

Cell and nuclear division

Revision notes • IB Biology D2.1: cytokinesis, mitosis and meiosis, non-disjunction and Down syndrome, sources of variation, and (HL) the cell cycle, cyclins and cancer.

For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

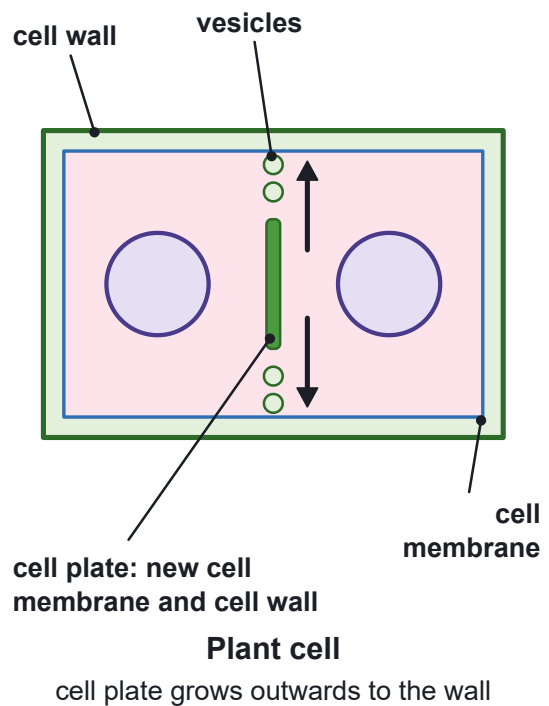
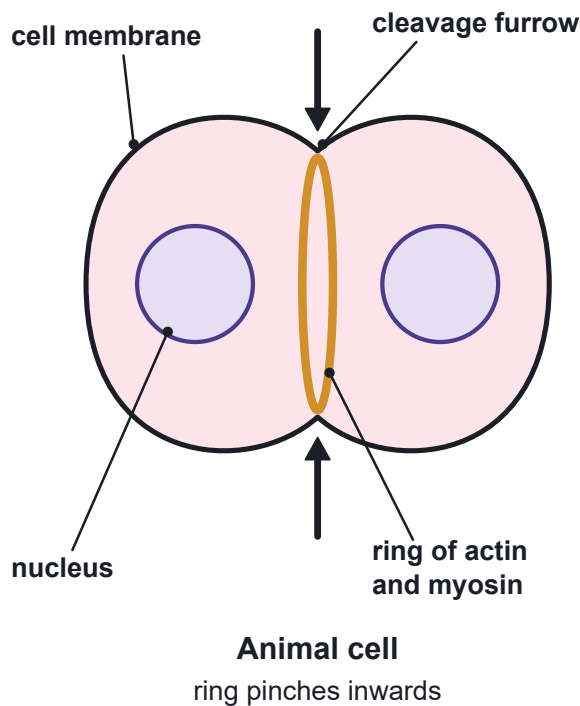
Cell and nuclear division Spec D2.1

Cell division and cytokinesis Spec D2.1.1, D2.1.2, D2.1.3

All new cells come from existing cells. In **cell division** a **parent cell** (often called a mother cell) divides to produce two **daughter cells**. This is how organisms grow, replace cells and, in unicellular organisms, reproduce.

In eukaryotes, cell division has two parts: the nucleus divides first (mitosis or meiosis), then the cytoplasm divides. **Cytokinesis** is the splitting of the cytoplasm of the parent cell between the daughter cells.

Cytokinesis in animal and plant cells		
Feature	Animal cell	Plant cell
What does the splitting	A ring of contractile actin and myosin proteins just inside the cell membrane at the equator	Vesicles that gather at the equator
How it happens	The ring contracts and pinches the cell membrane inwards (a cleavage furrow) until the cell is split in two	The vesicles fuse to form a cell plate, assembling sections of new cell membrane and cell wall that grow out to the existing wall
Direction	From the outside inwards	From the centre outwards



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Cytokinesis: in animal cells a **contractile ring of actin and myosin** pinches the membrane inwards; in plant cells vesicles fuse to build a **cell plate** from the centre outwards.

Equal and unequal cytokinesis

Division of the cytoplasm is **usually, but not always, equal**. Whatever the sizes, both daughter cells must receive at least one **mitochondrion**, and (in plant cells) plastids such as chloroplasts, plus any other organelle that can only be made by dividing a pre-existing one. A cell cannot build these from scratch.

- **Oogenesis in humans:** cytokinesis in both divisions of meiosis is unequal. Almost all the cytoplasm goes to the cell that becomes the ovum, which needs food reserves for the early embryo. The tiny cells produced, called **polar bodies**, degenerate.
- **Budding in yeast:** a small bud grows out of the parent yeast cell, receives a nucleus after mitosis, and then pinches off as a smaller daughter cell.

Common mistake: Cytokinesis is not part of mitosis. Mitosis is division of the nucleus; cytokinesis is division of the cytoplasm and usually begins in telophase.

Mitosis, meiosis and chromosome movement Spec D2.1.4, D2.1.5, D2.1.6

The nucleus must divide **before** the cell divides. Otherwise one daughter cell would have no nucleus (an **anucleate** cell), and it could not make new proteins or divide again. Eukaryotes use two types of nuclear division.

