

Cells (Continuity and change) revision notes

How cells divide to make new cells and how water moves into and out of them. D2.1 covers cytokinesis, mitosis and meiosis, and D2.3 covers osmosis.

For IB Diploma Biology SL undefined. **HL only** is additional higher level content, for HL students only.

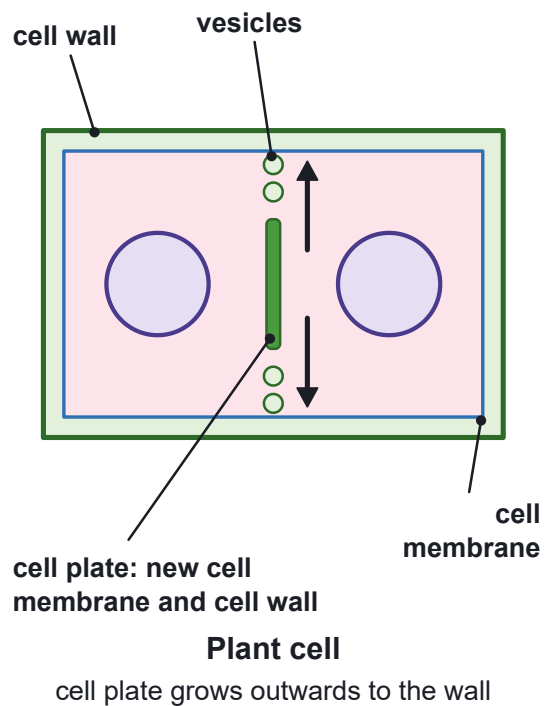
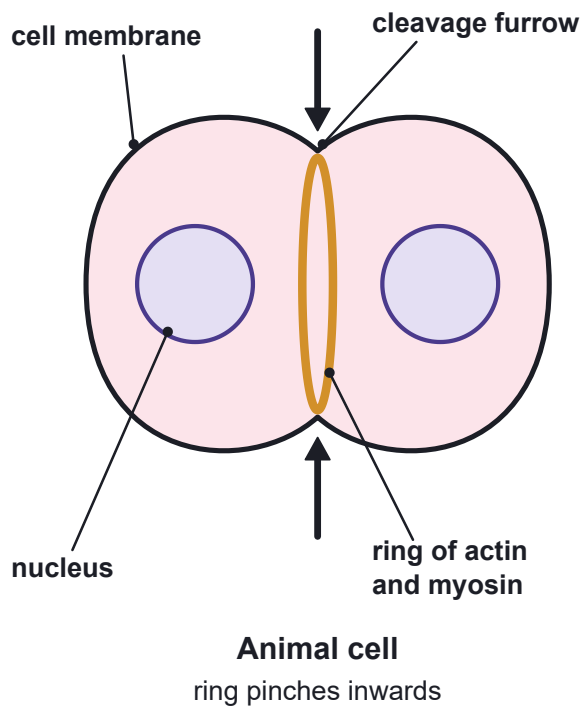
1 Cell and nuclear division Spec D2.1

