

Cells (Continuity and change) revision notes

How cells divide to make new cells, how they control which genes they use, and how water moves into and out of them. D2.1 covers cytokinesis, mitosis, meiosis and, at HL, the cell cycle and cancer. D2.2 (HL only) covers gene expression and epigenetics, and D2.3 covers osmosis and, at HL, water potential.

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

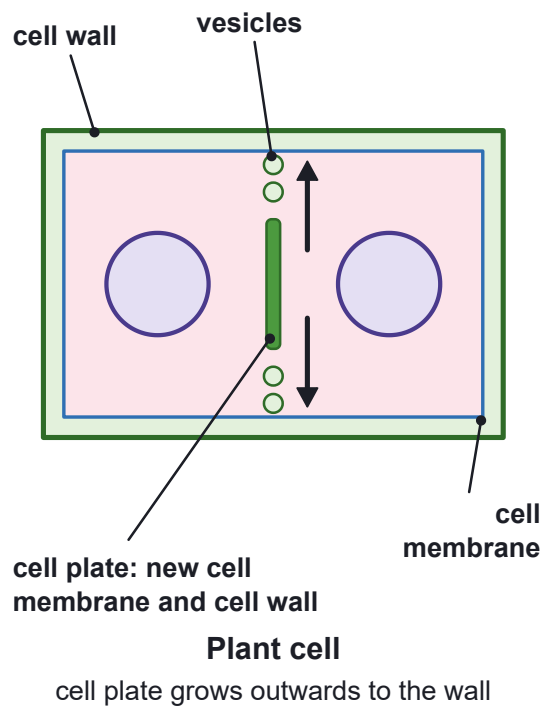
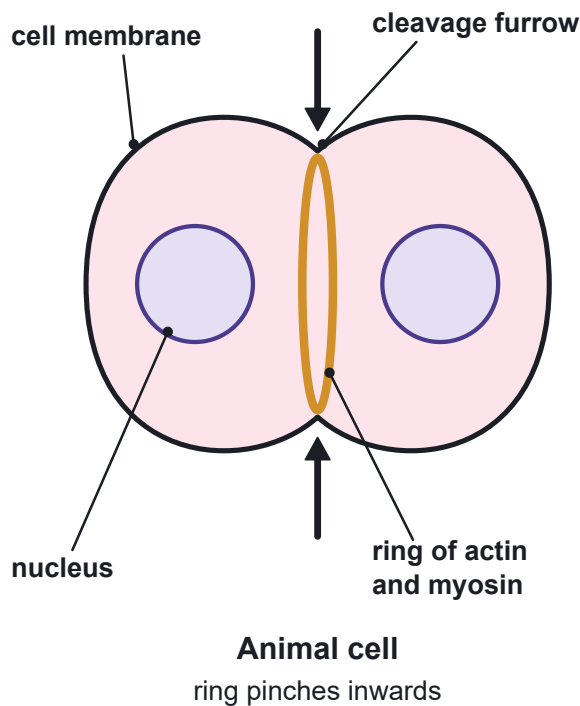
1 Cell and nuclear division Spec D2.1

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



[\(opens full size in a new tab\)](#)

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

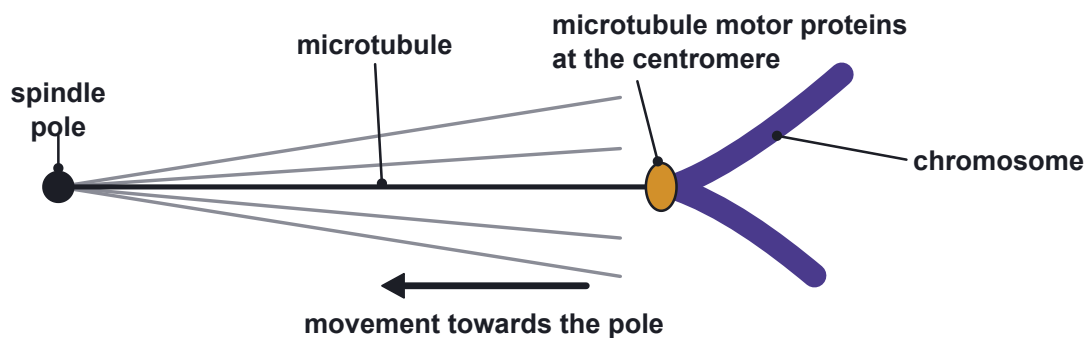
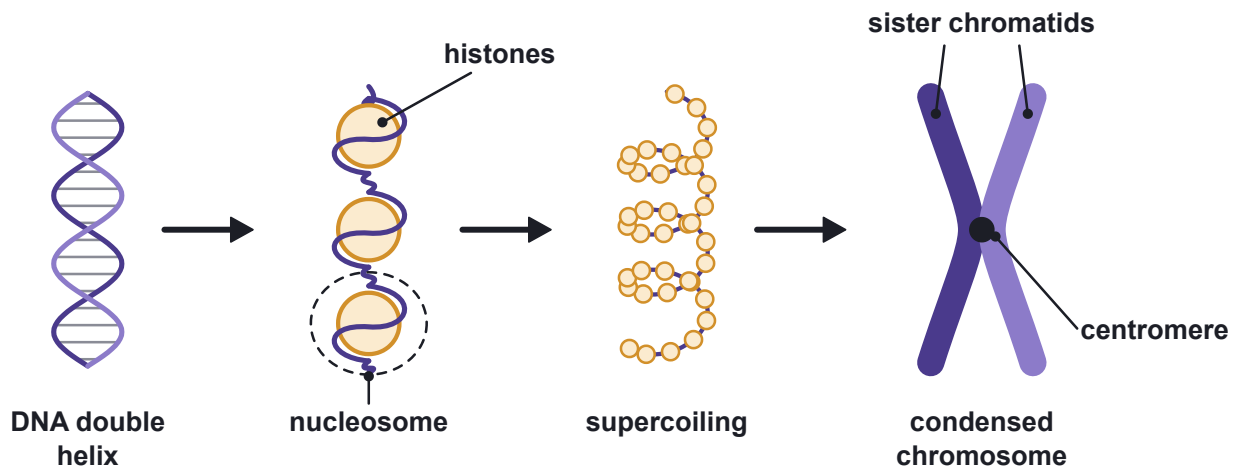
DNA replication comes first

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.



[\(opens full size in a new tab\)](#)

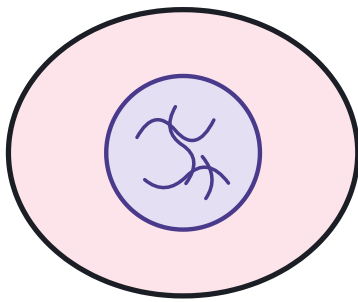
Chromosomes condense by wrapping DNA around **histones** (nucleosomes) and **supercoiling**; they are moved by **microtubules** and motor proteins attached at the centromere.

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.

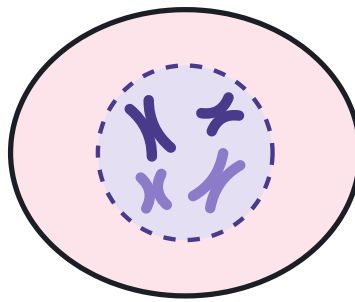
Phases of mitosis Spec D2.1.7, D2.1.8

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.

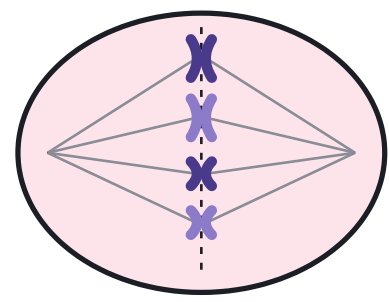
The process as a whole gives two **genetically identical** daughter nuclei. DNA replication made an exact copy of every chromosome, and anaphase sends one chromatid of every chromosome to each pole, so each nucleus receives a complete, identical set.