Roles of mitosis and meiosis in eukaryotes		
	Mitosis	Meiosis
Chromosome number	Maintained: daughter nuclei have the same number as the parent	Halved: diploid to haploid
Genome of daughter nuclei	Identical to each other and to the parent	Genetically different from each other and from the parent
Number of nuclei produced	Two	Four
Used for	Growth, cell replacement, tissue repair, asexual reproduction	Producing gametes (or spores) for sexual reproduction

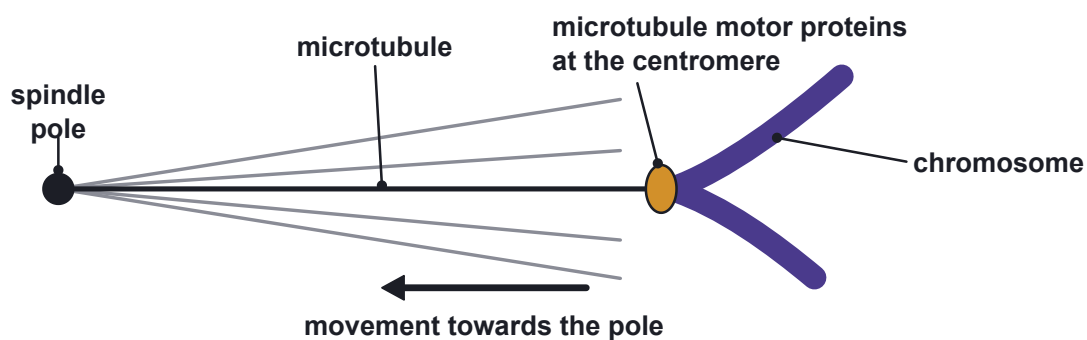
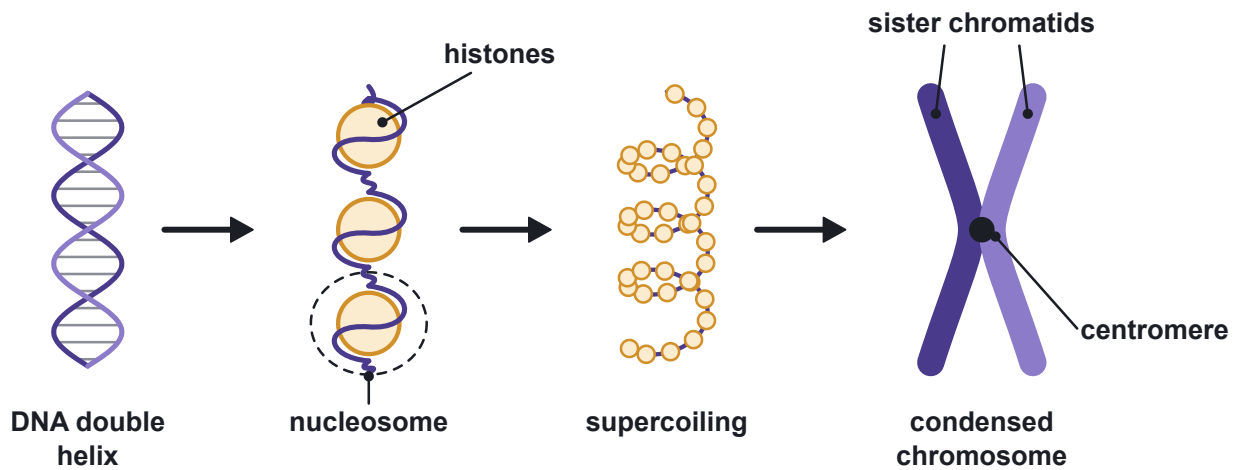
DNA replication comes first

DNA replication is a prerequisite for both mitosis and meiosis. It happens before division begins. After replication, each chromosome consists of **two elongated DNA molecules** called **sister chromatids**, which are genetically identical and held together at the centromere until **anaphase**.

Condensation and movement of chromosomes

Two features are shared by mitosis and meiosis. First, chromosomes **condense**. Each DNA molecule is wrapped around **histone** proteins to form nucleosomes, and the chain of nucleosomes is coiled again and again (**supercoiling**). This makes chromosomes short and thick, so they can be moved without tangling or breaking.

Second, chromosomes are **moved** by the spindle. The spindle is made of **microtubules** that attach to the centromere of each chromosome. **Microtubule motor proteins** at the attachment point, together with shortening of the microtubules, pull chromosomes or chromatids towards the poles.



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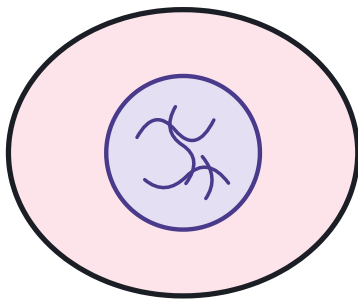
Chromosomes condense by wrapping DNA around **histones** (nucleosomes) and **supercoiling**; they are moved by **microtubules** and motor proteins attached at the centromere.

