CELL DIVISION

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CELL CYCLE

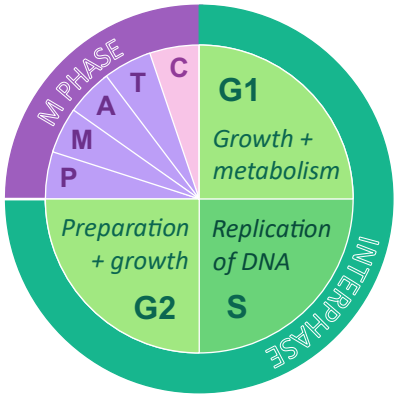
The cell cycle is an ordered set of events which results in the division of eukaryotic cells into identical daughter cells. It involves two key phases:

Interphase is an active phase of the cycle with many processes occurring in the nucleus and cytoplasm. It is a continuum of three distinct stages:

- **G1:** Cell grows and prepares for division (organelles are duplicated)
- **S:** A synthesis stage in which DNA replication occurs in the nucleus
- **G2:** Acts as a final growth and preparation stage prior to cell division

The **M phase** is the period of the cycle in which the cell and its contents are divided into two separate daughter cells. It involves two key stages:

- **Mitosis or Meiosis:** A process of nuclear division (DNA is separated)
- **Cytokinesis:** A process of cytoplasmic division (the cell splits in two)

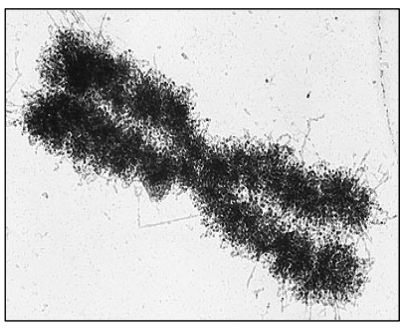


The cell cycle moves in a clockwise direction as per the diagram shown above

CHROMOSOMES

Within eukaryotic cells, the DNA is organised into discrete units that are called **chromosomes**. Normally, these chromosomes are packaged in an uncondensed form called **chromatin** to allow for the cellular machinery to access the genetic instructions that determine cell activity. However, when a cell divides, the DNA supercoils and the chromatin condenses to form discrete chromosomes that will be visible under a light microscope (after division, chromosomes decondense and reform into chromatin).

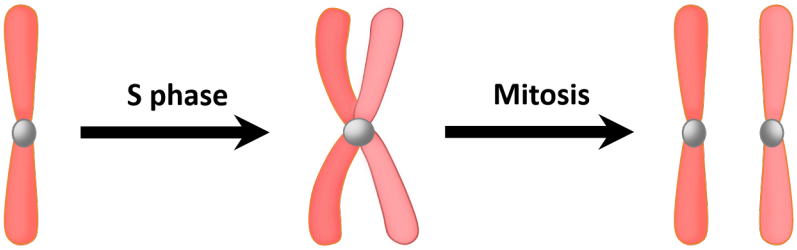
Prokaryotic cells only have a single circular chromosome and will not undergo the events of the cell cycle (bacteria divide by binary fission).



Eukaryotic Chromosome

SISTER CHROMATIDS

When DNA is replicated during the S phase, chromosomes will temporarily consist of two identical DNA molecules. These strands are called **sister chromatids** and are held together at a site called a **centromere**. A protein complex (called a **kinetochore**) attaches to the centromere and connects to microtubule spindle fibres. Motor proteins (*dynein* and *kinesin*) control the lengthening and shortening of these **spindle fibres**, which causes the chromosomes to be moved around the cell and also allows the chromatids to separate. When chromatids separate during mitosis, they become two identical chromosomes (one for each cell).