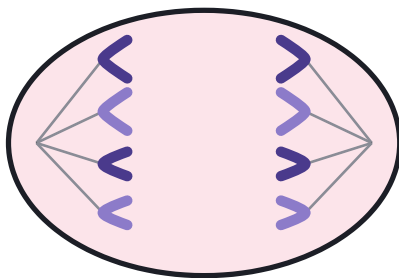
1 Interphase
cell grows; DNA replicated



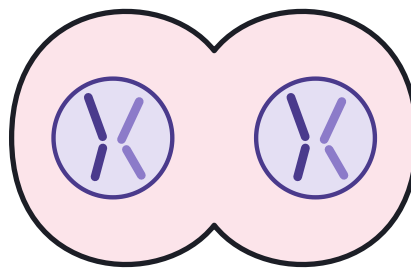
2 Prophase
chromosomes visible;
nuclear membrane breaks down



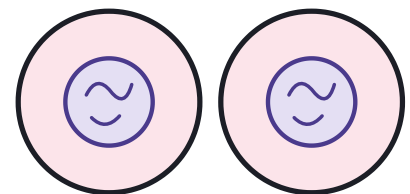
3 Metaphase
chromosomes line up on the
equator; microtubules attach
to the centromeres



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

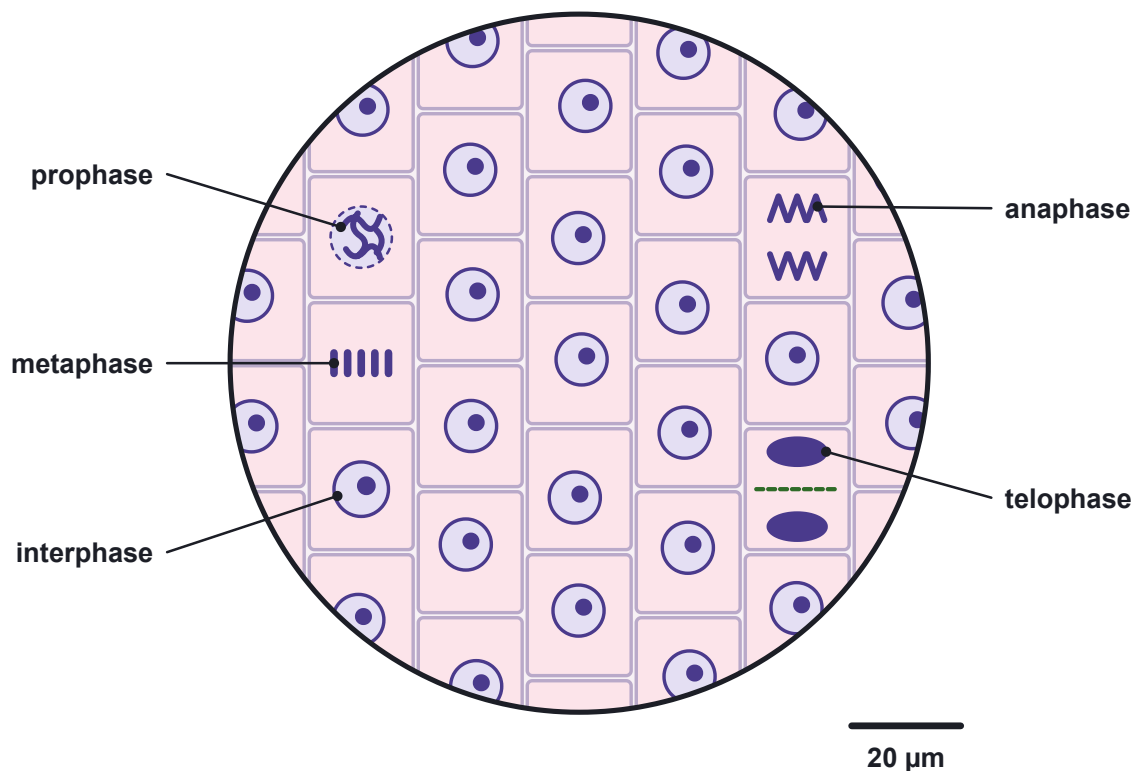
[\(opens full size in a new tab\)](#)

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.



[\(opens full size in a new tab\)](#)

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

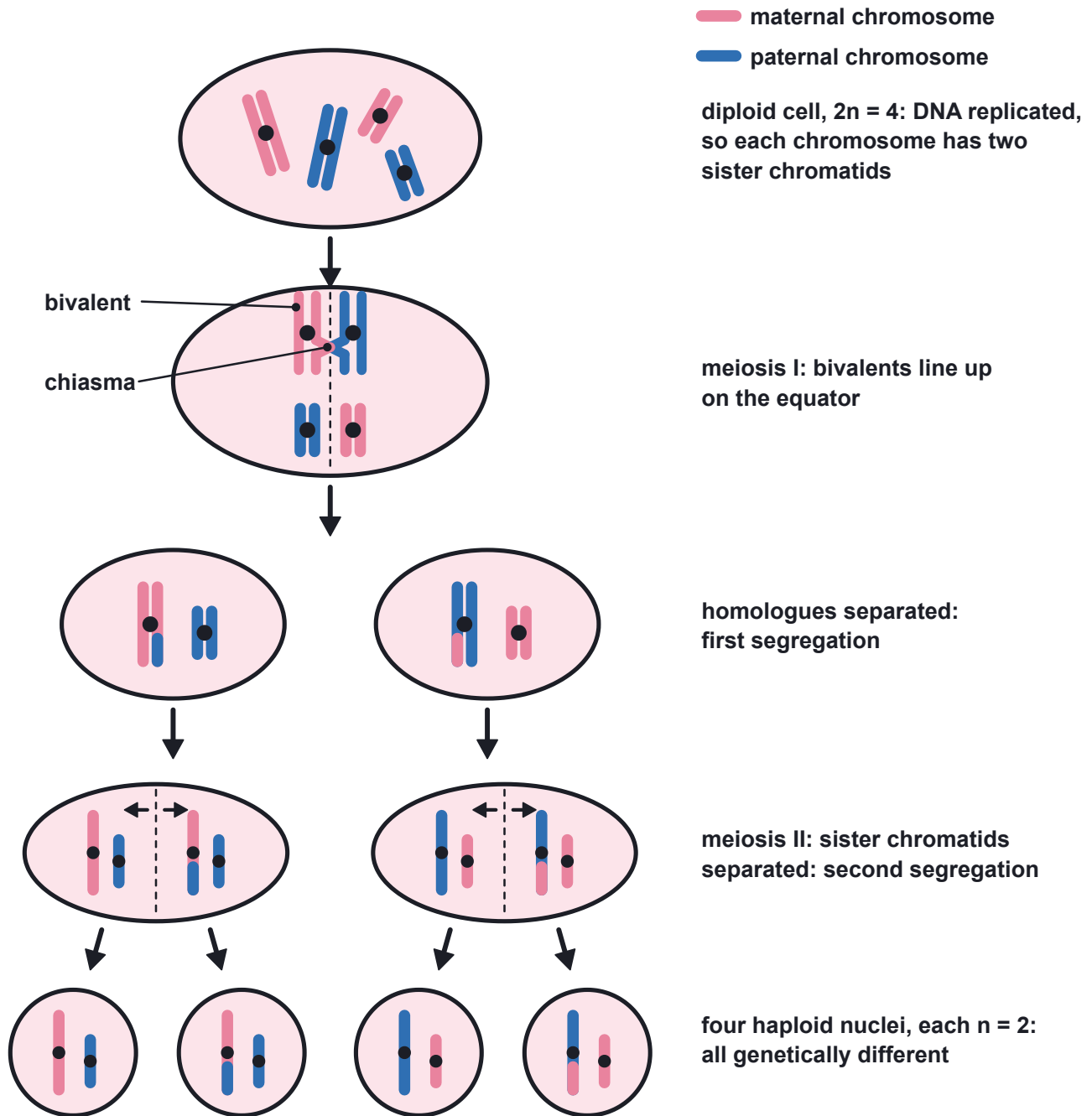
Diploid (2n)	A nucleus with two of each type of chromosome, one from each parent (two full sets). Human body cells have 46 chromosomes.
Haploid (n)	A nucleus with one of each type of chromosome (one full set). Human gametes have 23 chromosomes.
Homologous chromosomes	A pair of chromosomes with the same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