Exam tip: Do not draw or describe a replicated chromosome as two chromosomes. It is one chromosome made of two chromatids until the chromatids separate in anaphase.

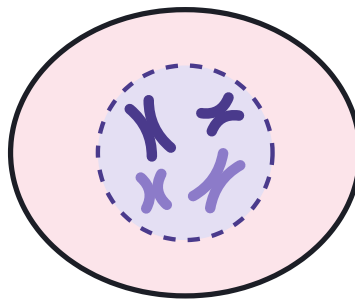
Phases of mitosis Spec D2.1.7, D2.1.8

1. **Prophase**: chromosomes condense and become visible, each as two sister chromatids. Spindle microtubules start to form, and the nuclear membrane breaks down at the end of prophase.
2. **Metaphase**: microtubules attach to the centromeres. Chromosomes are lined up in a single line on the **equator** of the cell.
3. **Anaphase**: the centromeres split, so the sister chromatids separate. Each chromatid is now a chromosome, and the two sets are pulled to **opposite poles**.
4. **Telophase**: chromosomes reach the poles and uncoil. A nuclear membrane forms around each set, giving two nuclei. Cytokinesis usually starts.

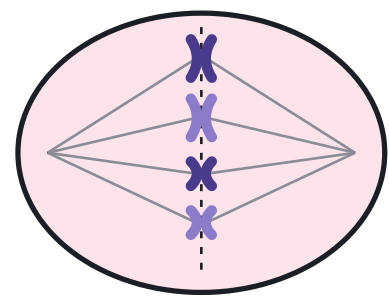
The process as a whole gives two **genetically identical** daughter nuclei. DNA replication made an exact copy of every chromosome, and anaphase sends one chromatid of every chromosome to each pole, so each nucleus receives a complete, identical set.



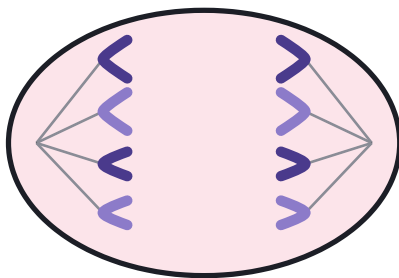
1 Interphase
cell grows; DNA replicated



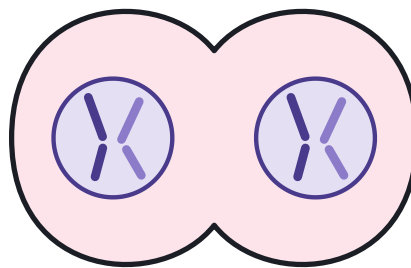
2 Prophase
chromosomes visible;
nuclear membrane breaks down



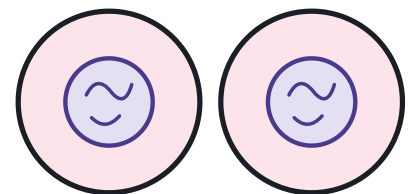
3 Metaphase
chromosomes line up on the
equator; microtubules attach
to the centromeres



4 Anaphase
sister chromatids pulled
to opposite poles



5 Telophase
new nuclear membranes form:
two nuclei



6 Cytokinesis
cytoplasm and cell membrane
divide: two daughter cells

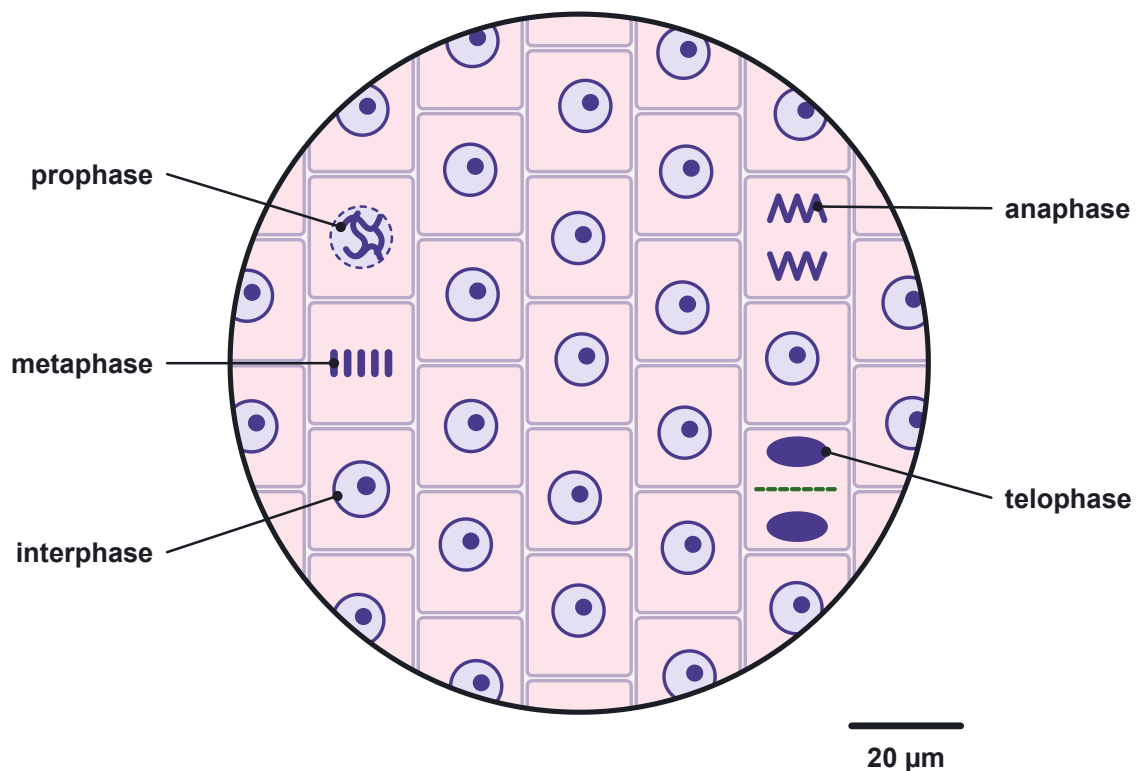
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Interphase, the four phases of mitosis ([prophase](#), [metaphase](#), [anaphase](#), [telophase](#)), then cytokinesis.

