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Cell & Nuclear Division



IB Biology - Revision Notes

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Cell Division

Formation of New Cells

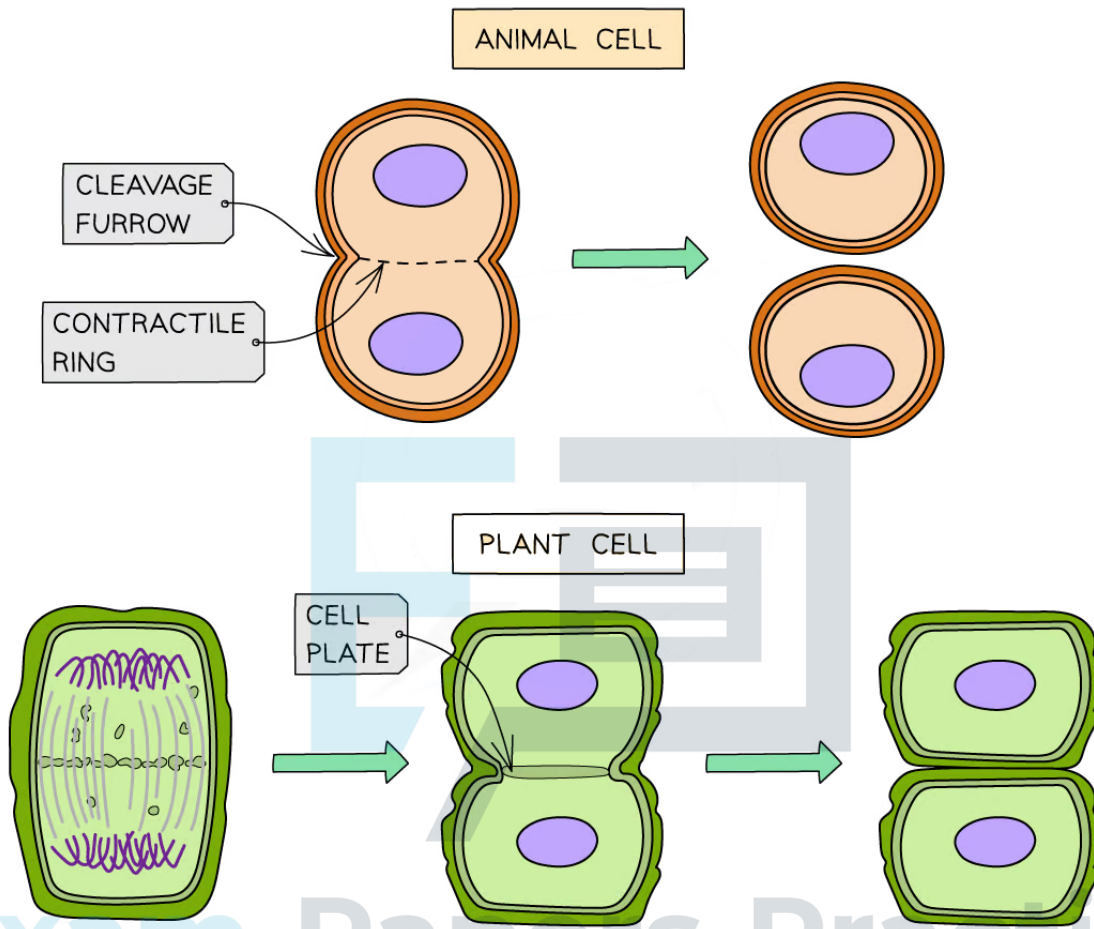
- According to the cell theory, new cells are produced from pre-existing ones
- The cells that make up a multicellular organism are the result of a single cell undergoing many cycles of **cell division**
 - This single cell will initially form embryonic stem cells which will **specialise** to form the 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

- 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**



Cytokinesis in an animal cell and a plant cell

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Exam Tip

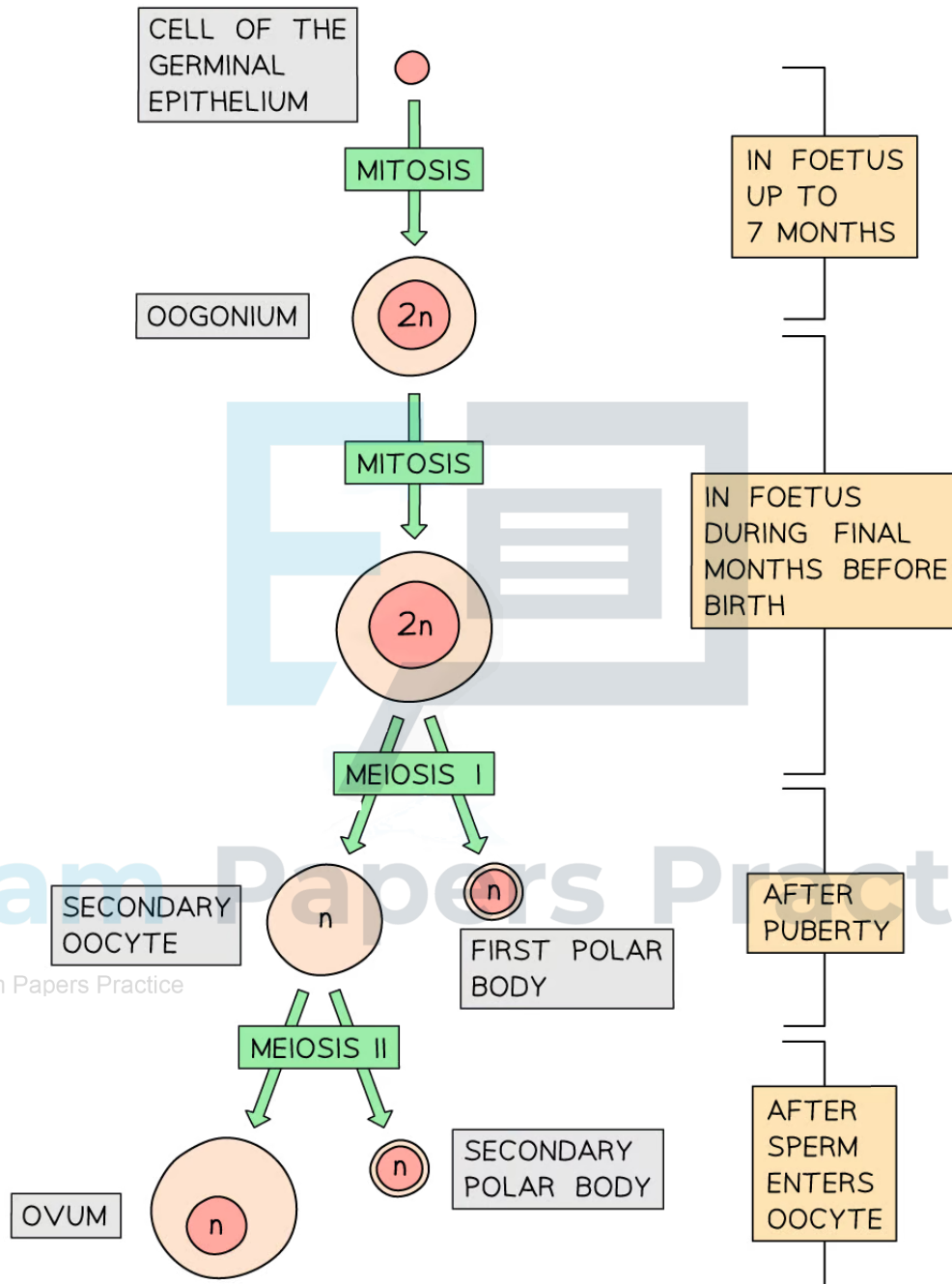
Remember that cytokinesis will only occur **after** nuclear division has happened.