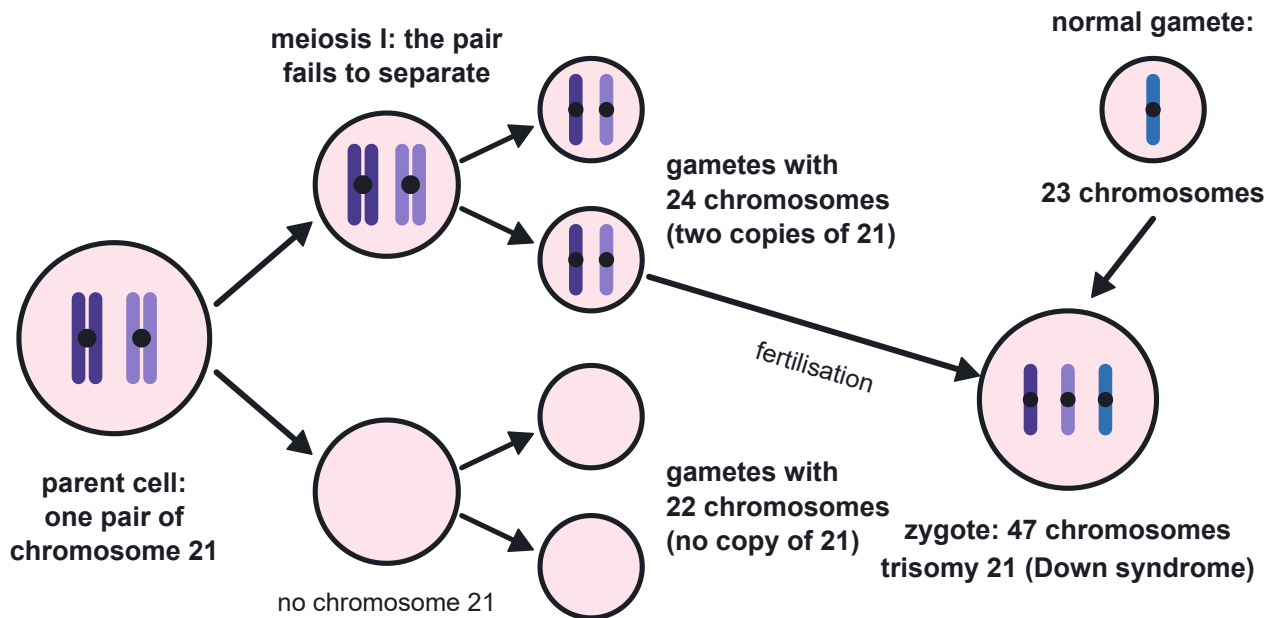
[\(opens full size in a new tab\)](#)

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.



[\(opens full size in a new tab\)](#)

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.

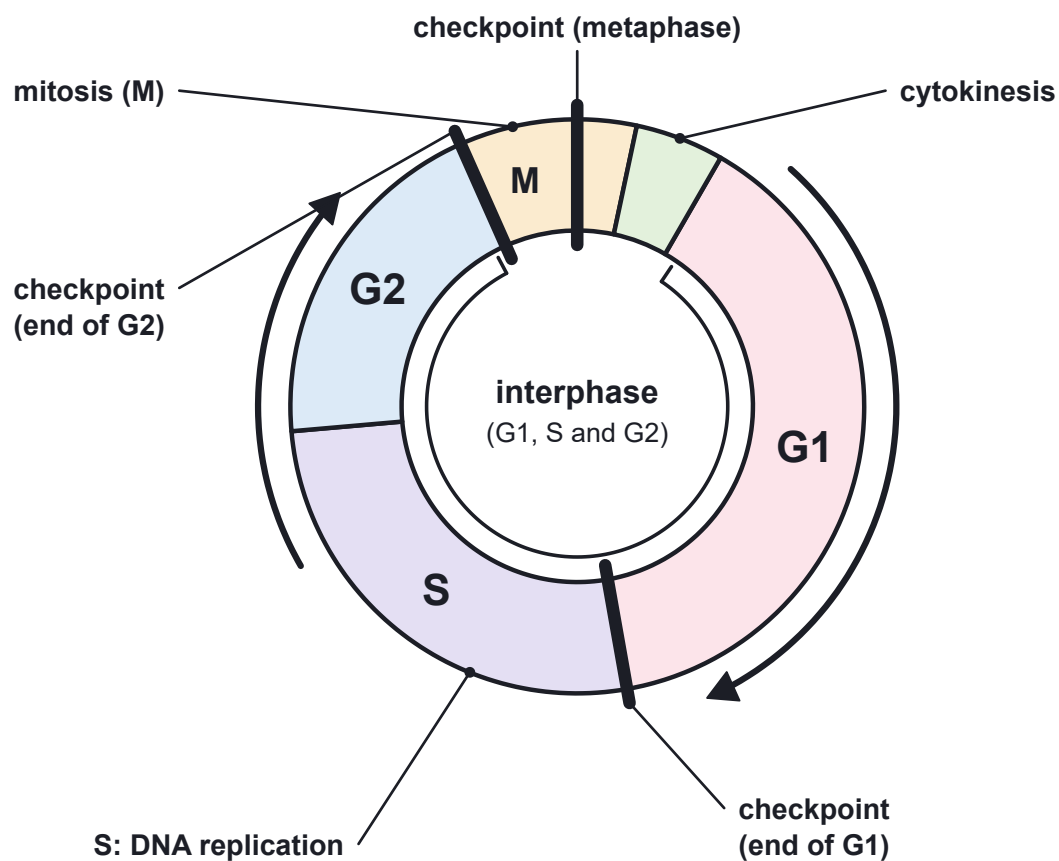
- **Growth:** in plant **meristems** (at root and shoot tips) cells divide again and again to add new cells. In **early-stage animal embryos** the zygote divides repeatedly to form a ball of many cells.
- **Cell replacement:** in **skin**, cells in the deepest layer divide continually to replace cells 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.