Identifying the phases

What to look for in a diagram or micrograph	
Phase	Key features you can see
Interphase	Intact nucleus, often with a nucleolus; chromosomes not visible as separate threads
Prophase	Chromosomes visible as thick threads inside the nuclear area; no metaphase plate yet
Metaphase	Chromosomes in a line across the middle of the cell; no nuclear membrane
Anaphase	Two groups of V-shaped chromosomes moving apart towards opposite poles
Telophase	Two compact groups of chromosomes at the poles; nuclear membranes re-forming; a cell plate or furrow may be visible

Practical skill: Root tip squashes (for example onion or garlic) show many dividing cells. The tip is softened in warm dilute hydrochloric acid, stained (for example with toluidine blue or acetic orcein) and squashed under a cover slip so cells form a single layer for viewing with a light microscope.



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A root tip squash: most cells are in **interphase**; the dividing cells can be identified by the arrangement of their chromosomes.

Exam tip: In anaphase, chromatids move with the centromere first, so the arms trail behind in a V shape. That V shape is the quickest way to spot anaphase in a micrograph.

Meiosis, non-disjunction and variation Spec D2.1.9, D2.1.10, D2.1.11

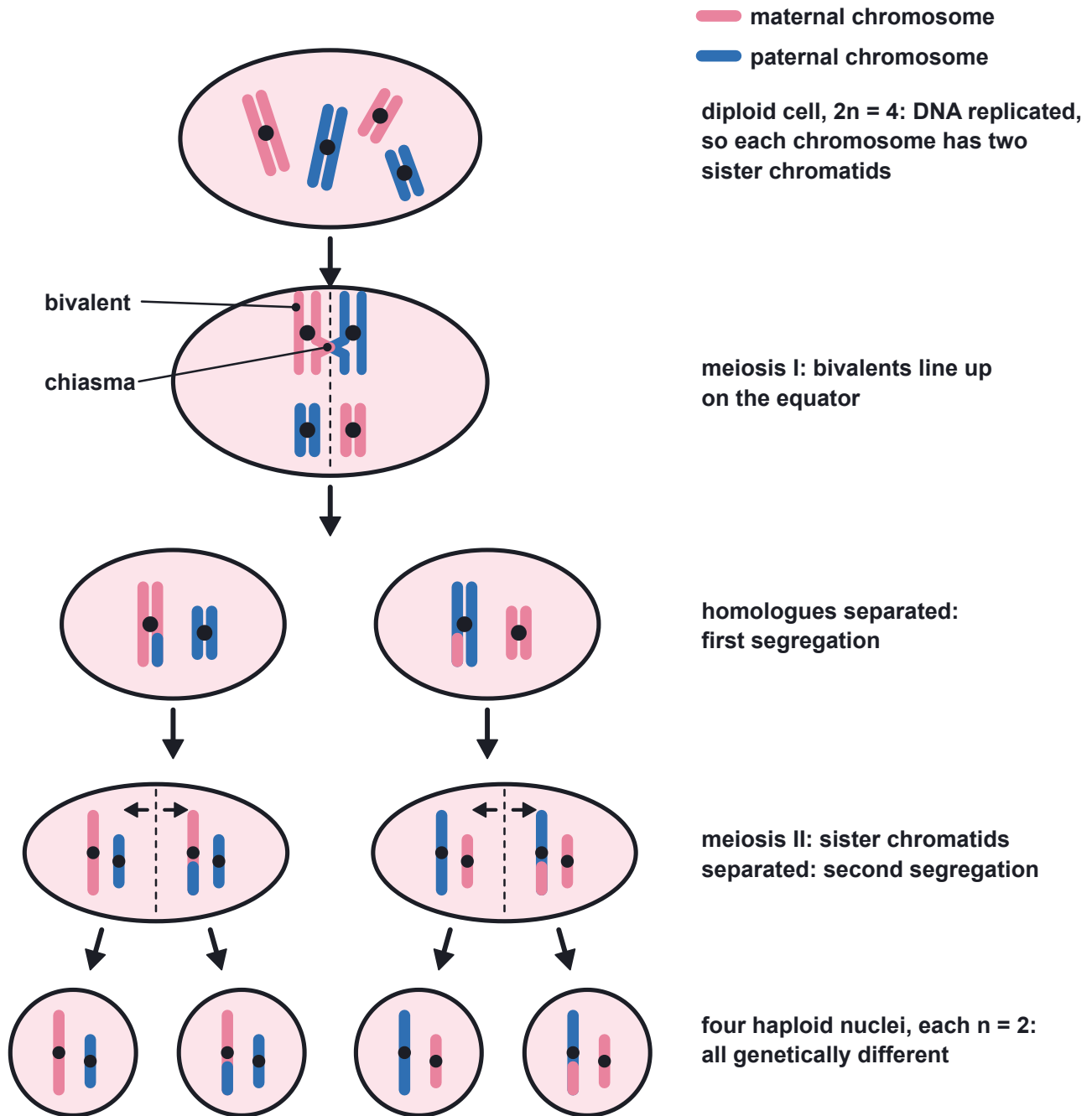
Diploid (2n)	A nucleus with two of each type of chromosome, one from each parent (two full sets). Human body cells have 46 chromosomes.
Haploid (n)	A nucleus with one of each type of chromosome (one full set). Human gametes have 23 chromosomes.
Homologous chromosomes	A pair of chromosomes with the same genes in the same sequence, but not necessarily the same alleles.
Bivalent	A pair of homologous chromosomes held together during meiosis I.