Equal & Unequal Cytokinesis

- 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



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Oogenesis is an example of unequal cytokinesis

Nuclear Division

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**

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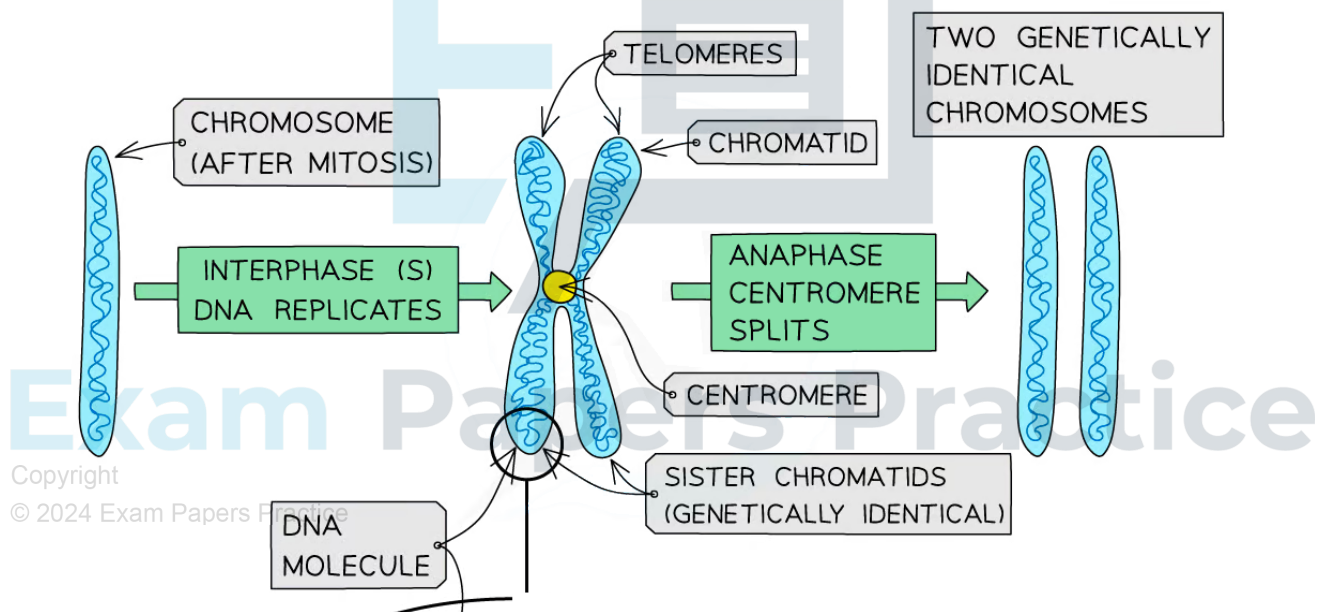
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DNA Replication in Nuclear Division

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



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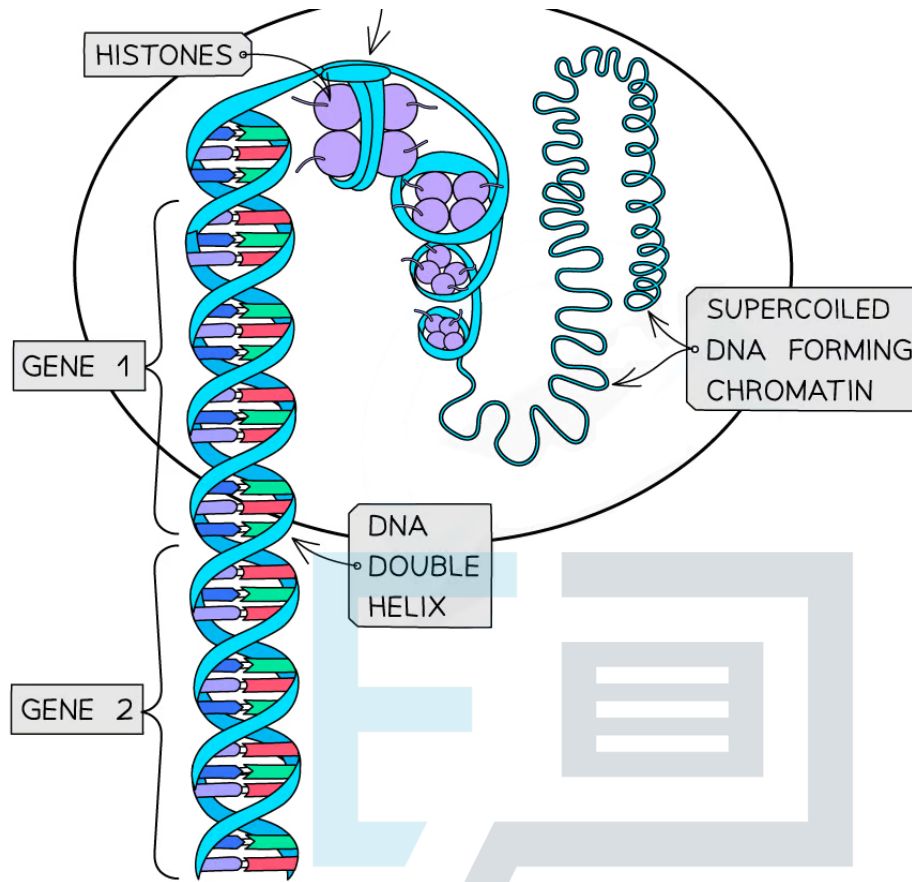


Diagram illustrating the structure of a chromosome at different stages of mitosis