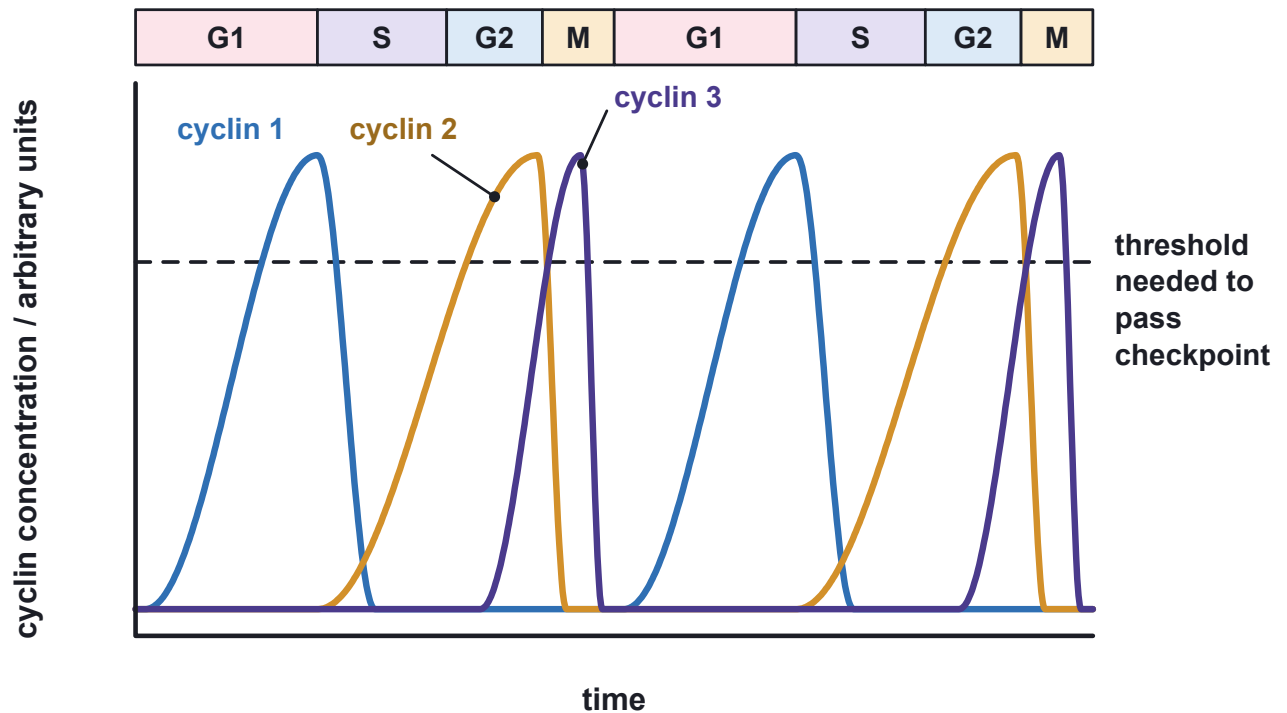
The cell cycle in order

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



[\(opens full size in a new tab\)](#)

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



[\(opens full size in a new tab\)](#)

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.

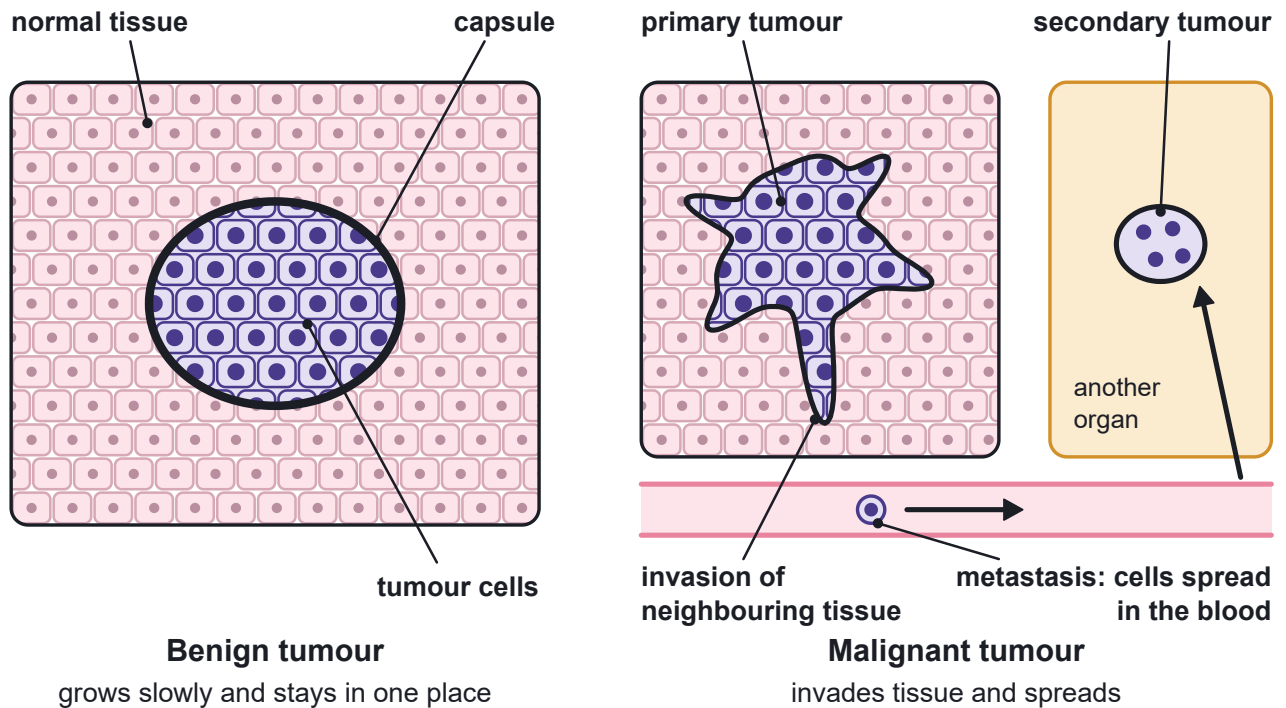
Genes that control the cell cycle		
	Proto-oncogenes	Tumour suppressor genes
Normal role	Code for proteins that stimulate the cell cycle when division is needed	Code for proteins that slow or stop the cell cycle, for example if DNA is damaged (p53 is a well-known example)
Effect of mutation	Converted 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**.



[\(opens full size in a new tab\)](#)

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?

2 Gene expression Spec D2.2 HL only

Gene expression and its regulation Spec D2.2.1, D2.2.2, D2.2.3

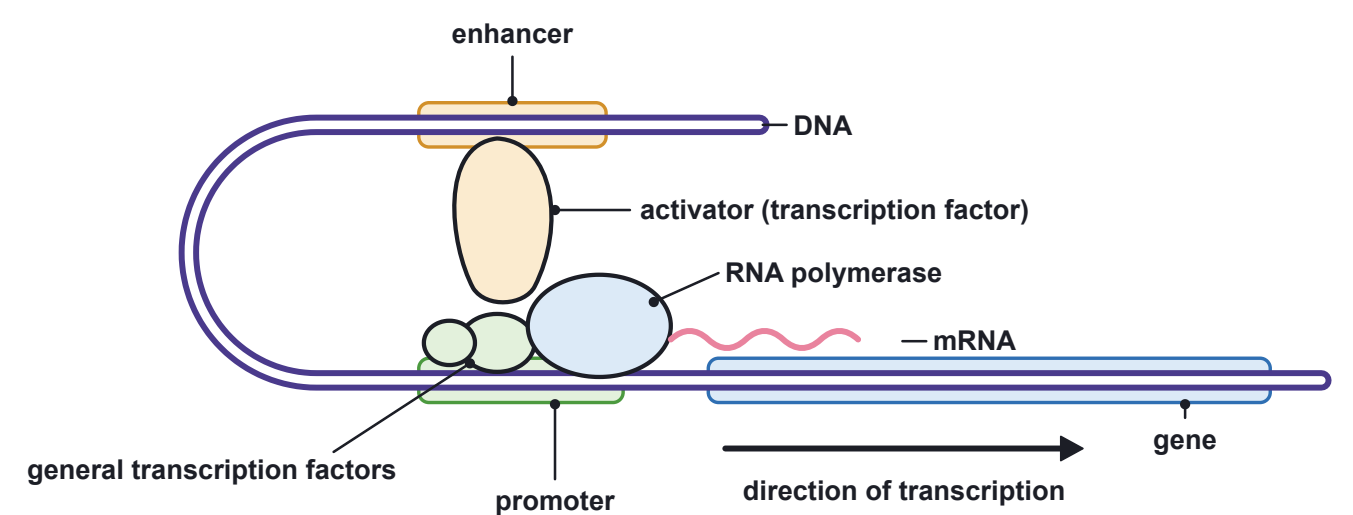
Gene expression is the mechanism by which the information in a gene has an effect on the **phenotype**. The most common stages are **transcription** (making mRNA from the gene), **translation** (making a polypeptide from the mRNA) and the **function of the protein product**, for example an enzyme that catalyses a reaction producing a pigment.

Regulation of transcription

Transcription is regulated by **proteins that bind to specific base sequences in DNA**. Each binding protein has a shape that fits only one base sequence.

Promoter	A base sequence just before (upstream of) a gene where RNA polymerase binds to start transcription.
Transcription factor	A protein that binds to a specific base sequence in DNA, such as a promoter or enhancer, and increases or decreases the rate of transcription of a gene.
Enhancer	A base sequence, which can be some distance from the gene, where activator transcription factors bind to increase the rate of transcription.