Meiosis is a **reduction division**: one diploid nucleus divides twice to give **four haploid nuclei**. It is needed in a sexual life cycle because fertilisation joins two gametes. If gametes were diploid, the chromosome number would double every generation. Halving it in meiosis keeps the number constant from one generation to the next.

Two rounds of segregation

1. DNA is replicated before meiosis, so each chromosome consists of two sister chromatids.
2. **Meiosis I**: homologous chromosomes pair up to form bivalents, and crossing over can occur. Bivalents line up on the equator. The **homologous chromosomes separate** to opposite poles (first segregation). Each of the two nuclei is haploid, but each chromosome still has two chromatids.
3. **Meiosis II**: in each of the two cells the chromosomes line up on the equator and the **sister chromatids separate** to opposite poles (second segregation).

4. Result: four haploid nuclei, each with one chromosome of every type, all genetically different.



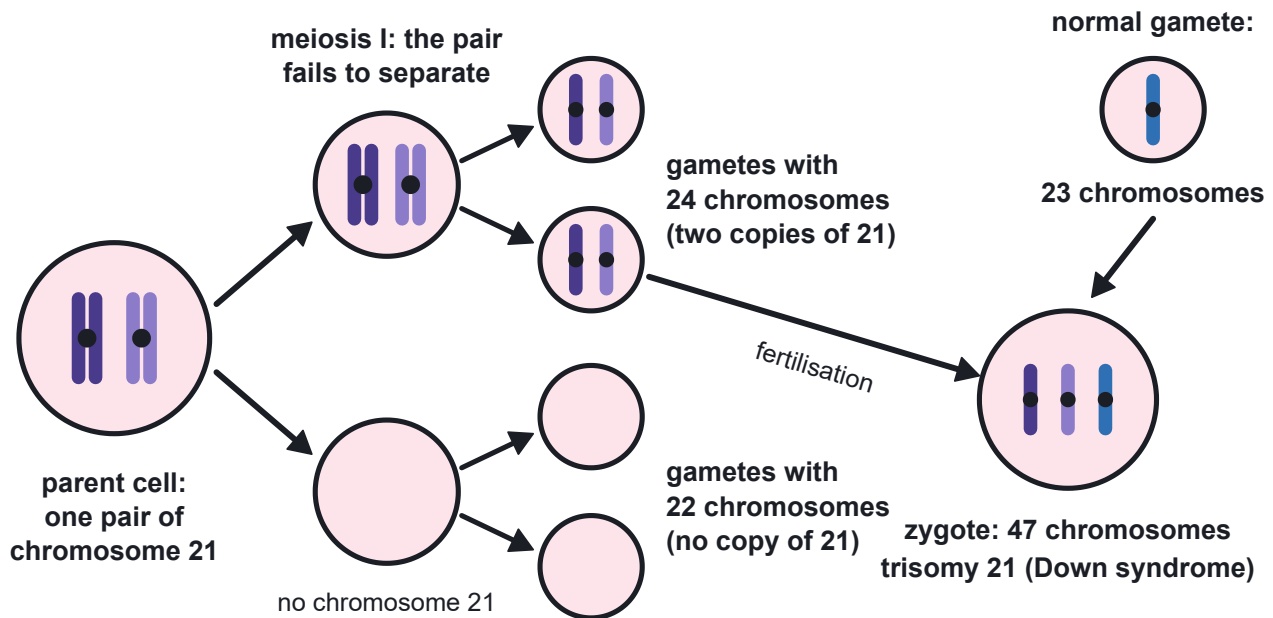
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Meiosis: **homologous chromosomes** separate in meiosis I and **sister chromatids** separate in meiosis II, giving four haploid nuclei. Crossing over at the chiasma and random orientation make each one different.