Exam Tip

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

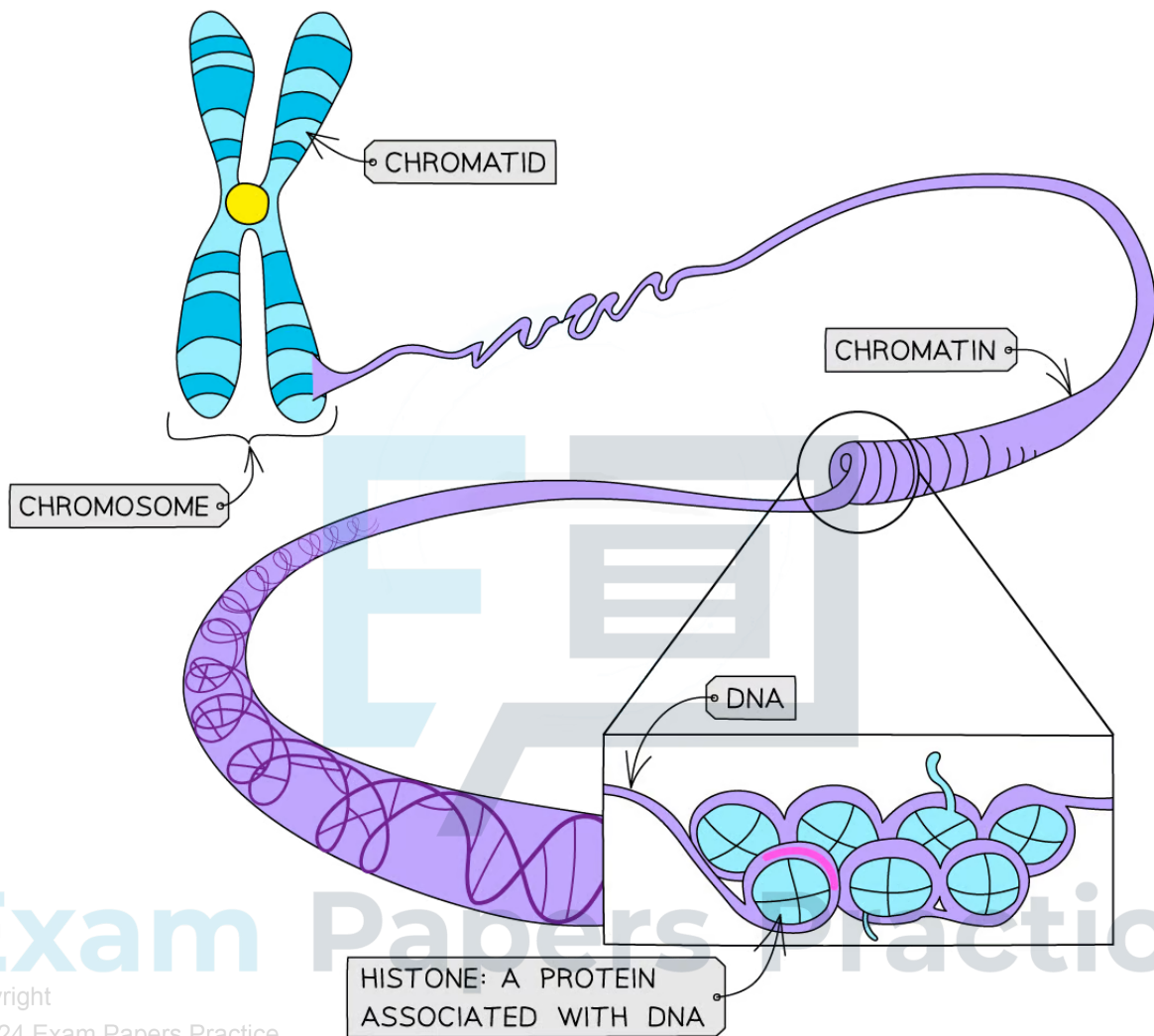
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Condensation & Movement of Chromosomes

Condensation of chromosomes

- 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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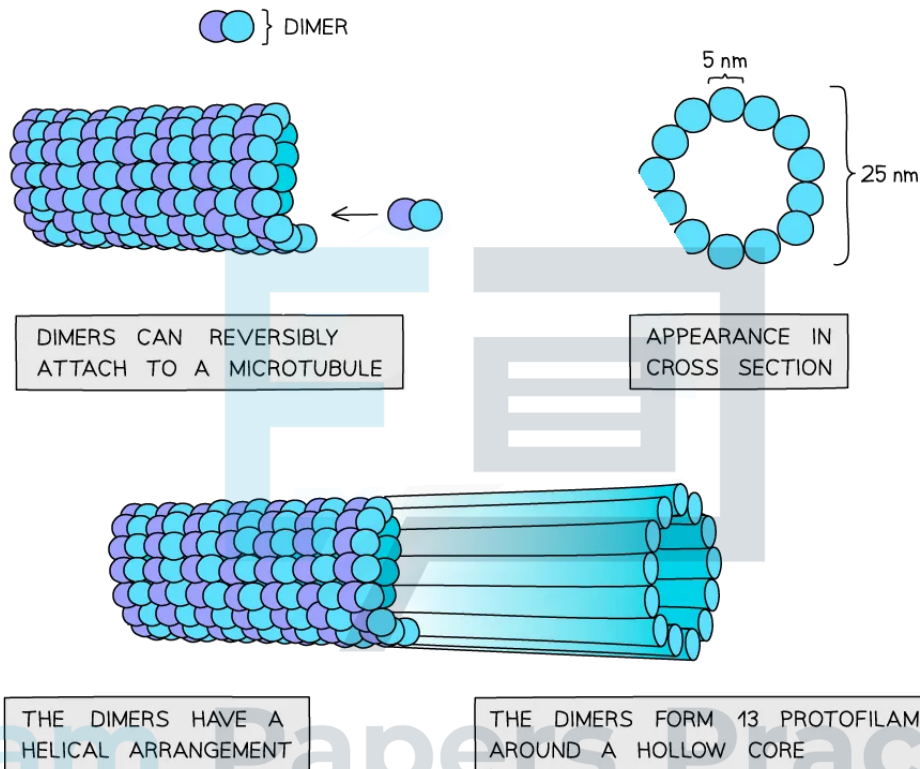
DNA is coiled around histone proteins to make chromatin

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

Microtubule formation diagram



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Microtubules are responsible for the movement of chromosomes during cell division