RNA polymerase usually cannot bind to a promoter on its own. **General transcription factors** must bind to the promoter first. **Activator** proteins binding to enhancers increase the rate of transcription, while **repressor** proteins can block it. Different cells contain different transcription factors, so they express different genes.



[\(opens full size in a new tab\)](#)

An **activator** bound to an **enhancer** interacts with the transcription factors and RNA polymerase at the **promoter**, increasing the rate of transcription.

Control of mRNA degradation

The amount of protein made also depends on how long each mRNA molecule lasts, because the same mRNA can be translated many times. mRNA is broken down by enzymes called **nucleases**. In human

cells, mRNA may persist for anything from **minutes up to days**. By changing the rate of breakdown of a particular mRNA, a cell regulates how much **translation** of that gene happens.

Exam tip: Linking question: what mechanisms are there for inhibition in biological systems? Repressor proteins blocking transcription and nucleases destroying mRNA both inhibit gene expression; compare them with enzyme inhibition (C1.1).

Epigenesis, the transcriptome and epigenetic tags Spec D2.2.4, D2.2.5, D2.2.6

Epigenesis is the development of patterns of differentiation in the cells of a multicellular organism. A zygote divides to form cells that become specialised in different ways: muscle, nerve, skin. All these cells have the same DNA. What differs is which genes are switched on.

Epigenetic changes **do not alter the DNA base sequence**. So they alter the **phenotype** of a cell, but not its **genotype**.

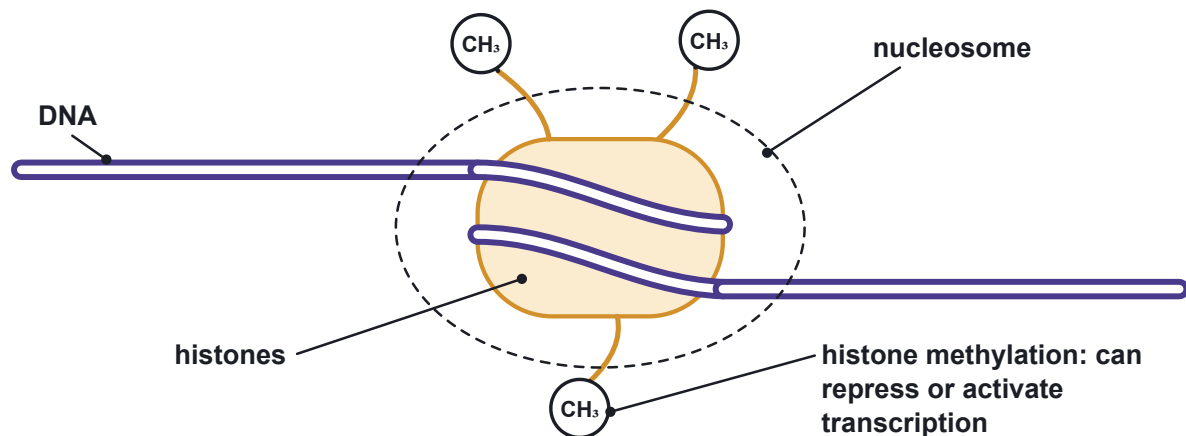
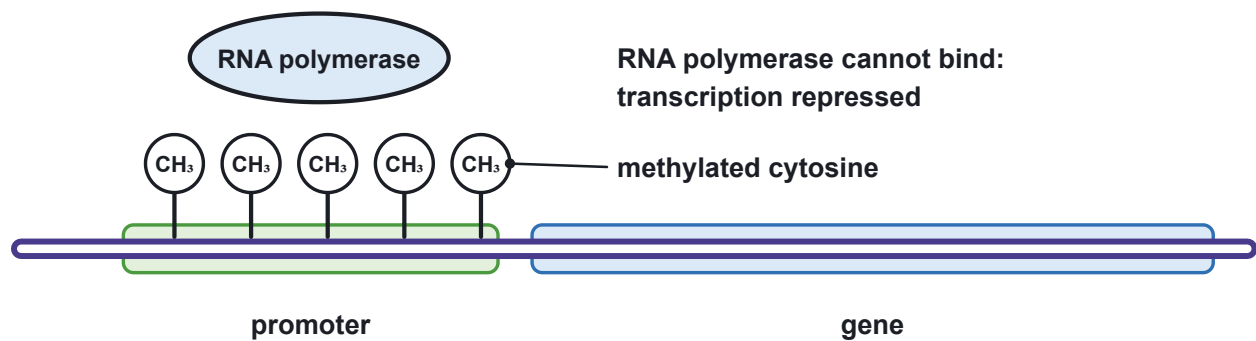
Genome, transcriptome and proteome

Three sets of molecules in a cell		
Term	Meaning	Same in all cells of an organism?
Genome	All of the genetic information (DNA) of the cell	Yes (almost always)
Transcriptome	All the RNA molecules transcribed in the cell at a given time	No: depends on which genes are being transcribed
Proteome	All the proteins produced by the cell at a given time	No: depends on which mRNAs are translated

No cell expresses all of its genes. The pattern of gene expression in a cell determines how it differentiates. A red blood cell precursor transcribes the haemoglobin genes, for example, but not the genes for the digestive enzymes made in the pancreas.

Methylation as an epigenetic tag

- **DNA methylation:** methyl groups are added to **cytosine** bases in the DNA of a **promoter**. This **represses transcription**, so the gene downstream is not expressed.
- **Histone methylation:** DNA is wound around histones in **nucleosomes**. Methyl groups added to amino acids in the histones can cause transcription to be **repressed or activated**, depending on which amino acid is methylated.



[\(opens full size in a new tab\)](#)

Epigenetic tags: methylation of cytosine in a promoter represses transcription; methylation of histones can repress or activate it.

Common mistake: Methylation does not change a base into another base or change the sequence. The base is still cytosine; it just carries a methyl tag.

Epigenetic inheritance and the environment Spec D2.2.7, D2.2.8, D2.2.9, D2.2.10

Epigenetic inheritance is the passing on of phenotypic changes in a cell or organism to daughter cells or offspring **without changes in the nucleotide sequence of DNA**. This can happen if epigenetic tags, such as DNA methylation or histone modification, **remain in place during mitosis or meiosis**.

In mitosis, methylation patterns are copied onto new DNA, so a differentiated cell such as a skin cell produces more skin cells. This is how a tissue keeps its pattern of gene expression.

Environmental effects on gene expression

The environment can change epigenetic tags. **Air pollution** is the example to learn. Studies of people exposed to high levels of air pollution, such as fine particles and polycyclic aromatic hydrocarbons (PAHs) from traffic and burning fuels, have found altered **methyl tags on DNA** in their blood cells. Some genes gain methyl tags and others lose them. For example, children with asthma living in a city with heavily polluted air had more methylation of the promoter of *FOXP3*, a gene needed by regulatory T cells that dampen immune responses, than children with asthma in a cleaner city. More methylation means less transcription, so their regulatory T cells worked less well, which is linked to worse asthma symptoms.