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

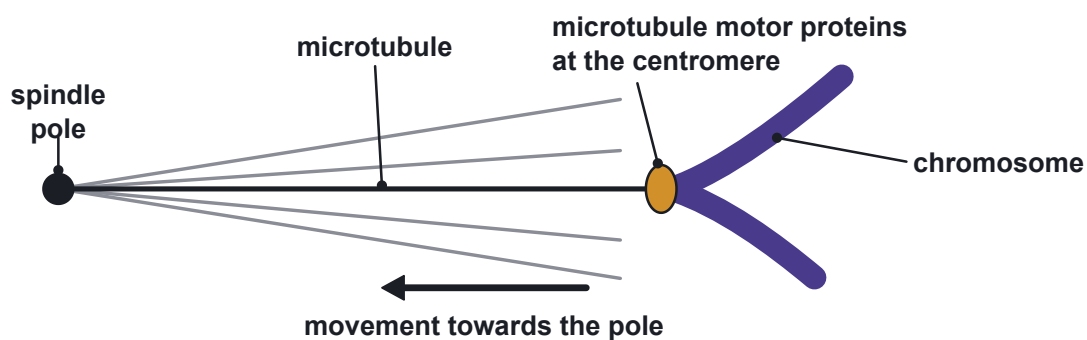
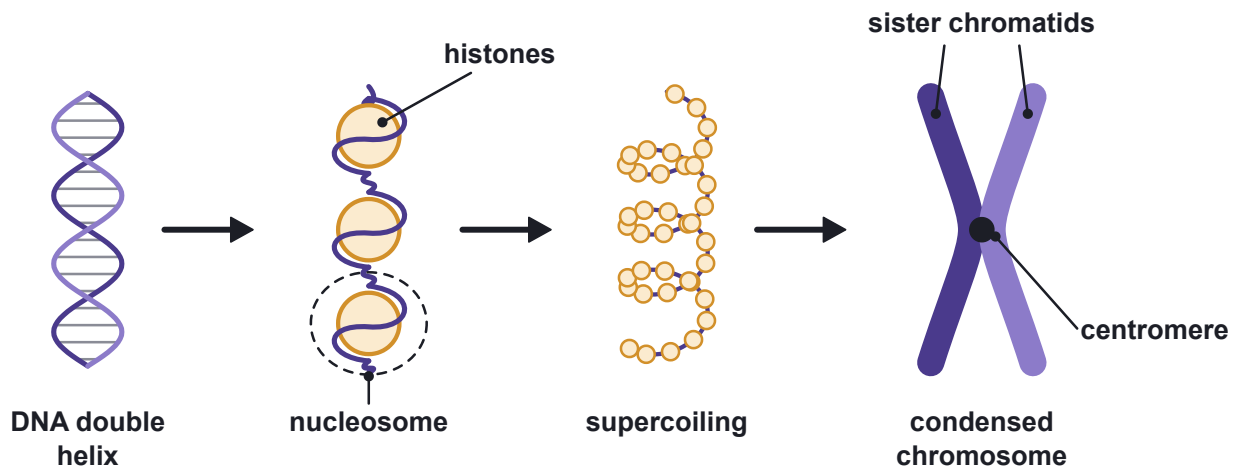
DNA replication comes first

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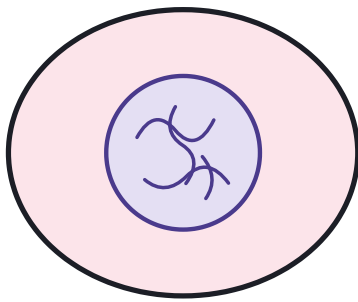
Chromosomes condense by wrapping DNA around **histones** (nucleosomes) and **supercoiling**; they are moved by **microtubules** and motor proteins attached at the centromere.

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.

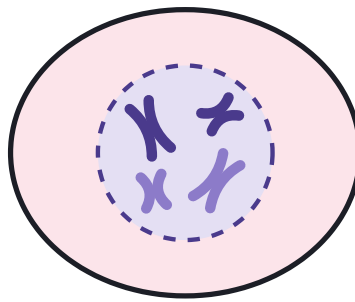
Phases of mitosis Spec D2.1.7, D2.1.8

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.

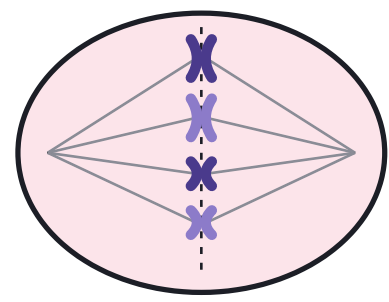
The process as a whole gives two **genetically identical** daughter nuclei. DNA replication made an exact copy of every chromosome, and anaphase sends one chromatid of every chromosome to each pole, so each nucleus receives a complete, identical set.



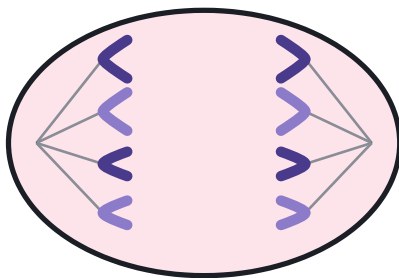
1 Interphase
cell grows; DNA replicated



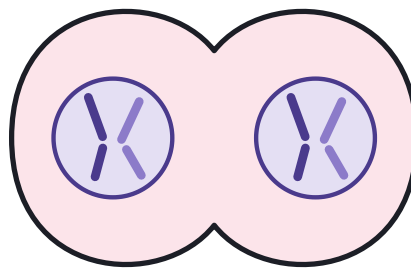
2 Prophase
chromosomes visible;
nuclear membrane breaks down