DNA replication (S phase) produces chromosomes with sister chromatids

These will separate during mitosis into two genetically identical chromosomes

MITOSIS

Mitosis is the process of **nuclear division**, whereby the duplicated DNA molecules (i.e. sister chromatids) are arranged into two separate nuclei. Mitosis is preceded by interphase and involves four distinct stages:

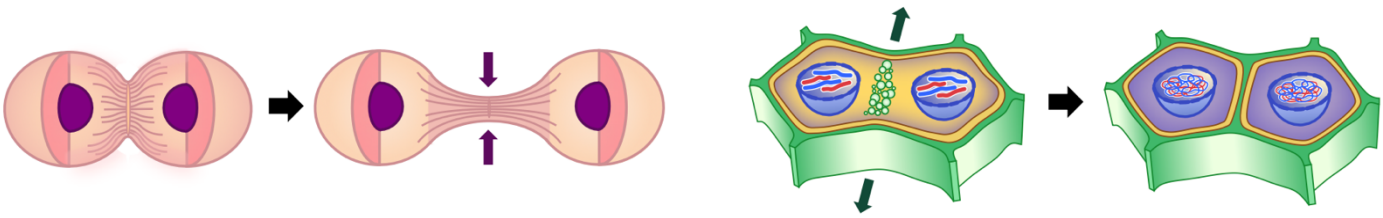
- **Prophase:** Chromosomes condense, nucleus dissolves and paired centrosomes move to opposite poles
- **Metaphase:** Centrosomes connect to centromeres via spindle fibres and move chromosomes to middle
- **Anaphase:** Spindle fibres contract and separate sister chromatids, moving them to the opposite poles
- **Telophase:** Chromosomes decondense and nuclei reform around the two separated chromosome sets

CYTOKINESIS

Mitosis only separates the duplicated DNA into separate nuclei. The division of the cell in two (cytokinesis) occurs concurrently with the final stage of mitosis (telophase). Cytokinesis differs in animal and plant cells:

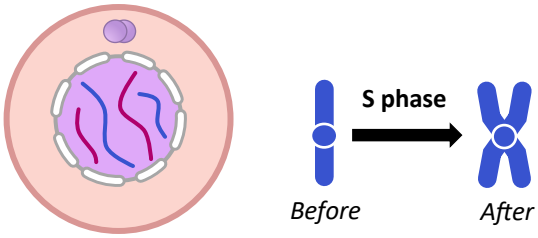
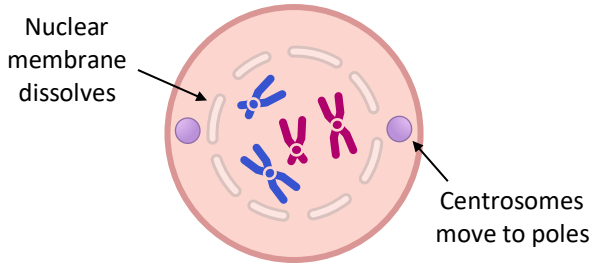
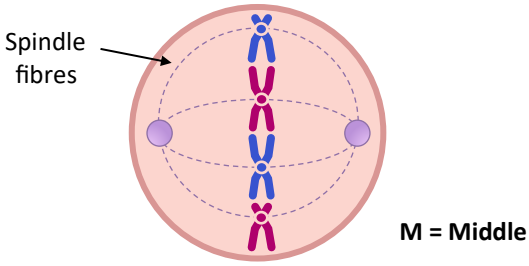
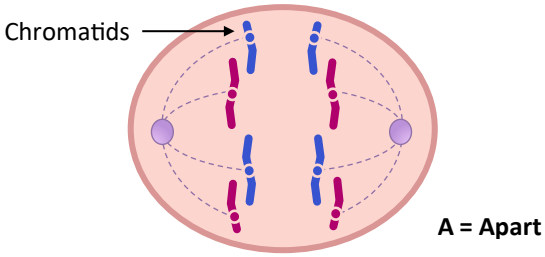
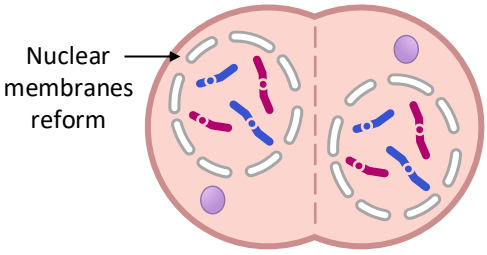
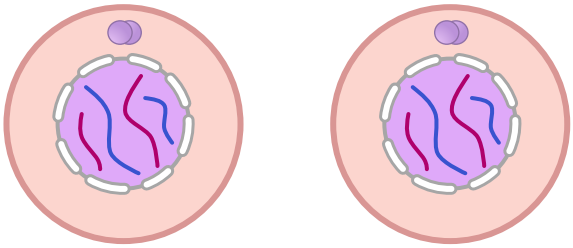
- **Animals:** Microtubule fibres form an outer contractile ring (cleavage furrow) – division is *centripetal*
- **Plants:** Vesicles form at the centre of the cell and fuse to form an end plate – division is *centrifugal*