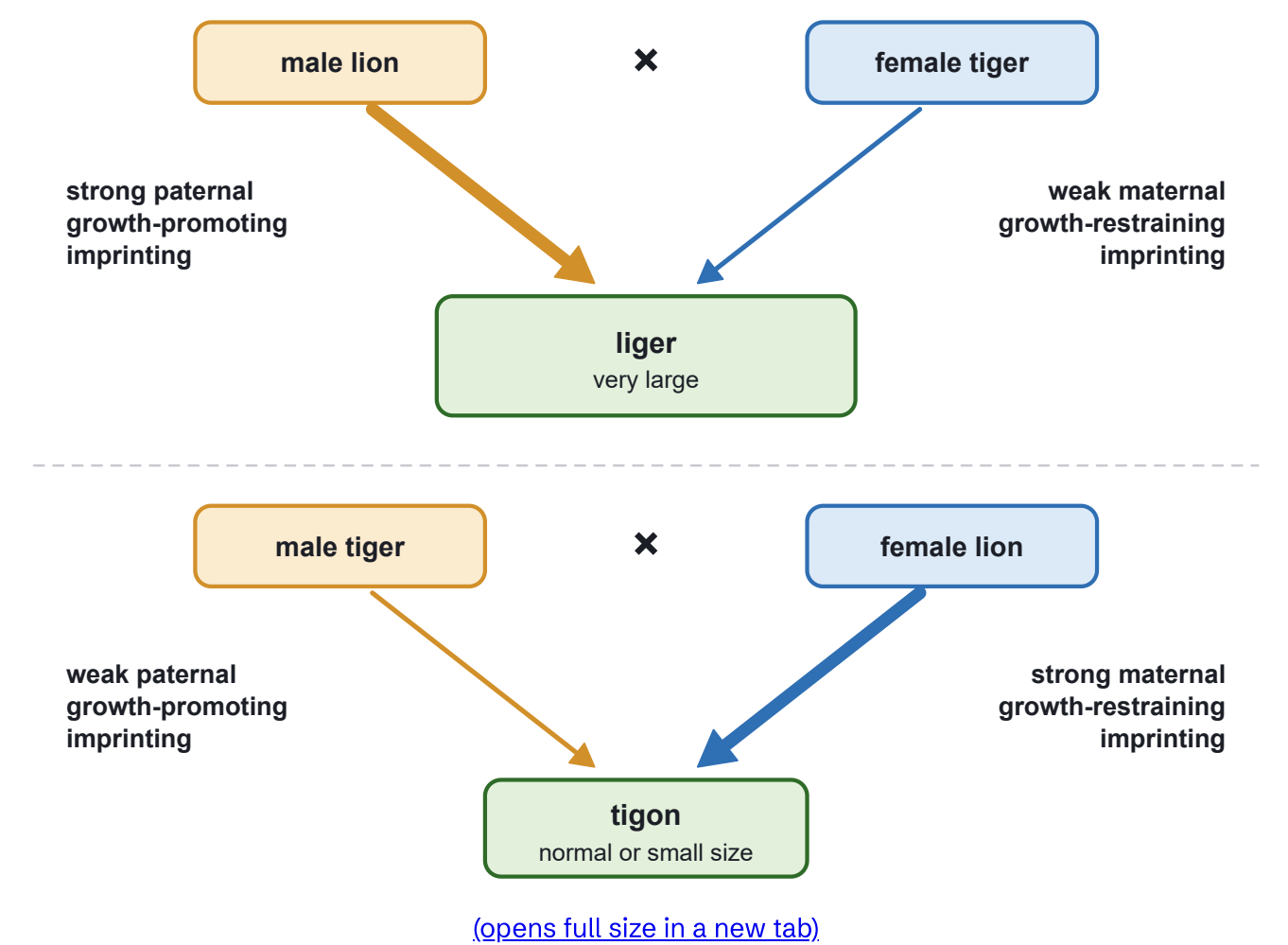
Removal of most but not all tags from gametes

During the formation of the **ovum and sperm**, and soon after fertilisation, **most** epigenetic tags are removed, so the zygote can develop all cell types. **Not all** are removed. Some genes keep tags that

depend on which parent they came from. This is **genomic imprinting**: for an imprinted gene, the copy from one parent is silenced by methylation, so the gene is expressed only from the mother's copy or only from the father's copy. Several imprinted genes control growth before birth. In general, some **growth-promoting** genes are expressed only from the father's copy, and some **growth-restraining** genes only from the mother's copy.

Tigons and ligers (lion-tiger hybrids)		
Hybrid	Parents	Phenotype
Liger	Male lion × female tiger	Grows much larger than either parent
Tigon	Male tiger × female lion	Similar in size to, or smaller than, the parents

Both hybrids have one set of chromosomes from a lion and one from a tiger, so the difference in size is put down to **epigenetics**: which parent each set of imprinted genes came from. The most widely accepted hypothesis is this. In lions, the paternal growth-promoting imprinting is strong, and it is balanced by strong maternal growth-restraining imprinting in lionesses. In tigers, both effects are weaker. A **liger** inherits strong growth promotion from its lion father but only weak restraint from its tigress mother, so it grows much larger than either parent. A **tigon** inherits only weak growth promotion from its tiger father but strong restraint from its lioness mother, so it is no larger than its parents and is often smaller.



Genomic imprinting explains why ligers grow much larger than tigons. Arrow thickness shows the strength of each effect.

Monozygotic twin studies

Monozygotic (identical) twins develop from one zygote, so they have the same genome. Any differences between them must come from the **environment** and its effect on gene expression. Studies comparing twins show that their methylation patterns are very similar when they are young but become **more different as they get older**, especially if they have lived apart with different diets, habits and exposures. This shows the environment changing epigenetic tags.

Exam tip: Linking question: in what ways does the environment stimulate diversification? Twin studies are the classic evidence that the same genotype can produce different phenotypes through epigenetic changes.

External factors and gene expression Spec D2.2.11

Cells change which genes they express in response to signals from outside the cell. Two examples are a hormone in animals and a nutrient in bacteria.

A hormone: oestrogen

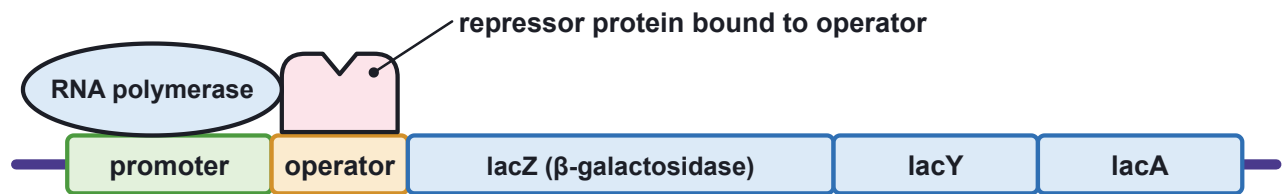
1. Oestrogen is a steroid hormone, so it diffuses through the cell membrane of target cells, for example cells of the uterus lining.
2. Inside the cell (mainly in the nucleus) it binds to a specific **oestrogen receptor** protein.
3. The hormone–receptor complex acts as a **transcription factor**: it binds to specific base sequences in DNA near target genes.
4. Transcription of those genes increases, so the cell makes new proteins, for example those needed for the uterus lining to thicken.

A biochemical: lactose in *E. coli*

The bacterium *Escherichia coli* only makes the enzymes for using lactose when lactose is present. The genes for these proteins (including β -galactosidase, which hydrolyses lactose) are together in the **lac operon**, controlled by one promoter and an **operator** sequence.

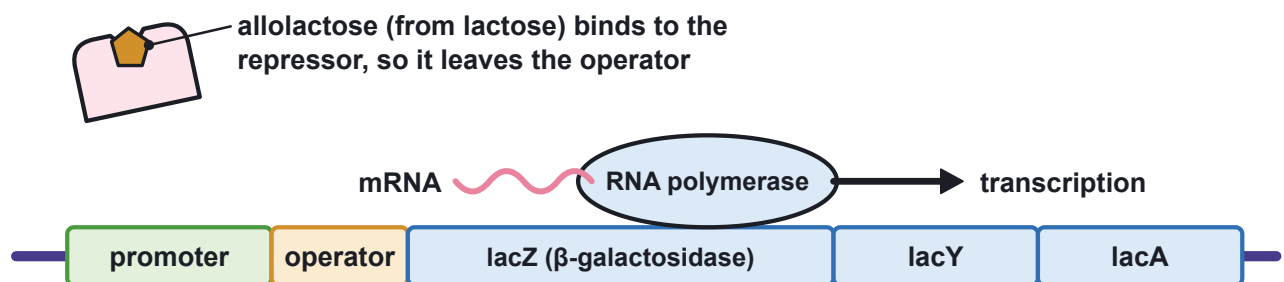
The lac operon		
Condition	What happens	Result
Lactose absent	A repressor protein binds to the operator and blocks RNA polymerase	Genes not transcribed: no enzymes wasted
Lactose present	Allolactose (an isomer formed from lactose) binds to the repressor, changing its shape so it detaches from the operator	RNA polymerase transcribes the genes; enzymes for lactose uptake and breakdown are made

Lactose absent



RNA polymerase is blocked: the genes are not transcribed and no enzymes are made

Lactose present



RNA polymerase transcribes the genes: enzymes for lactose uptake and breakdown are made

[\(opens full size in a new tab\)](#)

The **lac operon**: with no lactose the repressor blocks transcription; lactose (as allolactose) releases the repressor so the genes are transcribed.