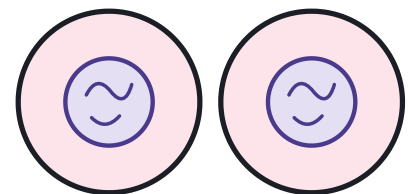
3 Metaphase
chromosomes line up on the
equator; microtubules attach
to the centromeres



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

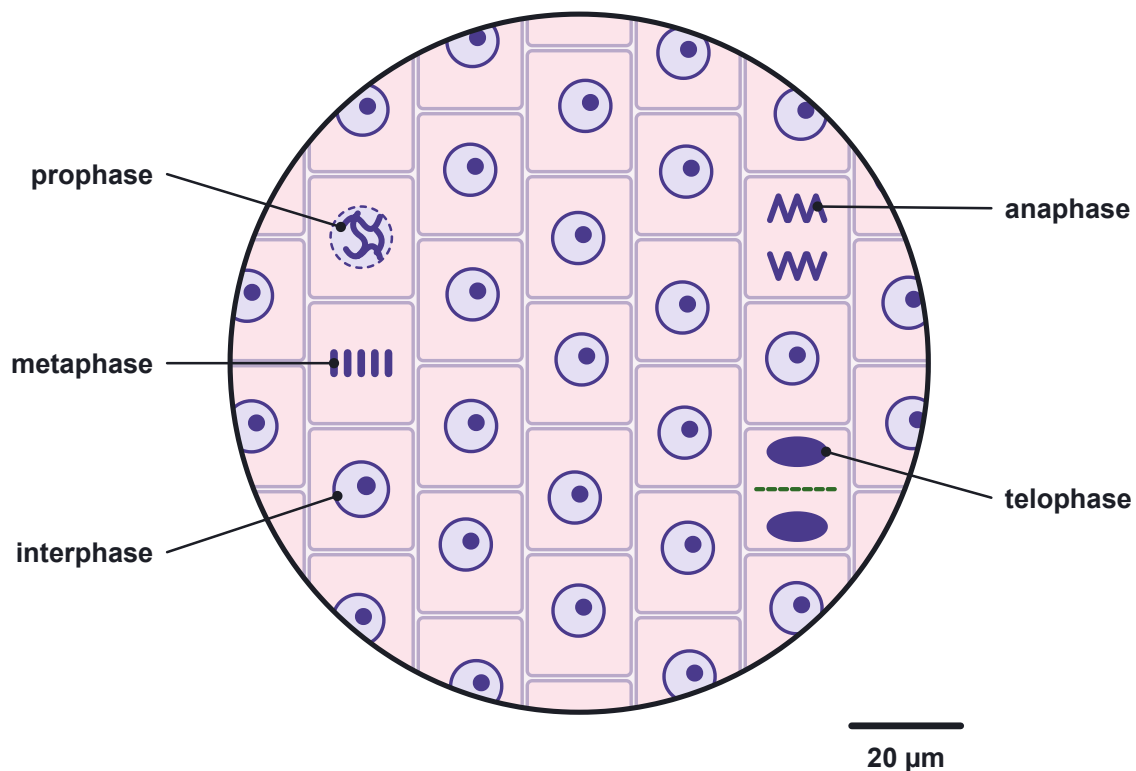
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Interphase, the four phases of mitosis ([prophase](#), [metaphase](#), [anaphase](#), [telophase](#)), then cytokinesis.