The division of cytoplasm is usually equal, as both daughter cells must receive at least one mitochondrion and any other organelle that can only be made by dividing a pre-existing structure. However, sometimes cells will undergo **unequal cytokinesis**, such as is seen during oogenesis (egg production) and budding.



OVERVIEW OF MITOSIS

Mitosis involves four phases (prophase, metaphase, anaphase, telophase) and is preceded by interphase.

Stage	Diagram	Key Events
Interphase (2n)		• DNA is uncondensed (chromatin) • DNA is replicated (S phase) to form two identical sister chromatids • Cell grows in size and organelles duplicate (G_1 and G_2 phases)
Prophase (2n)		• DNA supercoils and condenses (forms visible chromosomes) • Nuclear membrane dissolves • Centrosomes move to poles and begin to produce spindle fibres
Metaphase (2n)		• Kinetochores connect centromeres to the microtubule spindle fibres • Spindle fibres contract (shorten) • Chromosomes move to form a line along the middle of the cell
Anaphase (2n → 4n)		• Spindle fibres continue to contract • Sister chromatids separate and move to opposite sides of the cell • Sister chromatids are now regarded as two separate chromosomes
Telophase (4n)		• Chromosomes decondense (DNA reforms into chromatin) • Nuclear membranes form around the two identical chromosome sets • Cytokinesis occurs concurrently
Cytokinesis (2 × 2n)		• Cytoplasmic division occurs and divides the one cell into two cells • Each daughter cell contains one of the identical sister chromatids • The two daughter cells are clones

MEIOSIS

Meiosis is the process by which haploid sex cells (gametes) are made in the reproductive organs. It involves the separation of homologous pairs in a **reduction division**, which reduces the chromosome number within the cell by half. When two gametes are fused together to reconstitute the original chromosome number, the resulting diploid cell will be genetically distinct. Hence, meiosis is used to promote genetic diversity.

MEIOSIS VERSUS MITOSIS

Meiosis follows a similar process to mitosis: it is preceded by interphase, separates the chromosomes in sequential stages (prophase, metaphase, anaphase, telophase) and divides cells via cytokinesis. However, there are also several key differences between the two processes – resulting in their divergent functions.

	MEIOSIS	MITOSIS
Type of Cell Produced	Sex cells / gametes	Body cells
Number of Divisions	Two divisions (MI and MII)	One division
Number of Cells Formed	Four haploid cells	Two diploid cells
Outcome of Process	Cells are different (genetic variation)	Cells are identical (cloning)
Purpose of Process	Sexual reproduction (more biodiversity)	Growth and repair of tissues

HOMOLOGOUS CHROMOSOMES

Sexually reproducing organisms receive genetic information from both parents and so have two copies of every chromosome – a maternal copy and a paternal copy. The chromosome pairs are called homologous chromosomes and the cell is described as **diploid** (two chromosome sets). Meiosis functions to separate the homologous pairs to form sex cells that are **haploid** (one chromosome set). Via sexual reproduction, the male and female gametes can then be fused (fertilisation) to form a new, distinct diploid cell (zygote). Homologous chromosomes will have the same genes, but may have different versions of the gene (alleles).