Down syndrome and non-disjunction

Non-disjunction is the failure of chromosomes to separate correctly in meiosis. Either a pair of homologous chromosomes fails to separate in meiosis I, or a pair of sister chromatids fails to separate in meiosis II. One gamete then has an extra chromosome and another has one missing.

Down syndrome is an example of an error in meiosis. If a gamete with two copies of chromosome 21 (24 chromosomes) is fertilised by a normal gamete (23), the zygote has three copies of chromosome 21 (**trisomy 21**) and 47 chromosomes in every cell.



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Non-disjunction of chromosome 21 (only chromosome 21 is shown): fertilisation of a gamete with two copies gives **trisomy 21**, Down syndrome.

Meiosis as a source of variation

- **Crossing over** in prophase I: non-sister chromatids of a bivalent exchange sections at a chiasma. This creates chromatids with **new combinations of alleles** of linked genes.
- **Random orientation of bivalents** in metaphase I: each bivalent lines up independently of the others, so the maternal or paternal chromosome of each pair can face either pole. With n pairs there are 2^n possible combinations; in humans 2^{23} , which is about 8.4 million.

Exam tip: Linking question: how does the variation produced by sexual reproduction contribute to evolution? Meiosis and random fertilisation produce new allele combinations, giving natural selection variation to act on (D4.1).

Cell proliferation and the cell cycle Spec D2.1.12, D2.1.13, D2.1.14, D2.1.15 HL only

Cell proliferation is a rapid increase in cell number by repeated cell division. It is used for three purposes.

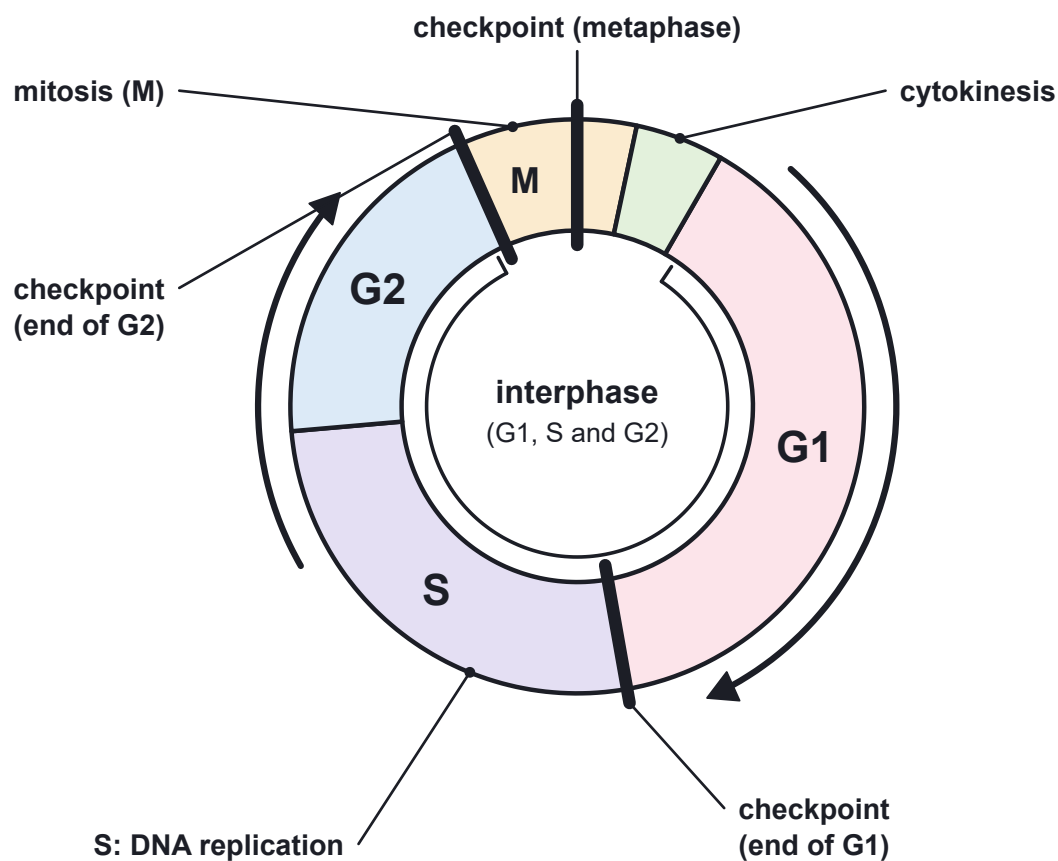
- **Growth:** in plant **meristems** (at root and shoot tips) cells divide again and again to add new cells. In **early-stage animal embryos** the zygote divides repeatedly to form a ball of many cells.
- **Cell replacement:** in **skin**, cells in the deepest layer divide continually to replace cells that are lost from the surface.
- **Tissue repair:** when skin is wounded, cell division increases so that new cells fill and cover the wound.

Phases of the cell cycle

Cell proliferation is achieved using the **cell cycle**: the sequence of events between one cell division and the next.

