grow back
- The formation of malignant tumours can be initiated by carcinogens such as:
  - UV or X-ray exposure
  - Tobacco from cigarettes
  - Asbestos
  - Processed meat

Cancer formation diagram



Your notes

Your notes



Stages in the development of cancer

Benign tumours

- Benign tumours are **not cancerous**
- These tumours **grow slowly**
- Benign tumours do not invade other tissues and **do not metastasise**, unlike malignant tumours

- These tumours **can cause damage** such as blockages or by exerting pressure on the organ it is growing in or those surrounding it
- When removed, benign tumours do not usually grow back
- The formation of benign tumours can be initiated by:
  - Inflammation or infection
  - Injury
  - Diet
  - Genetics
  - Toxins and radiation
- Examples of benign tumours are:
  - Polyps found in the nose, colon and ovaries
  - Non-cancerous brain tumours
  - Warts, caused by a viral infection


Your notes

Examiner Tip

Make sure that you are able to distinguish between tumours that do cause cancer (malignant) and those that don't (benign).

Pay attention to the differences in:

- rates of cell division and growth
- the capacity for metastasis and invasion of neighbouring tissue

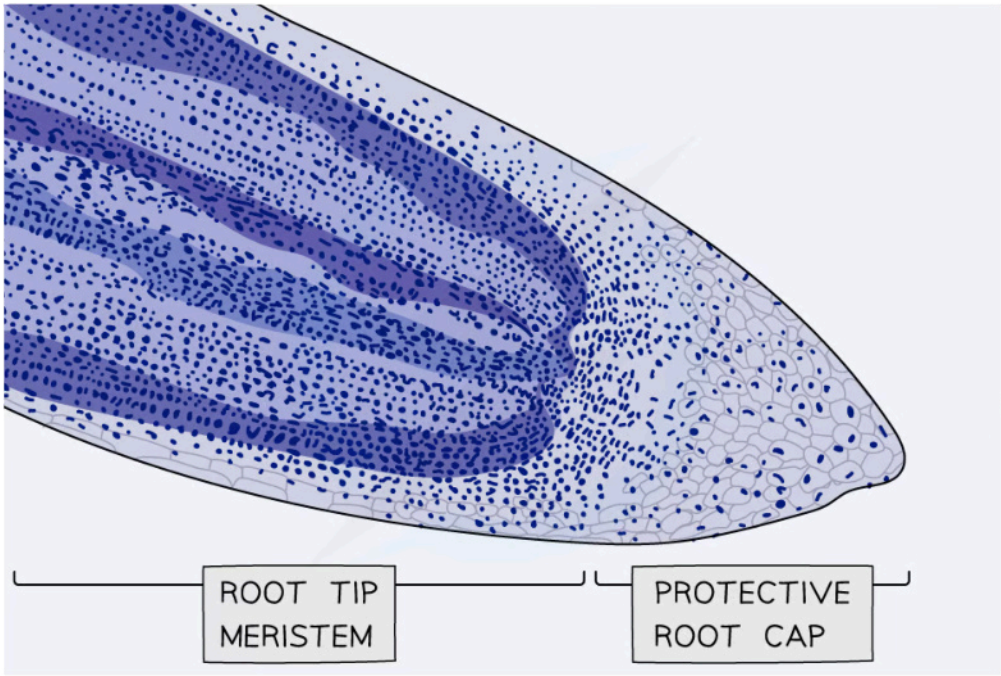
Mitotic Index: Skills (HL)

Your notes

Determining Mitotic Index

Investigating mitosis in root tissue

- Growth in plants occurs in specific regions called **meristems**
- The root tip meristem can be used to study **mitosis**
- The root tip meristem can be found **just behind the protective root cap**
- In the root tip meristem, there is a **zone of cell division** that contains cells undergoing **mitosis**
- Pre-prepared slides of root tips can be studied or temporary slides can be prepared using the **squash technique** (root tips are **stained** and then **gently squashed**, spreading the cells out into a thin sheet and allowing individual cells undergoing mitosis to be clearly seen)



Micrograph showing a stained root tip

Analysis

- Cells undergoing mitosis (similar to those in the images below) can be seen and drawn
- Annotations can then be added to these drawings to show the **different stages of mitosis**
- The **mitotic index** can be calculated

The mitotic index

- The mitotic index is the **proportion** of cells (in a group of cells or a sample of tissue) that are **undergoing mitosis**
- The mitotic index can be calculated using the formula below:

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

- You can multiply the answer by **100** if you need to give the mitotic index as a **percentage**

Your notes

Worked example

A student who wanted to observe mitosis prepared a sample of cells. They counted a **total of 42** cells in their sample, **32 of which had visible chromosomes**. Calculate the mitotic index for this sample of cells (give your answer to 2 decimal places).