Mitosis

Phases of Mitosis

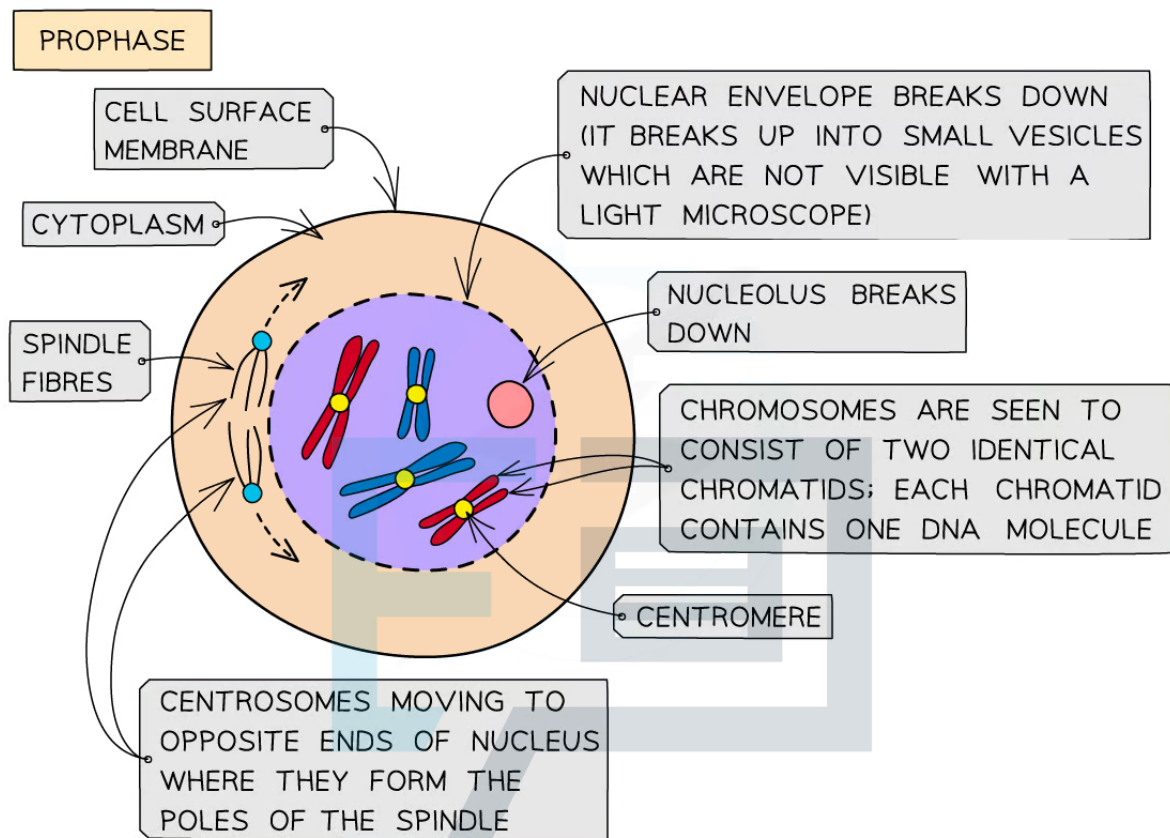
- Mitosis is the process of nuclear division by which **two genetically identical daughter nuclei** are produced that are also genetically identical to the parent cell nucleus (they have the same number of chromosomes as the parent cell)
- **Significance of mitosis:** mitosis occurs whenever the production 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



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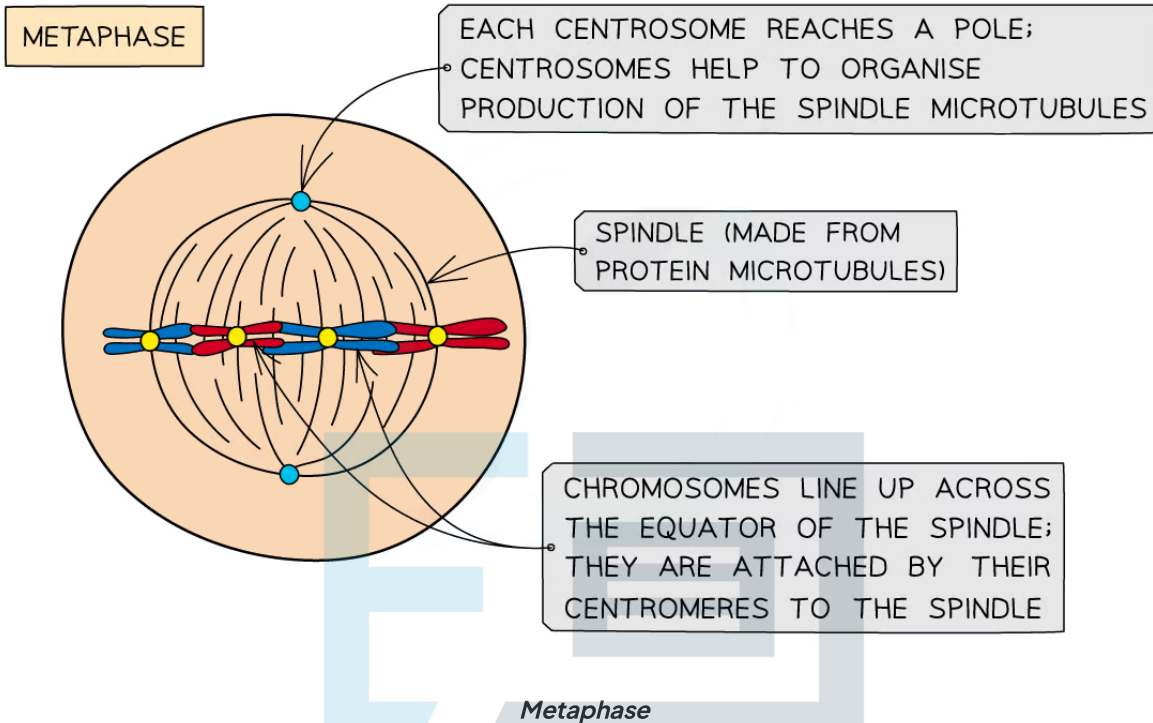
Prophase

Metaphase

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© 2024 **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**

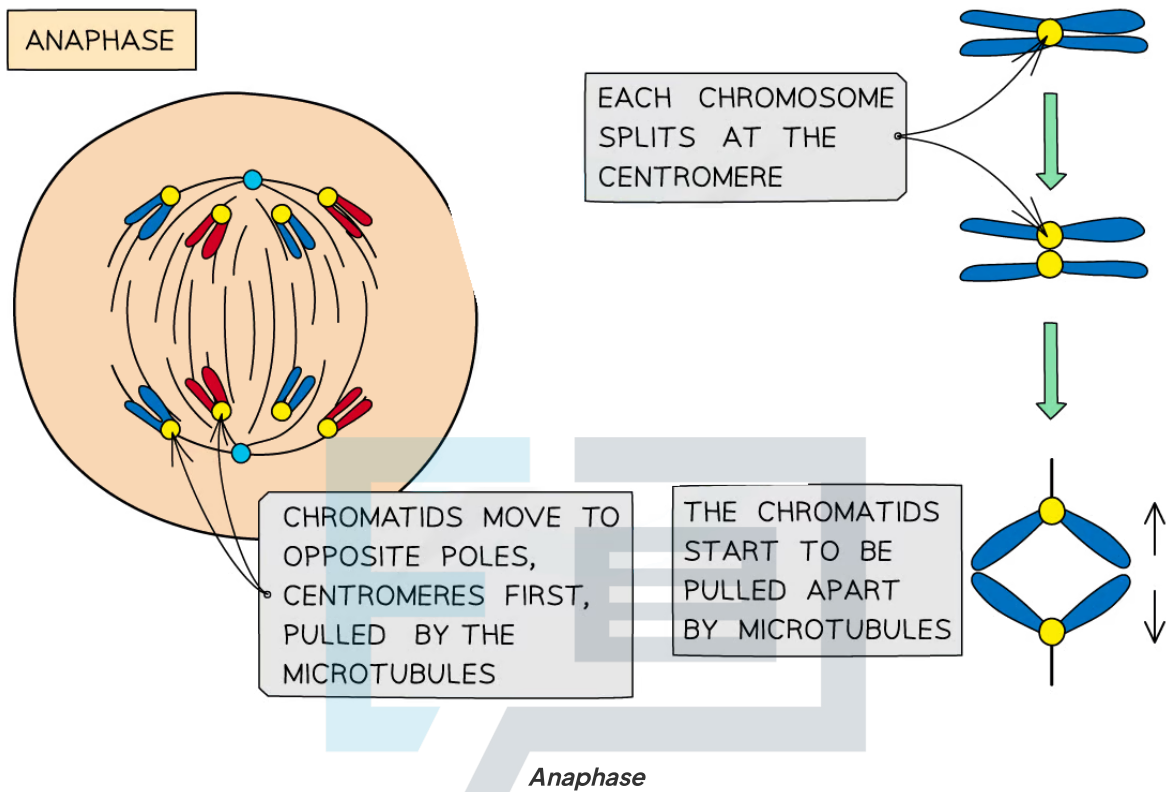


Anaphase

- 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)