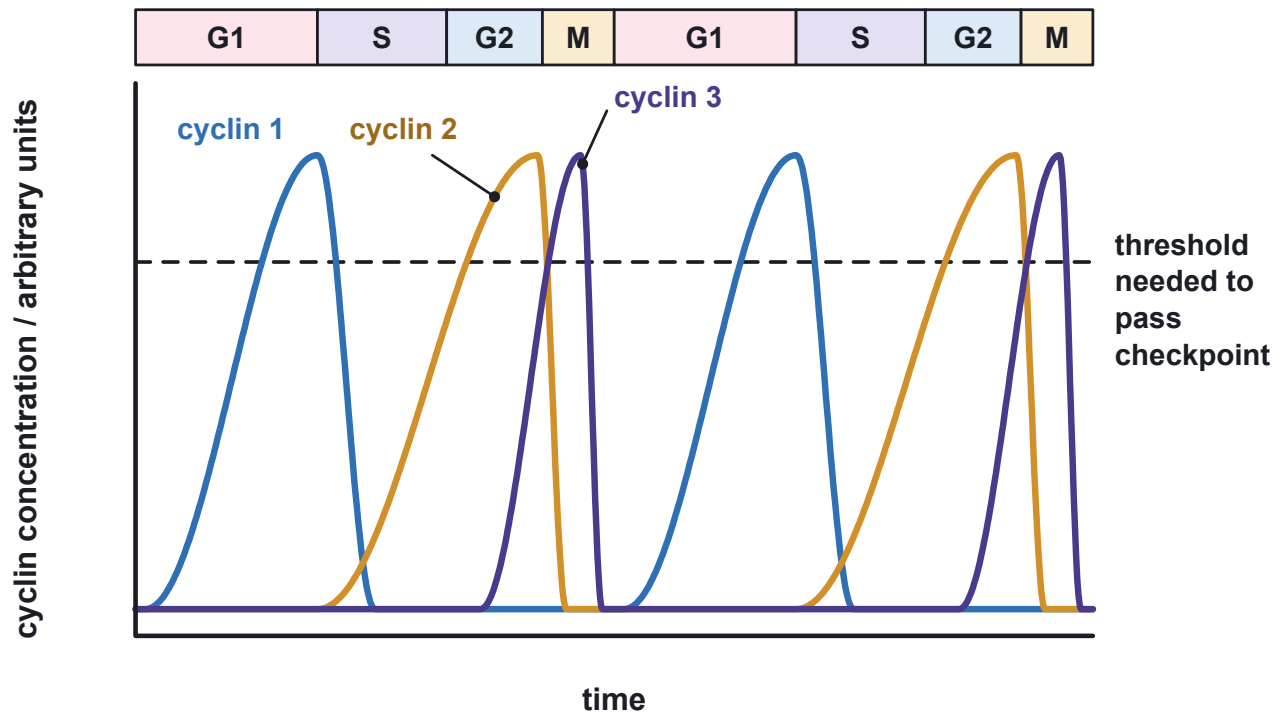
The cell cycle in order

Phase	What happens
G1 (interphase)	The cell grows: proteins are made and organelles increase in number
S (interphase)	DNA replication: every chromosome is copied, giving two sister chromatids
G2 (interphase)	Further growth and preparation for division, for example making the proteins of the spindle
Mitosis	The nucleus divides: prophase, metaphase, anaphase, telophase
Cytokinesis	The cytoplasm divides, giving two daughter cells



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The **cell cycle**: interphase (G1, S, G2), then mitosis and cytokinesis. The cell must pass **checkpoints** to move into the next phase.



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Cyclin concentrations rise and fall; each cyclin must reach a **threshold** to pass its checkpoint (illustrative curves).

Cell growth during interphase

Interphase is not a resting phase. It is a **metabolically active** period: the cell carries out respiration, protein synthesis and many other reactions. Growth involves **biosynthesis** of cell components, including proteins and DNA. The numbers of **mitochondria and chloroplasts** increase as these organelles grow and divide, so that each daughter cell will receive some.

Control of the cell cycle using cyclins

Cyclins are proteins that control progression through the cell cycle. The concentrations of different cyclins **increase and decrease** at different points in the cycle. To pass each **checkpoint**, a **threshold level** of a specific cyclin is needed. When its concentration is above the threshold, the cell moves into the next phase; the cyclin is then broken down and its concentration falls again.

Exam tip: You do not need the names or roles of specific cyclins. Describe the pattern: concentrations rise and fall, and a threshold of a specific cyclin must be reached to pass each checkpoint.

Mutations, tumours and the mitotic index Spec D2.1.16, D2.1.17 HL only

Mutations in the genes that control the cell cycle can lead to **uncontrolled cell division**. Two groups of genes are involved.