Exam tip: The guide asks for one hormone and one biochemical such as lactose or tryptophan. Learn one of each thoroughly and describe the binding to a specific DNA base sequence.

Quick check

1. What are the three most common stages in gene expression?
2. What is a transcription factor?
3. What effect does methylation of cytosine in a promoter have?
4. Why do monozygotic twins become more different with age?

3 Water potential Spec D2.3

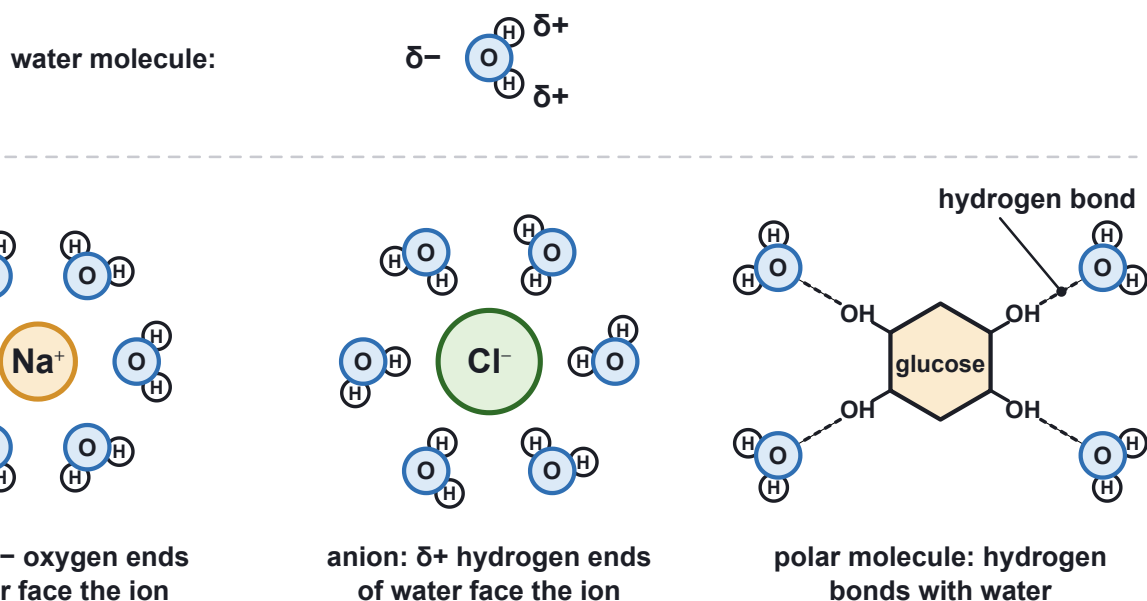
Solvation and osmosis Spec D2.3.1, D2.3.2, D2.3.3

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.



[\(opens full size in a new tab\)](#)

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.

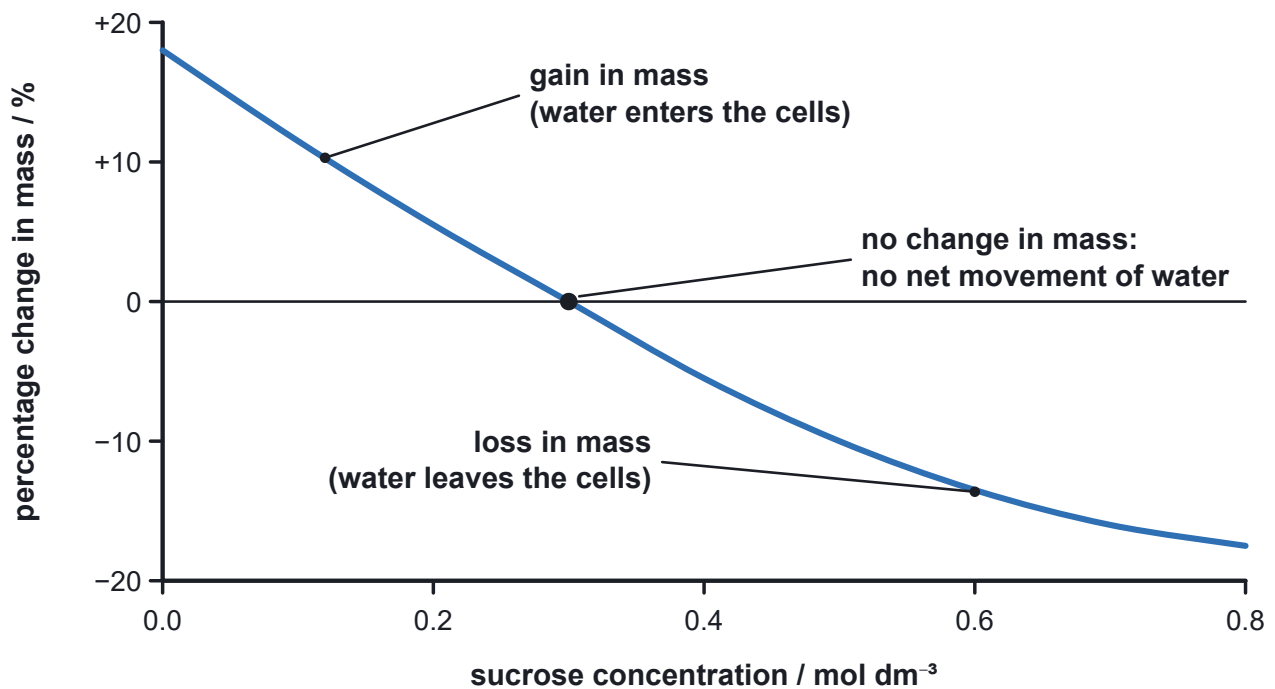
$$\text{percentage change} = (\text{final value} - \text{initial value}) \div \text{initial value} \times 100$$

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).



[\(opens full size in a new tab\)](#)