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

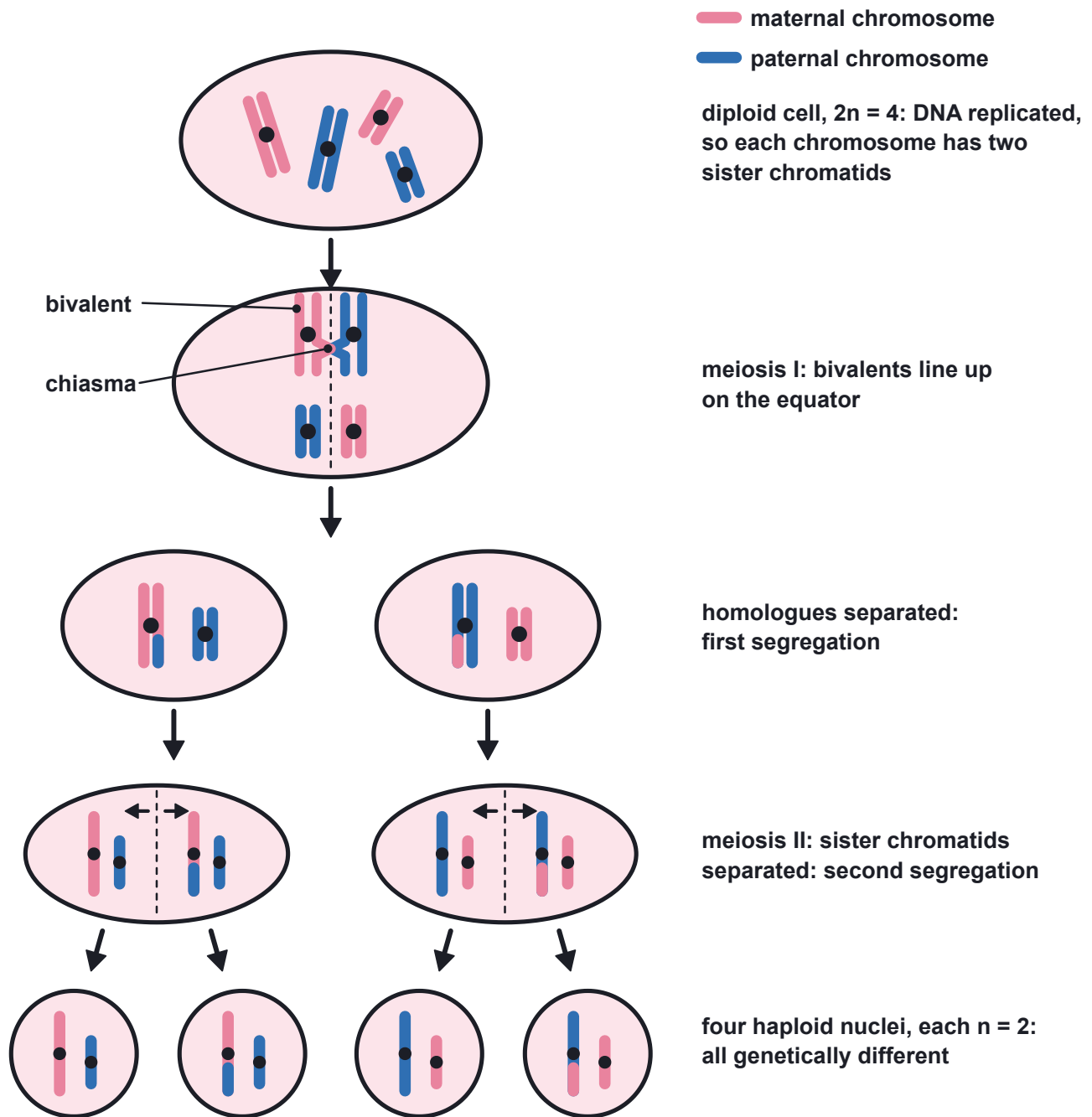
Diploid (2n)	A nucleus with two of each type of chromosome, one from each parent (two full sets). Human body cells have 46 chromosomes.
Haploid (n)	A nucleus with one of each type of chromosome (one full set). Human gametes have 23 chromosomes.
Homologous chromosomes	A pair of chromosomes with the same 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.