MEIOTIC DIVISIONS

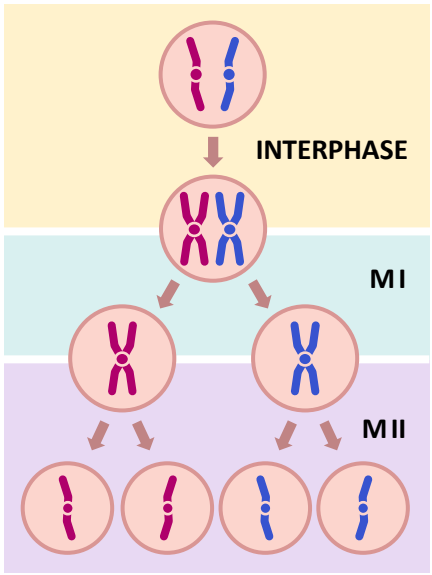
Meiosis consists of two cellular divisions which function to separate a germline cell (diploid) into four genetically distinct sex cells (haploid).

Because meiosis is preceded by interphase, all of the chromosomes will consist of two sister chromatids (formed via replication of DNA).

In the first meiotic division, homologous chromosomes will pair up via connection points called **chiasmata** to become single units (**bivalents**).

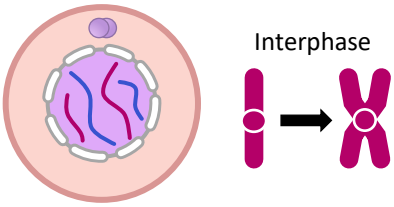
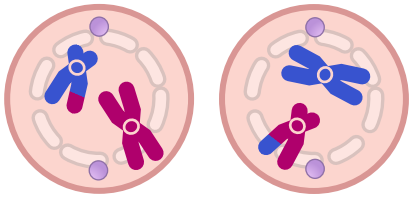
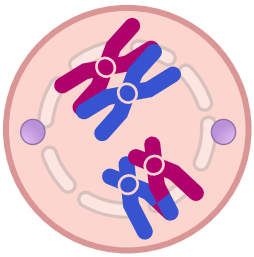
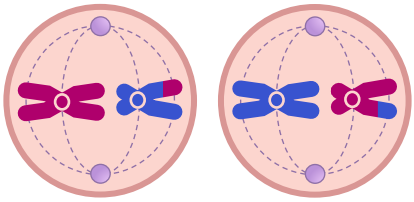
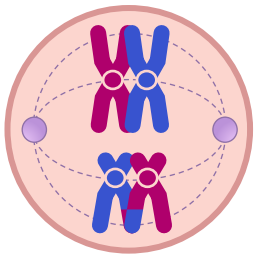
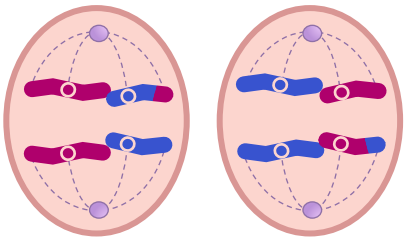
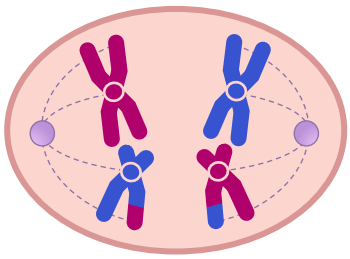
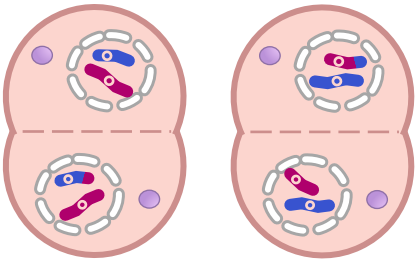
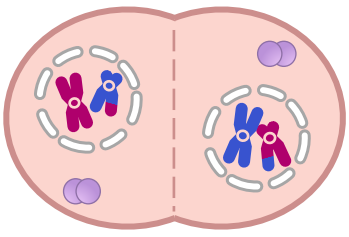
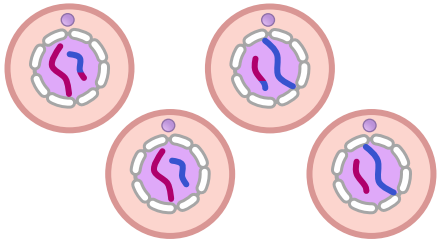
These bivalents are then separated in a reduction division that halves the chromosome number in the daughter cells (i.e. diploid → haploid).