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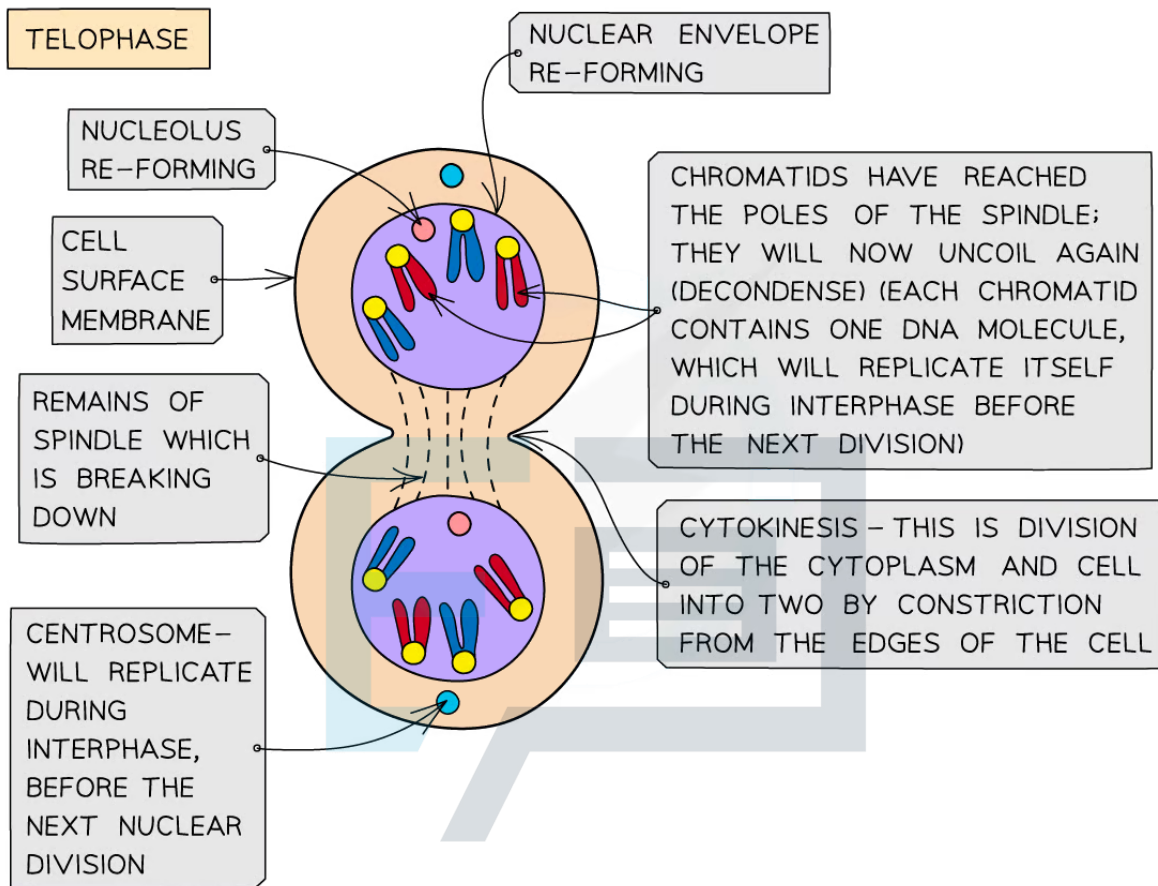
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Telophase

- 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**
- Copyright © New **nucleoli form** within each nucleus

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Telophase

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Exam 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!