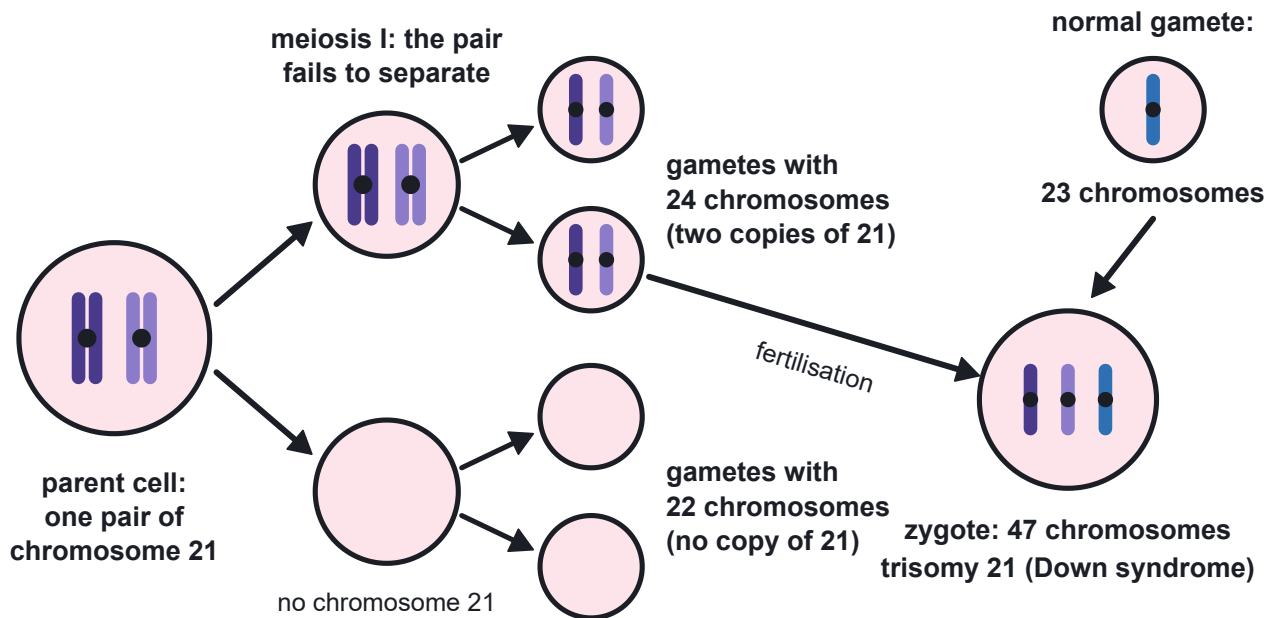
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Meiosis: **homologous chromosomes** separate in meiosis I and **sister chromatids** separate in meiosis II, giving four haploid nuclei. Crossing over at the chiasma and random orientation make each one different.

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).

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?

2 Water potential Spec D2.3

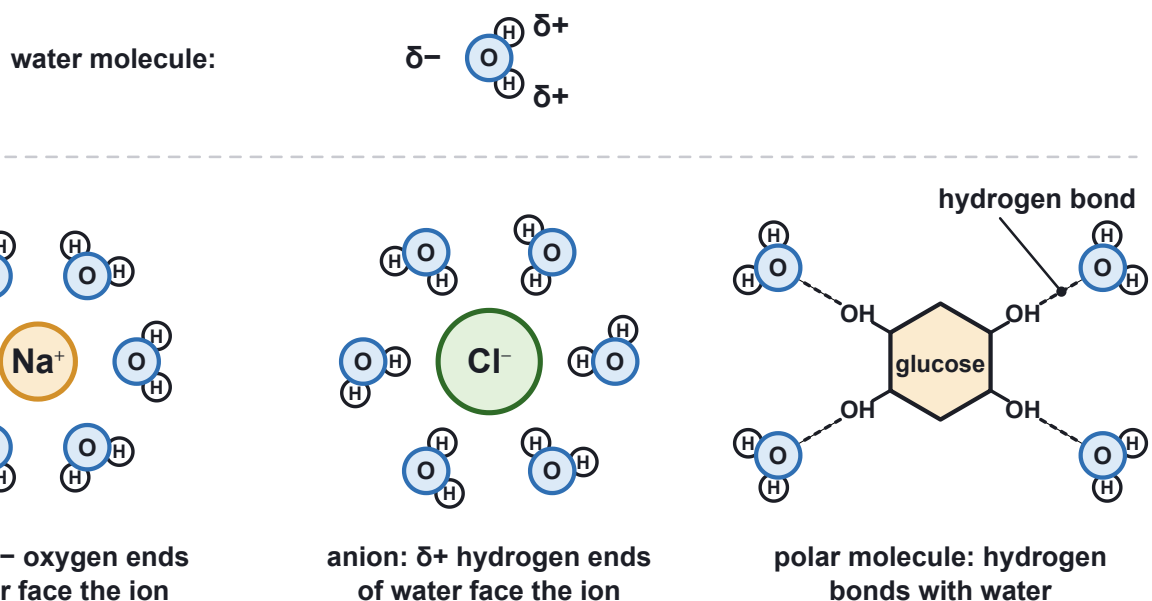
Solvation and osmosis Spec D2.3.1, D2.3.2, D2.3.3

Solvation

Solvation is the process of a solute dissolving, with each solute particle surrounded by solvent molecules. Water is a good solvent because its molecules are **polar**: the oxygen end is slightly negative (δ^-) and the hydrogen ends are slightly positive (δ^+).