The second meiotic division separates the two sister chromatids that were formed via replication of DNA during the S phase (interphase).



OVERVIEW OF MEIOSIS

Mitosis consists of two divisions, each involving four phases (prophase, metaphase, anaphase, telophase).

Stage	Diagram	Diagram	Stage
Before (1 × 2n)			**Prophase II** (n) × 2
Prophase I (2n)			**Metaphase II** (n) × 2
Metaphase I (2n)			**Anaphase II** (n ⟶ 2n) × 2
Anaphase I (2n)			**Cytokinesis** (2n ⟶ n) × 4 **Telophase II** (2n) × 2
Telophase I (2n) **Cytokinesis** (2n ⟶ n) × 2			**After** (4 × n)

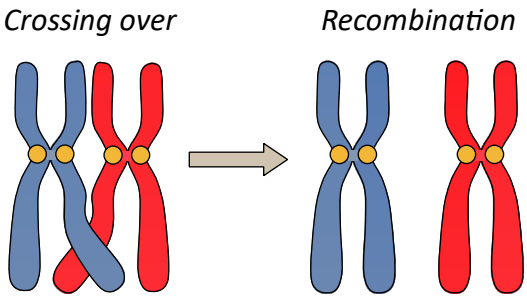
MEIOSIS I SUMMARY	MEIOSIS II SUMMARY
• Is a reduction division (diploid ⟶ haploid) • Separates the homologous chromosomes • Crossing over may occur during Prophase I to create genetically distinct sister chromatids	• Akin to a mitotic division (but of haploid cells) • Separates the sister chromatids • Occurs because DNA is replicated in interphase to create chromosomes with sister chromatids

GENETIC VARIATION

Sexual reproduction promotes variation in populations by creating new gene combinations in offspring. Progeny inherit genetic characteristics from both parents and the 'shuffling' of these characteristics via sexual reproduction may result in new phenotypic variants. This recombination of traits occurs via meiosis and involves two distinct processes: crossing over (in prophase I) and random assortment (in metaphase I). Also, fusion of male and female gametes is random, meaning the same parents have distinctive offspring.

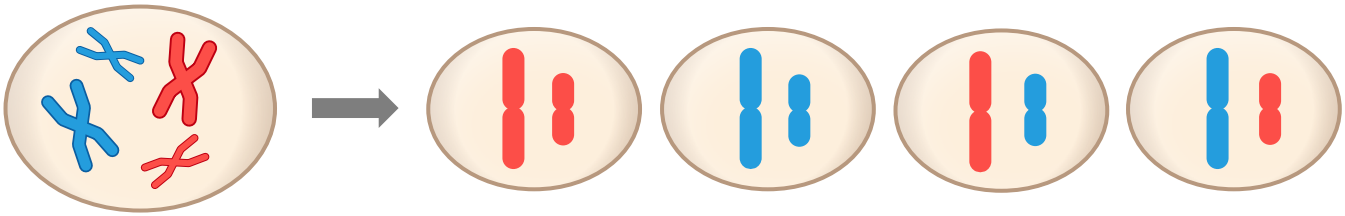
CROSSING OVER

Crossing over involves the exchange of segments of DNA between homologous chromosomes during prophase I of meiosis. This exchange of genetic material occurs at points called **chiasmata**. As a consequence of this recombination, all four chromatids of the homologous chromosomes will be genetically distinct, leading to new phenotypic variants.