Answer:

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{32}{42}$$

Mitotic index = **0.76**

Your notes

Worked example

The table below shows the number of cells in different stages of the cell cycle in a sample from a garlic root tip. Calculate the mitotic index for this tissue (give your answer to 2 decimal places).

Stages of cell cycle	Number of cells
Interphase	36
Prophase	14
Metaphase	5
Anaphase	3
Telophase	6

Answer:

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{(\text{prophase} + \text{metaphase} + \text{anaphase} + \text{telophase})}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{(14 + 5 + 3 + 6)}{(36 + 14 + 5 + 3 + 6)}$$

$$\text{Mitotic index} = \frac{28}{64}$$

Mitotic index = **0.44**

Worked example

The micrograph below shows a sample of cells from an onion root tip. Calculate the mitotic index for this tissue (give your answer to 2 decimal places).

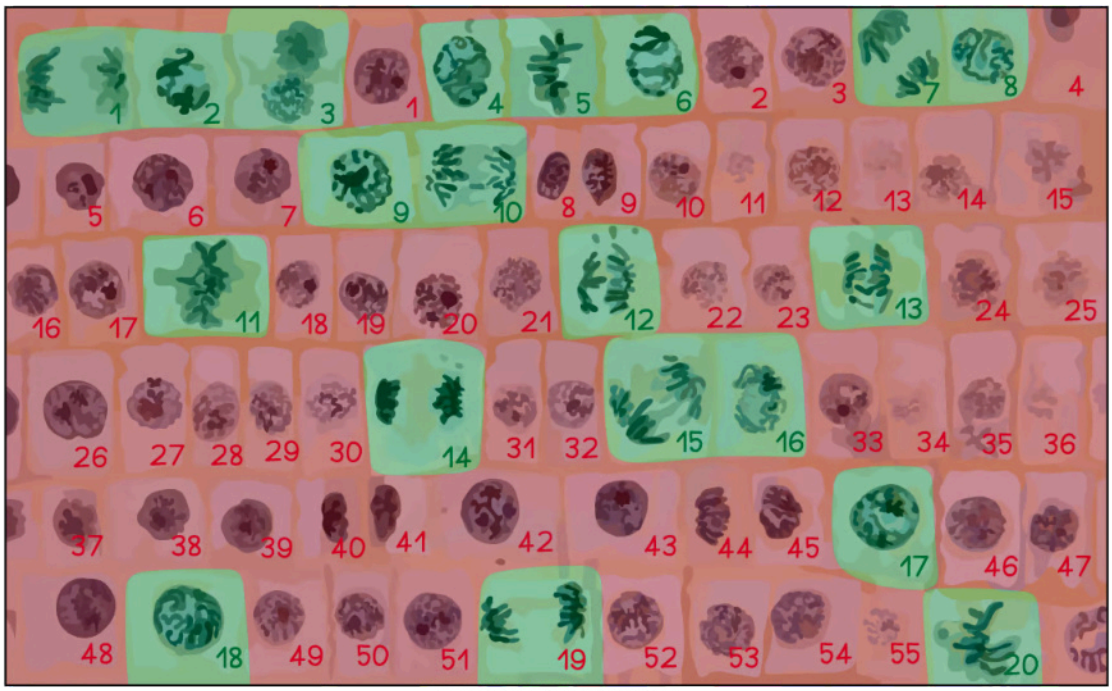
A sample of cells from an onion root tip

Answer:

Step 1: Identify the cells undergoing mitosis

Your notes

Your notes



Number of cells with visible chromosomes (green) = 20

Step 2: Count the total number of cells

Total number of cells (green + red) = 20 + 55 = 75

Step 3: Substitute numbers into the equation

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}}$$

$$\text{Mitotic index} = \frac{20}{75}$$

Mitotic index = **0.27**

Examiner Tip

You will need to remember the mitotic index formula as it will not be given to you.