- **Positively charged ions** (for example Na^+) attract the δ^- oxygen ends of water molecules.
- **Negatively charged ions** (for example Cl^-) attract the δ^+ hydrogen ends of water molecules.
- **Polar molecules** such as glucose form **hydrogen bonds** with water molecules.

Each ion or molecule becomes surrounded by a shell of water molecules, so it separates from the others and dissolves.



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Solvation: polar water molecules surround cations, anions and polar molecules such as glucose, so they dissolve.

Direction of water movement

Osmosis is the net movement of water through a partially permeable membrane. Water moves **from the less concentrated solution to the more concentrated solution**, meaning from lower to higher **solute** concentration. Water molecules bound to solutes move less freely, so more water molecules cross from the side with fewer solutes.

Hypertonic	Having a higher solute concentration than another solution.
Hypotonic	Having a lower solute concentration than another solution.
Isotonic	Having the same solute concentration as another solution.

Osmosis into and out of cells

Predicting net movement of water	
Environment of the cell	Net movement of water
Hypotonic (lower solute concentration than the cytoplasm)	Into the cell
Hypertonic (higher solute concentration than the cytoplasm)	Out of the cell
Isotonic	No net movement: water moves in and out at equal rates (dynamic equilibrium)

Common mistake: Describe direction in terms of solute concentration, not water concentration. And in an isotonic solution water still moves; the rates in and out are just equal.

Osmosis in plant tissue: the practical Spec D2.3.4

When plant tissue is bathed in a **hypotonic** solution, water enters the cells by osmosis, so the tissue **gains mass and gets longer** and becomes firm. In a **hypertonic** solution water leaves, so the tissue **loses mass and gets shorter** and becomes soft.

1. Cut equal-sized cylinders of tissue (for example potato) with a cork borer and trim them to the same length.
2. Blot each cylinder dry, then measure its length and mass.
3. Place cylinders in a range of solute concentrations, for example sucrose solutions from 0.0 to 1.0 mol dm⁻³, with several repeats at each concentration.
4. Leave for the same time at the same temperature, then blot dry and measure length and mass again.
5. Calculate the percentage change in mass and length for each cylinder, and the mean for each concentration.

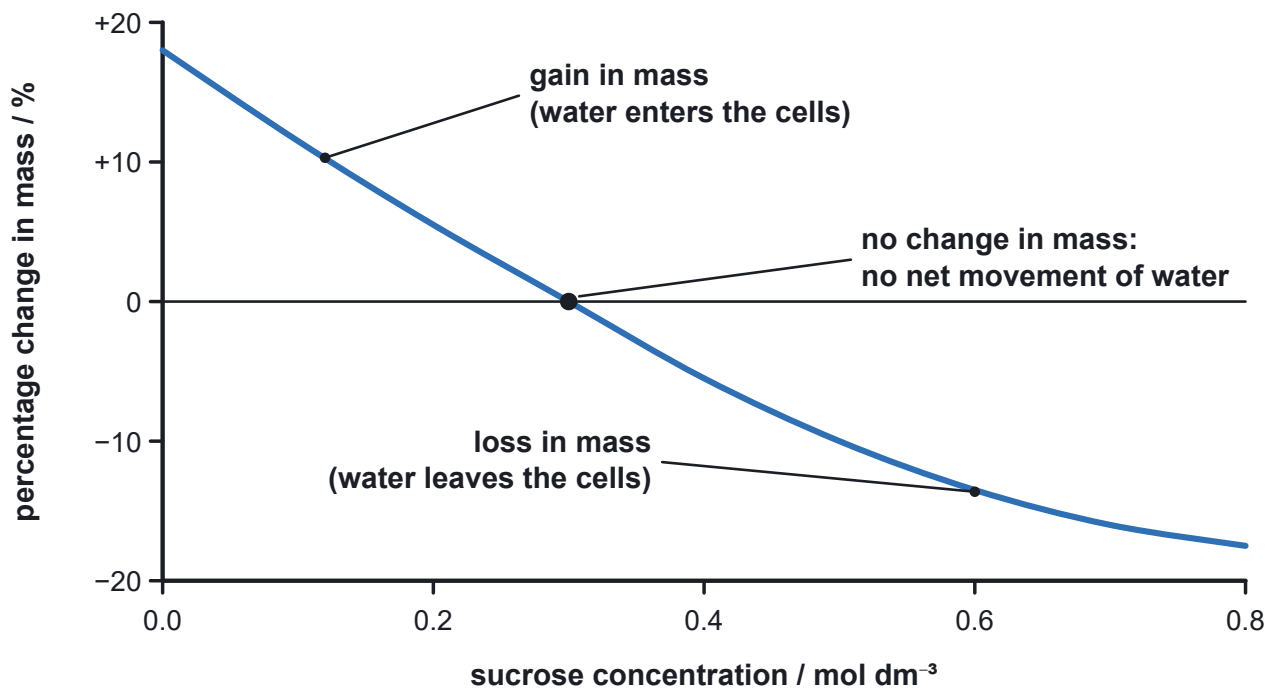
$$\text{percentage change} = (\text{final value} - \text{initial value}) \div \text{initial value} \times 100$$