Mitosis: Skills

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

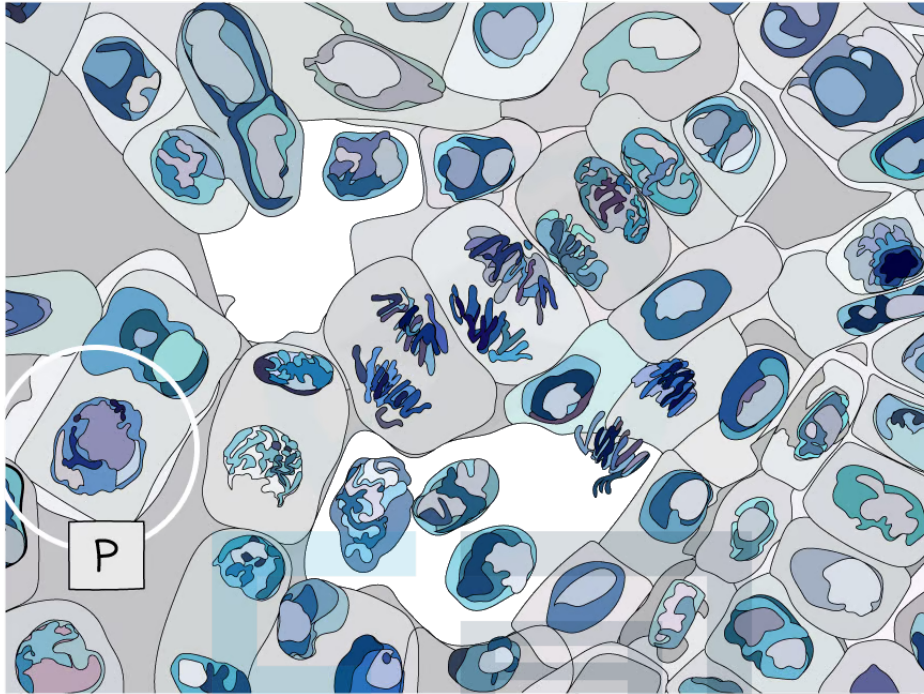
Cytokinesis

- 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

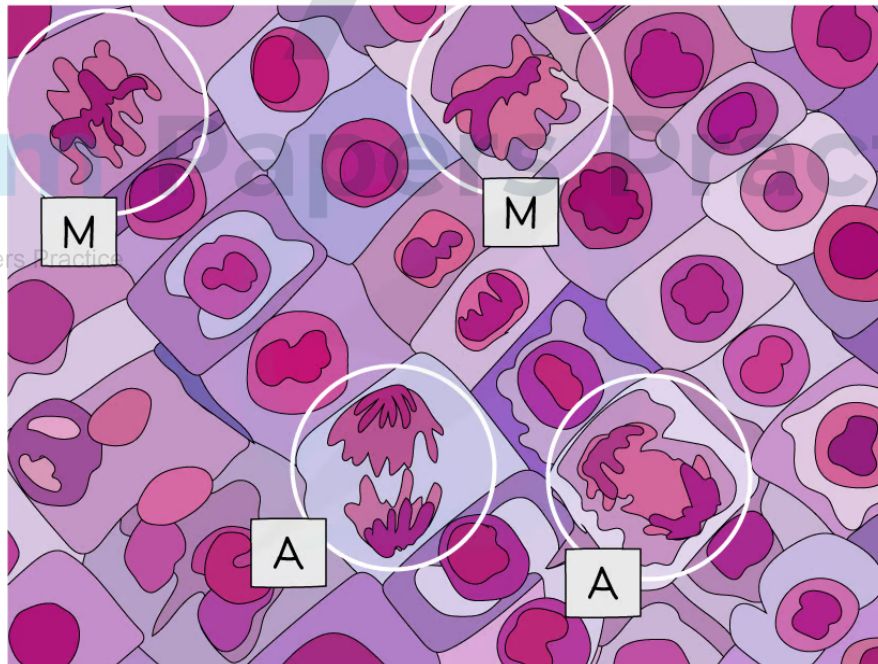
Identification of phases

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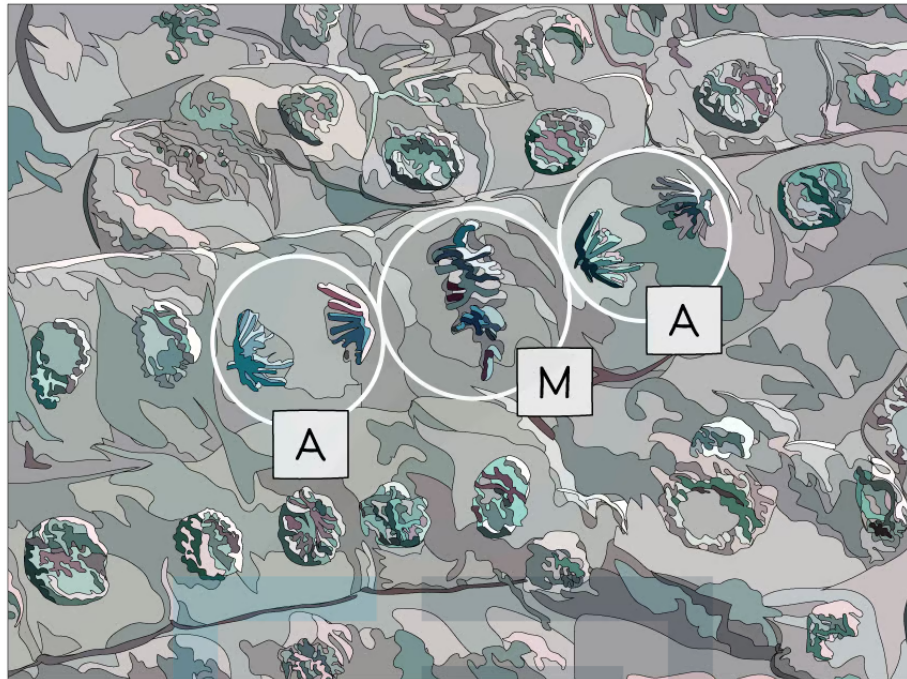
Micrograph showing a cell undergoing prophase (P)



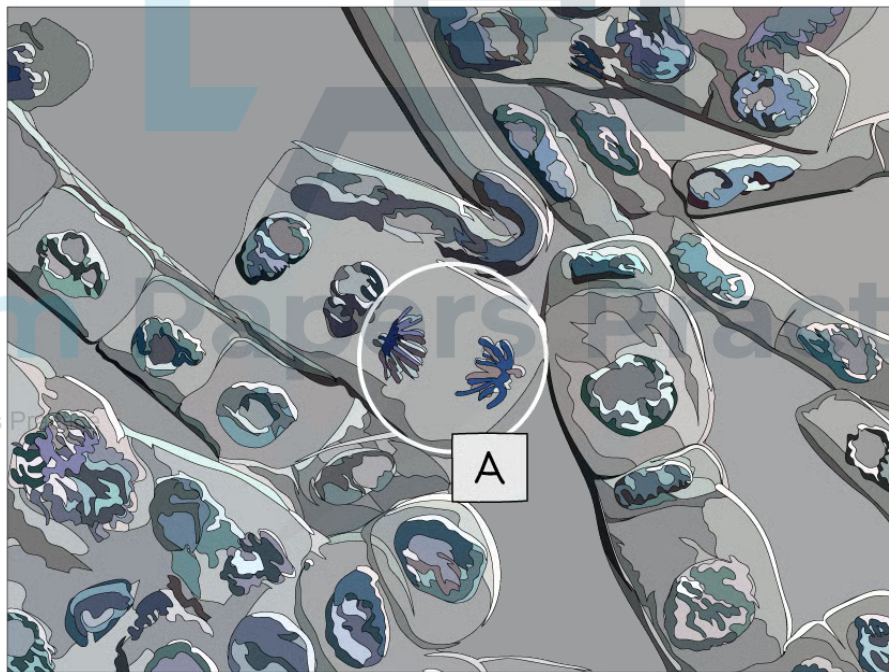
Micrograph showing cells undergoing metaphase (M) and anaphase (A)

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



Micrograph showing a cell undergoing anaphase (A)

Exam 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.