RANDOM ASSORTMENT

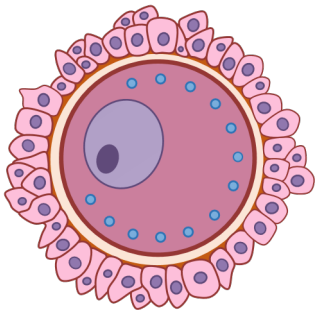
During metaphase I, the homologous chromosomes line up at the equator in a random orientation. The orientation of each homologous pair occurs independently of all other chromosome pairs, meaning that different combinations of maternal and paternal chromosomes will be formed within gametes. As humans have 23 pairs of chromosomes, each person can produce 2^{23} (over 8 million) distinct gamete combinations.



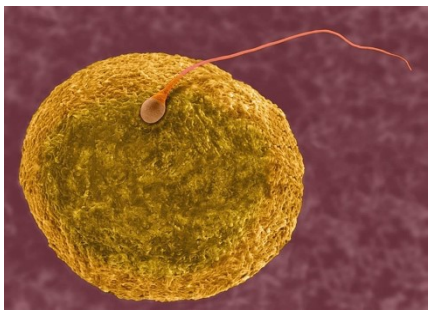
Parent Cell | Potential Gamete Combinations

RANDOM FERTILISATION

Following meiosis, the haploid daughter cells undergo a process called gametogenesis to differentiate into functional sex cells. Males form **spermatozoa** (via spermatogenesis), whereas females will form egg cells or **ova** (via oogenesis). Fertilisation is a random process (specific egg and sperm fusion is different each time), which means that all siblings should be genetically distinct from each other. Identical twins will only result if the diploid zygote is split into two separate cell masses *after* fertilisation has occurred.



Ovum (female egg) + Spermatozoa (male) =

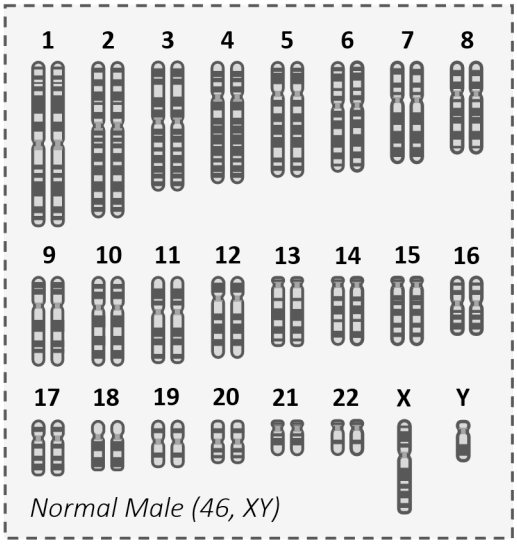


Fertilisation (micrograph)