Percentage change in mass

A potato cylinder has a mass of 2.50 g before and 2.20 g after 40 minutes in 0.6 mol dm⁻³ sucrose solution. Calculate the percentage change in mass.

1. Change in mass = 2.20 – 2.50 = –0.30 g.
2. Percentage change = –0.30 ÷ 2.50 × 100 = –12%.

Answer: –12% (a loss in mass, so the solution was hypertonic to the potato cells).



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The **isotonic concentration** is where the line crosses zero percentage change: there is no net movement of water (illustrative data).

Percentage change is used because cylinders start with slightly different masses and lengths. The **isotonic solute concentration** of the tissue is deduced by reading where the line of best fit crosses **zero** percentage change.

Maths skill: With repeats at each concentration, calculate the standard deviation (spread of the repeats) and standard error (how precisely the mean is known) with a calculator or spreadsheet. Show standard error as error bars; you do not need to memorise the formulae.

Practical skill: Comparing standard errors lets you judge whether length or mass measurements were more reliable. If error bars of two means overlap widely, the difference between them may not be significant.

Water movement in cells with and without walls Spec D2.3.5, D2.3.6, D2.3.7

Cells that lack a cell wall

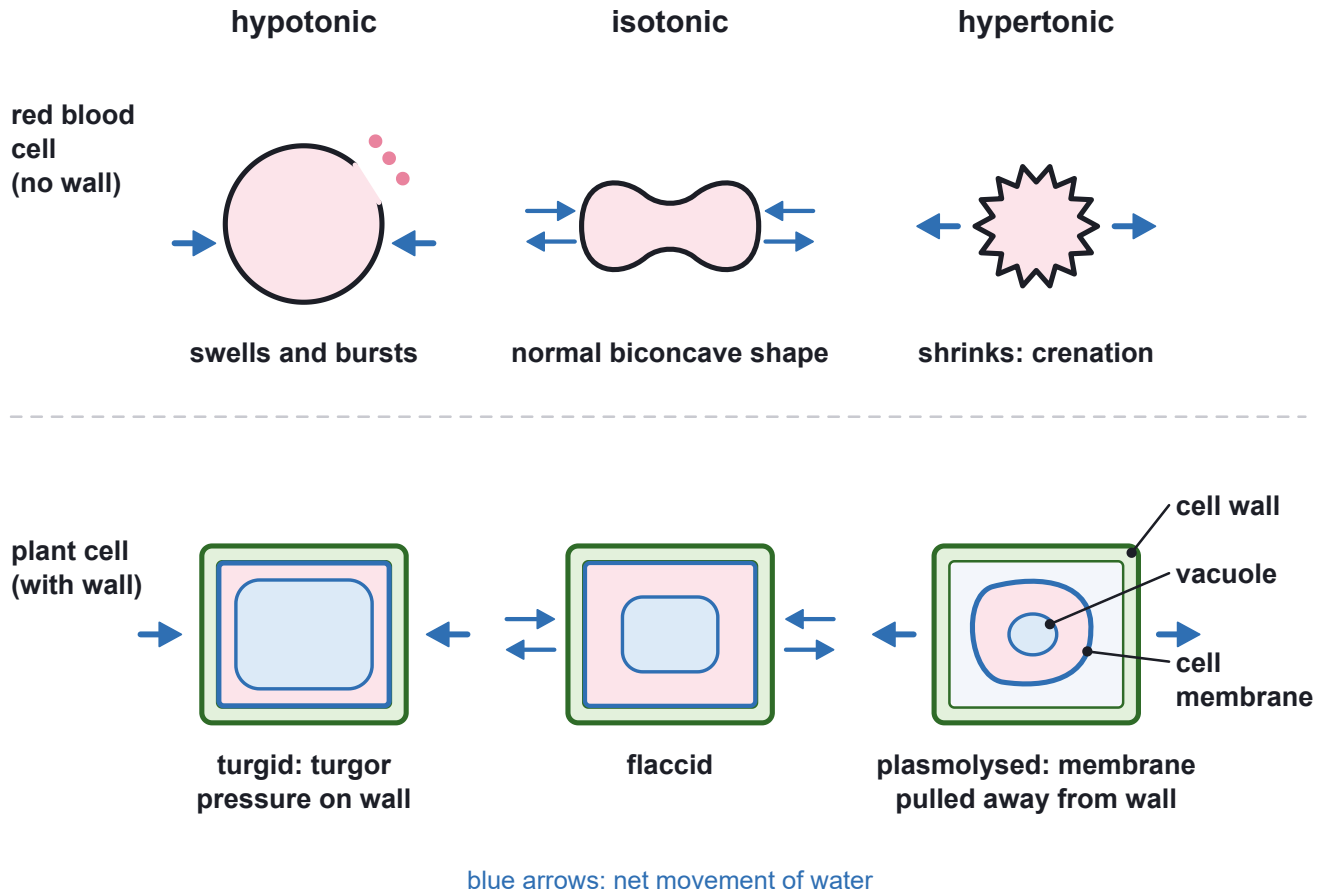
- **Hypotonic medium:** water enters, the cell **swells** and, with no wall to resist, may **burst** (red blood cells burst, called haemolysis).
- **Hypertonic medium:** water leaves, the cell **shrinks** and the membrane becomes wrinkled and spiky (**crenation**).

Freshwater unicellular organisms, such as *Paramecium*, live in a hypotonic environment and water constantly enters. They use **contractile vacuoles** to collect excess water and expel it from the cell, which needs energy from ATP. Without this the cell would burst.

In **multicellular organisms**, the tissue fluid that bathes cells must be kept **isotonic** with the cytoplasm to prevent harmful swelling or shrinkage. In humans, the kidneys regulate the solute concentration of blood plasma and so of tissue fluid.