Meiosis

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**

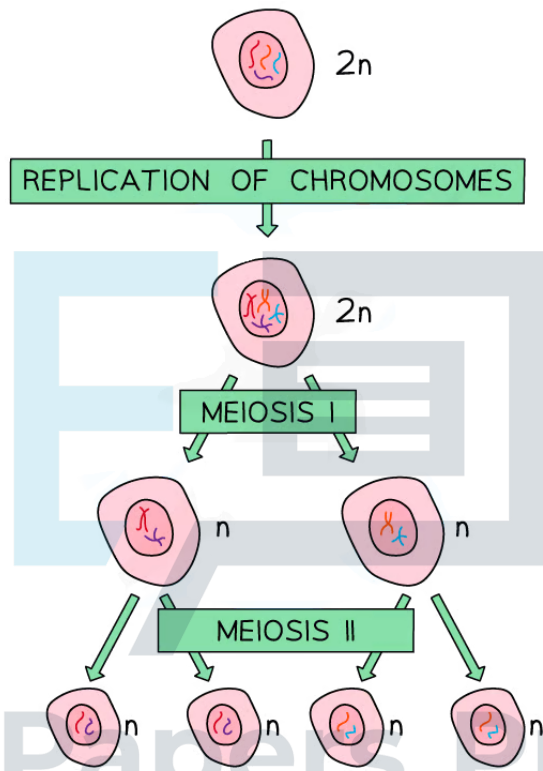
Meiosis I

- 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



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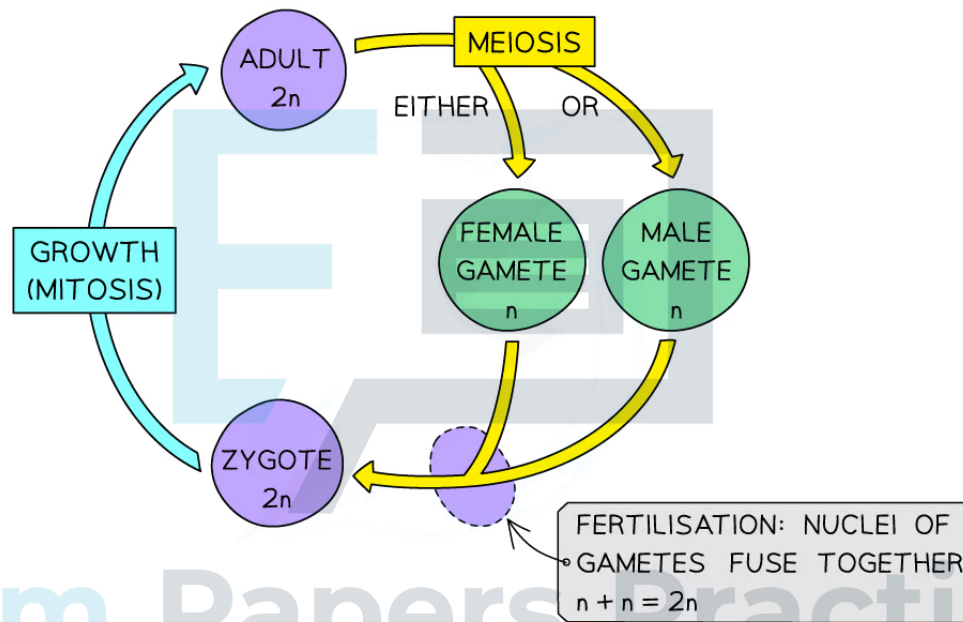
© 2024 Exam Papers | *One diploid nucleus divides by meiosis to produce four haploid nuclei*

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 life cycle overview diagram



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Sexual life cycle

Down Syndrome & Non-Disjunction

- **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

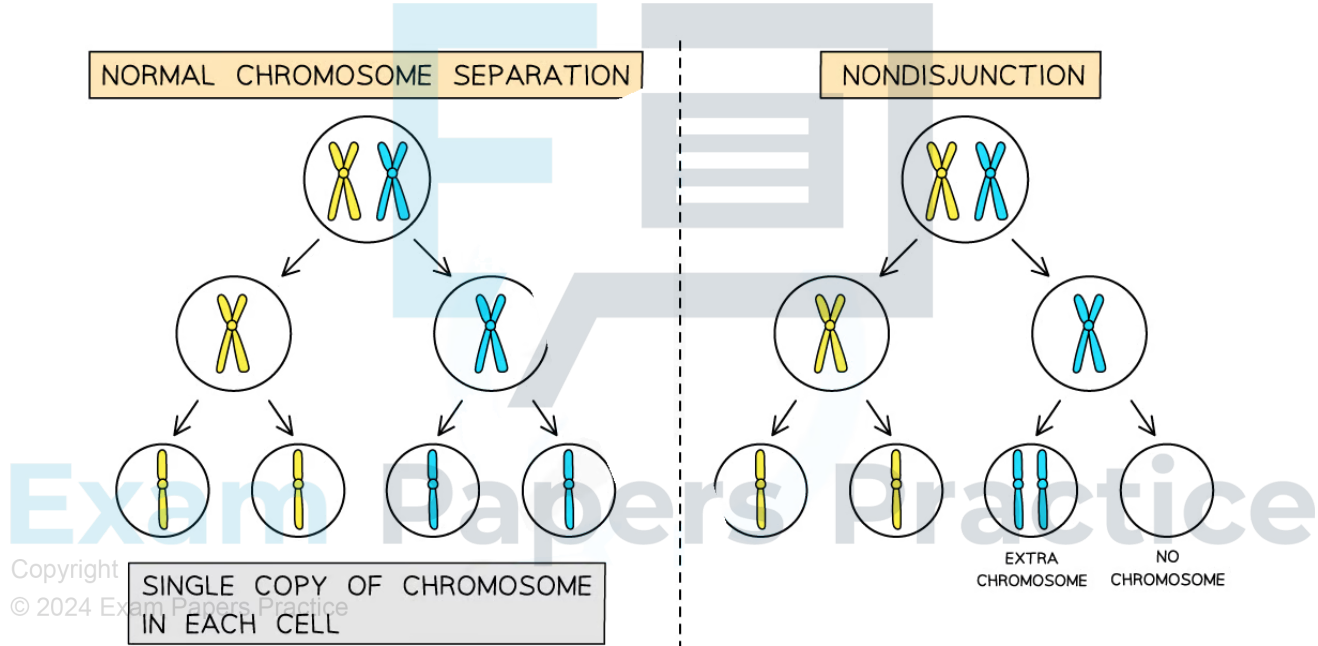


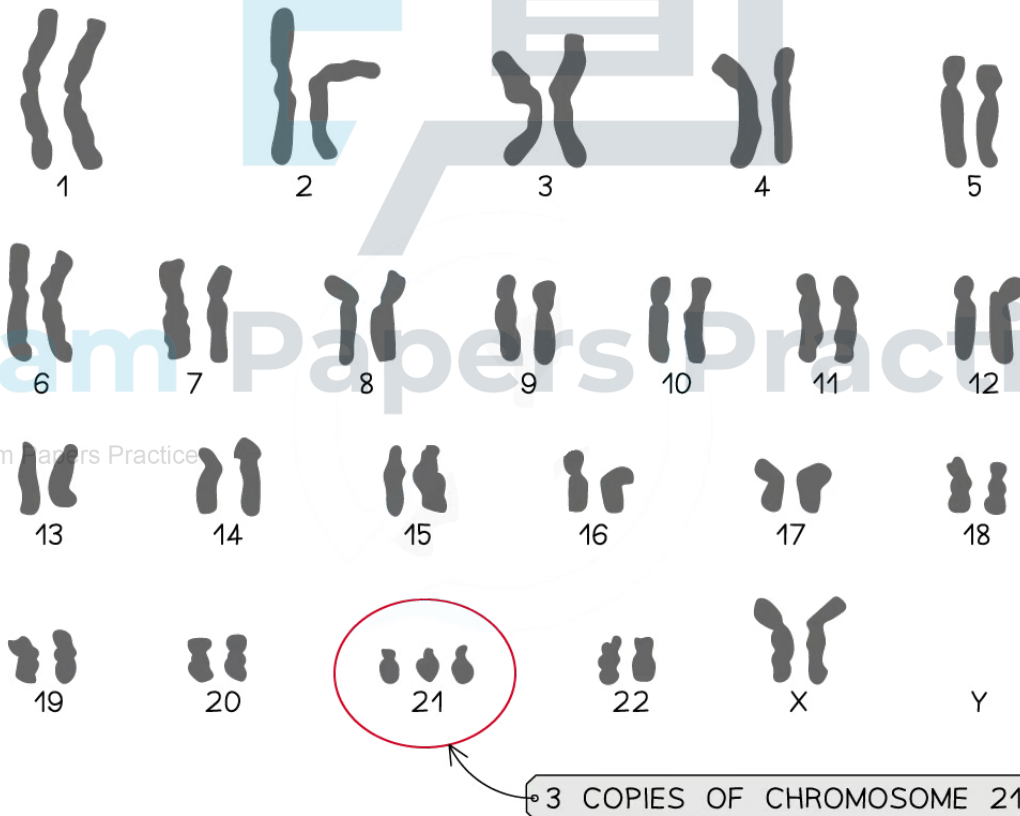
Image showing how chromosomes failing to separate properly during meiosis can result in gametes with the incorrect number of chromosomes