KARYOGRAMS

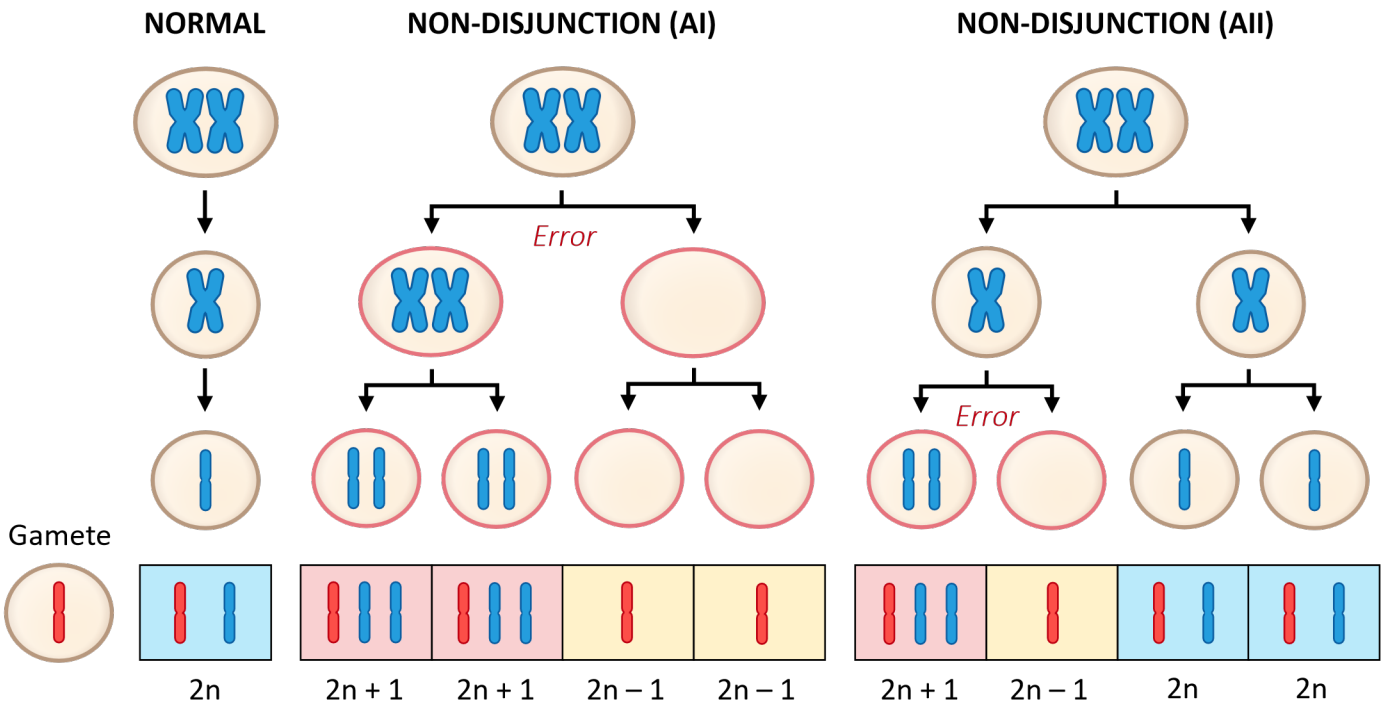
The chromosomal profile of an individual can be represented by a picture called a karyogram. In karyograms, the chromosomes are organised in homologous pairs according to descending size (with the sex chromosomes shown last). Humans normally have 46 chromosomes (22 autosome pairs and the sex chromosomes). Karyograms are prepared by a process called **karyotyping**, which involves inducing cell division with drugs (chromosomes become visible during prophase). Karyotyping typically occurs pre-natally using cells derived from the placenta (chorionic villi) or amniotic fluid. Karyotyping is typically employed for two main purposes:

- Determining sex of an unborn child (female = XX, male = XY)
- Identifying any chromosomal abnormalities (**aneuploidies**)



ANEUPLOIDY

Aneuploidy occurs when a single chromosome pair fails to separate, resulting in gametes that are not haploid for that particular chromosome. This failure to separate is called **non-disjunction** and occurs during anaphase (I or II) of meiosis. When the defective gamete is fertilised with a normal gamete, the resulting offspring will have either one missing chromosome (monosomy) or one additional chromosome (trisomy). Examples of aneuploidies in humans include Down's syndrome (trisomy 21), Klinefelter's syndrome (XXY) and Turner's syndrome (fragile X syndrome).



DOWN SYNDROME

A common condition that arises from a non-disjunction event is Down syndrome (individuals have three copies of chromosome 21). It is the most commonly occurring chromosomal abnormality, with an incidence of roughly 1 in every 1,000 live births. Individuals with Down syndrome nearly always have physical and intellectual disabilities, but their emotional and social awareness is very high. The risks of having a child with Down syndrome increases with maternal age (risk increases threefold when maternal age is >35).