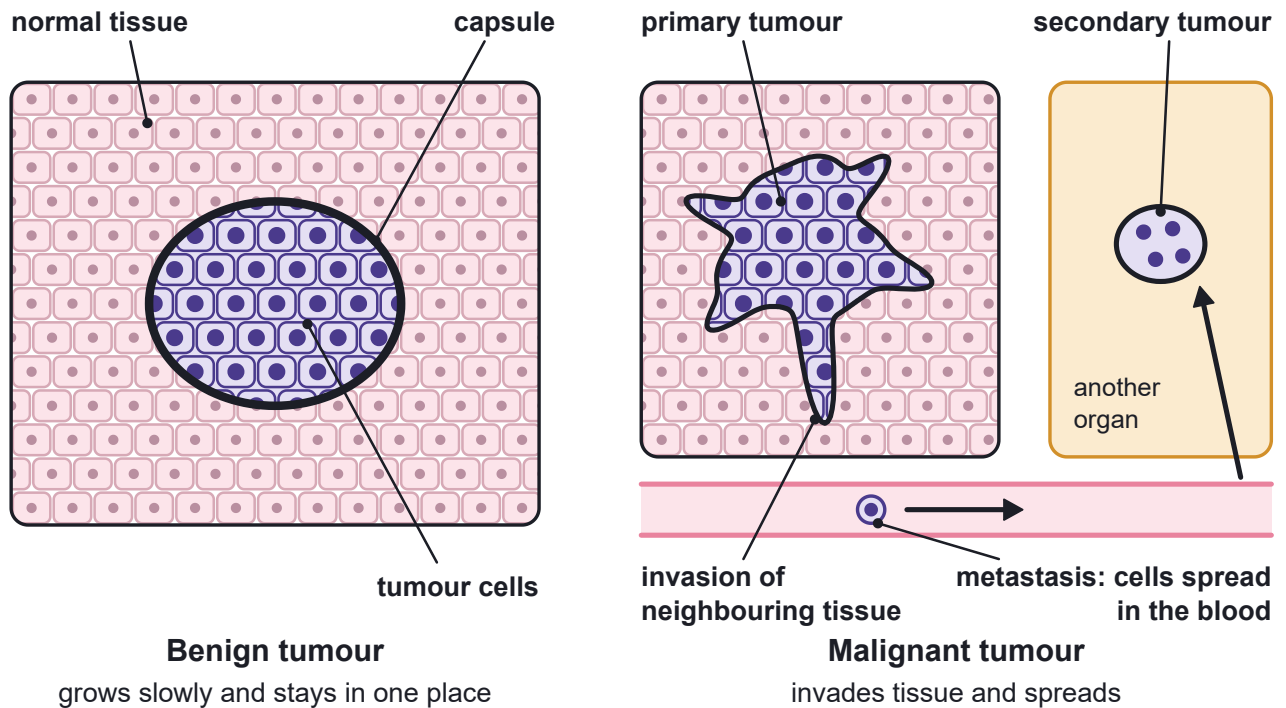
Genes that control the cell cycle		
	Proto-oncogenes	Tumour suppressor genes
Normal role	Code for proteins that stimulate the cell cycle when division is needed	Code for proteins that slow or stop the cell cycle, for example if DNA is damaged (p53 is a well-known example)
Effect of mutation	Converted into an oncogene , which is permanently active and stimulates division all the time	The protein stops working, so division is no longer held back
Result	Uncontrolled cell division	Uncontrolled cell division

Usually several mutations in the same cell are needed before a tumour forms. A **tumour** is an abnormal mass of cells that results from uncontrolled cell division.

Benign and malignant tumours

Differences between tumours		
	Benign tumour	Malignant tumour
Rate of cell division and growth	Usually slow	Usually fast
Invasion of neighbouring tissue	No: often enclosed and stays in one place	Yes: grows into neighbouring tissues
Metastasis	No	Yes: cells break away and spread in blood or lymph
Cancer?	Does not cause cancer (but can still harm by pressing on organs)	Causes cancer

The tumour that forms first is the **primary tumour**. When malignant cells detach, travel in the blood or lymph and start dividing elsewhere in the body (**metastasis**), they form a **secondary tumour**.



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A **benign tumour** stays in one place; a **malignant tumour** invades neighbouring tissue and metastasises to form secondary tumours.

The mitotic index

mitotic index = number of cells in mitosis ÷ total number of cells observed

Calculating a mitotic index

In a field of view of a tissue sample, 42 of 350 cells are in a phase of mitosis. Calculate the mitotic index.

1. Count every cell in prophase, metaphase, anaphase or telophase: 42.
2. Divide by the total number of cells: $42 \div 350 = 0.12$.

Answer: Mitotic index = 0.12 (12% of the cells are in mitosis).

Maths skill: A higher mitotic index means faster cell proliferation, so it is used to compare tumours with normal tissue. Count across several fields of view and decide in advance how to treat cells you cannot classify.

Practical skill: To determine the mitotic index, observe a population of cells, such as a root tip squash or a prepared slide, and count cells in mitosis and in interphase. Interphase cells count in the total but not in the numerator.

Quick check

1. What is cytokinesis?
2. Give two examples of unequal cytokinesis.
3. In which phase of mitosis do sister chromatids separate?
4. What happens to chromosome 21 to cause Down syndrome?
5. **HL only** What is the mitotic index?

Quick check answers

Cell and nuclear division

1. The splitting of the cytoplasm of a parent cell between the daughter cells.
2. Oogenesis in humans and budding in yeast.
3. Anaphase.
4. Non-disjunction in meiosis gives a gamete with two copies, so the zygote has three copies (trisomy 21).
5. The number of cells in mitosis divided by the total number of cells observed.