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 **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

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

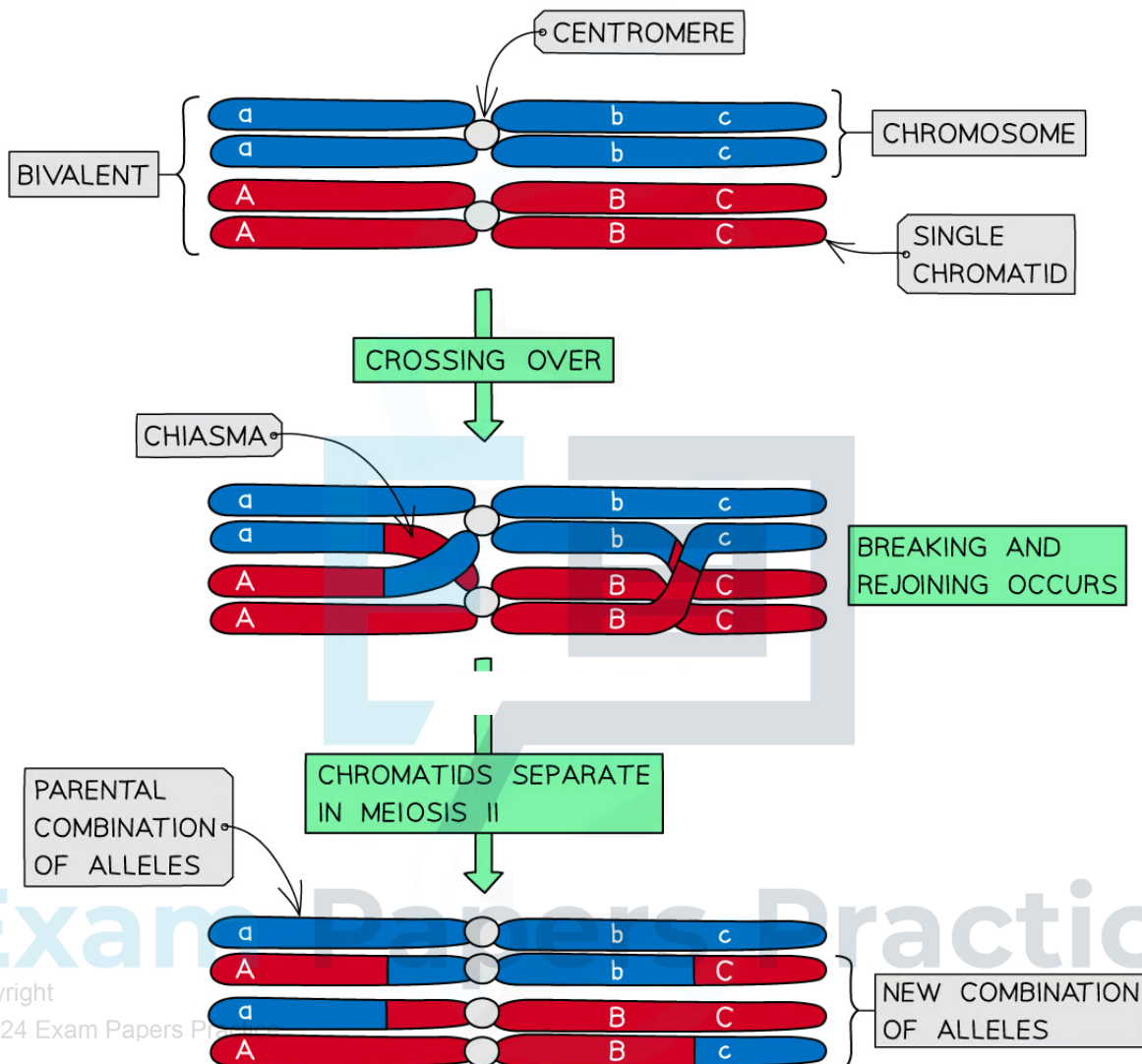
Crossing over

- 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

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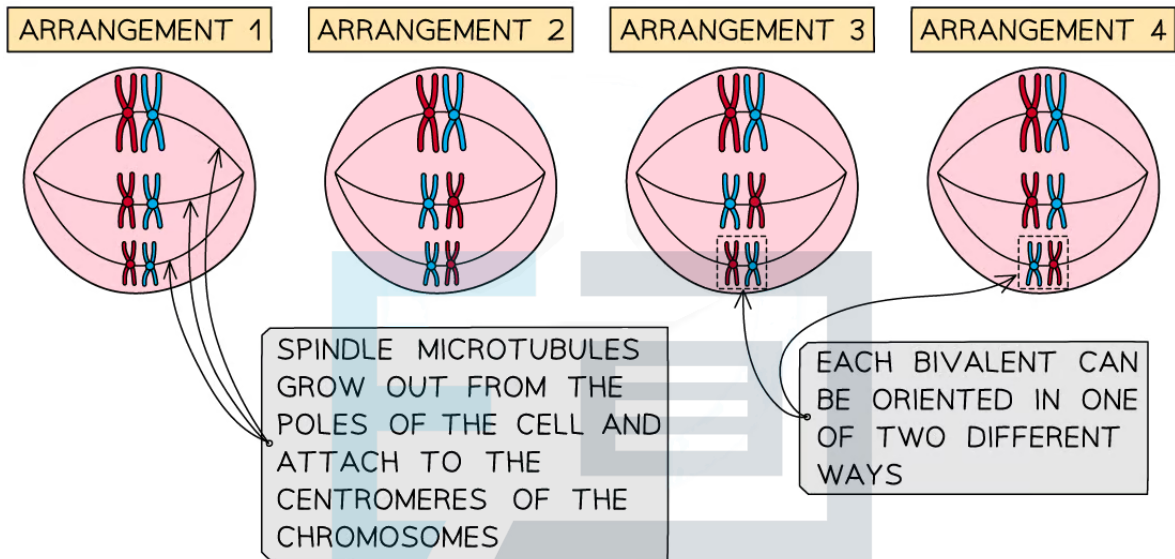
Crossing over of non-sister chromatids leading to the exchange of genetic material

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)

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 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

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