Cells with a cell wall

- **Hypotonic medium:** water enters and the cytoplasm and vacuole push against the cell wall, developing **turgor pressure**. The wall resists further expansion, so the cell becomes **turgid** but does not burst. Turgor supports non-woody plant tissue.
- **Hypertonic medium:** water leaves, the cytoplasm and vacuole shrink and the cell membrane pulls away from the cell wall. This is **plasmolysis**. The cell becomes flaccid and the tissue wilts.



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Cells without a wall **burst or crenate**; cells with a wall become **turgid** or **plasmolysed**.

Medical applications of isotonic solutions

- **Intravenous fluids:** fluids given into a vein as part of medical treatment, such as normal saline (0.9% sodium chloride), are isotonic with blood plasma so blood cells neither burst nor crenate.
- **Organs for transplantation:** donor organs are bathed in a cold isotonic solution, so their cells neither gain nor lose water while being stored and transported.

Exam tip: Linking question: how do plant and animal cells differ in their regulation of water movement? Plant cells rely on the cell wall and turgor; animal cells rely on keeping tissue fluid isotonic.

Quick check

1. Why are cations and anions both able to dissolve in water?
2. In which direction does water move between a hypotonic and a hypertonic solution?
3. What is plasmolysis?
4. Why are intravenous fluids isotonic?

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).

Water potential

1. Water is polar: cations attract the δ^- oxygen ends and anions attract the δ^+ hydrogen ends of water molecules.
2. From the hypotonic (less concentrated) solution to the hypertonic (more concentrated) solution.
3. The cell membrane pulling away from the cell wall as water leaves a plant cell in a hypertonic solution.
4. So that blood cells neither gain nor lose water, which would make them burst or crenate.