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

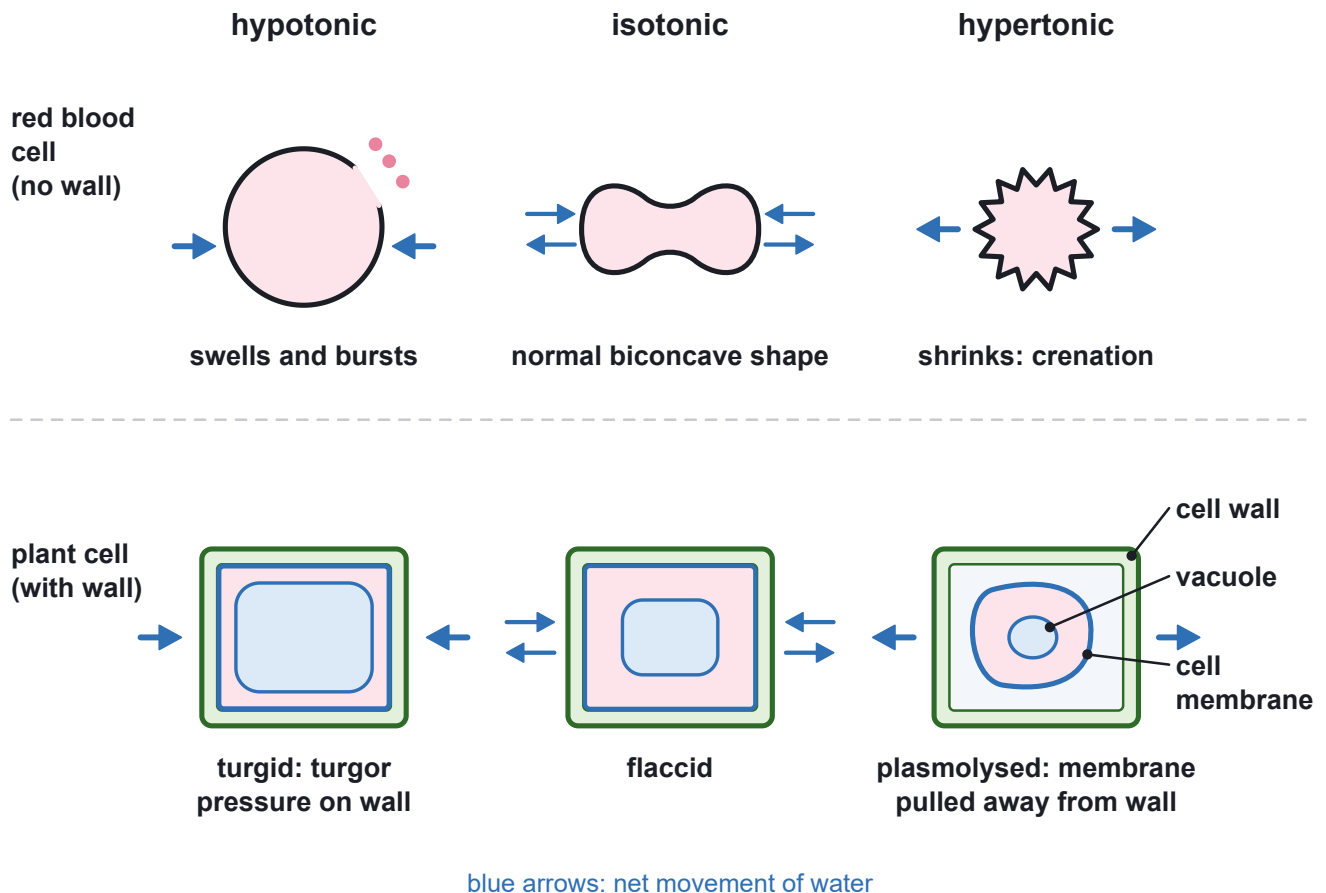
- **Hypotonic medium:** water enters, the cell **swells** and, with no wall to resist, may **burst** (red blood cells burst, called haemolysis).
- **Hypertonic medium:** water leaves, the cell **shrinks** and the membrane becomes wrinkled and spiky (**crenation**).

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.



blue arrows: net movement of water

[\(opens full size in a new tab\)](#)

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.

Water potential Spec D2.3.8, D2.3.9, D2.3.10, D2.3.11 HL only

Water potential (ψ_w) is the **potential energy of water per unit volume**. The absolute amount of potential energy cannot be measured, so values are given **relative to pure water at atmospheric pressure and 20°C**, which is defined as **zero**. The units are usually **kilopascals (kPa)**.

Movement from higher to lower water potential

Water always moves **from a higher water potential to a lower water potential**. This is the same as any movement that lowers potential energy, like a ball rolling downhill. Dissolving solutes lowers the

potential energy of water, because water molecules are held in shells around the solute particles. Pressure raises it.

Solute potential and pressure potential

$$\psi_w = \psi_s + \psi_p$$

Solute potential (ψ_s)	The effect of dissolved solutes on water potential. It ranges from zero (pure water) downwards: the more concentrated the solution, the more negative ψ_s .
Pressure potential (ψ_p)	The effect of pressure on water potential. It is generally positive inside cells, because the wall pushes back on the protoplast; it is negative in xylem vessels where sap is transported under tension.

Predicting the direction of water movement

A plant cell has a solute potential of -800 kPa and a pressure potential of $+300$ kPa. It is placed in a solution with a water potential of -650 kPa. Calculate the water potential of the cell and state the direction of net water movement.

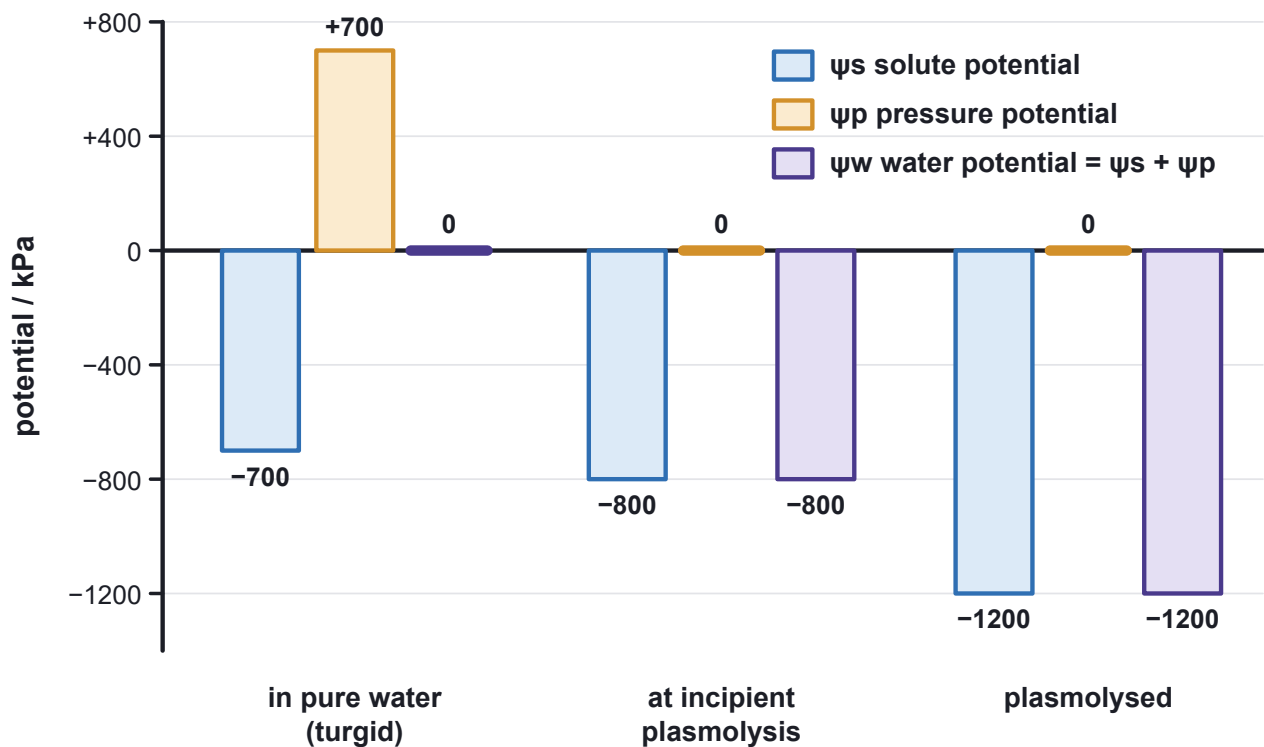
1. $\psi_w = \psi_s + \psi_p = -800 + 300 = -500$ kPa.
2. The solution (-650 kPa) has a lower water potential than the cell (-500 kPa).
3. Water moves from higher to lower water potential: out of the cell into the solution.

Answer: ψ_w of the cell = -500 kPa; net movement of water is out of the cell.

Water potential and plant tissue

Plant tissue bathed in hypotonic and hypertonic solutions

	Hypotonic solution	Hypertonic solution
Starting point	ψ_w of solution is higher than ψ_w of cells	ψ_w of solution is lower than ψ_w of cells
Water movement	Into the cells	Out of the cells
Change in ψ_s	Rises slightly (less negative) as the cell sap is diluted	Falls (more negative) as the cell sap becomes more concentrated
Change in ψ_p	Rises as the protoplast presses on the wall	Falls to zero as the cell becomes flaccid; it stays near zero during plasmolysis
End point	Net uptake stops when ψ_w of the cells equals ψ_w of the solution (the cells are turgid)	Net loss stops when ψ_w of the cells equals ψ_w of the solution (the cells are plasmolysed)



[\(opens full size in a new tab\)](#)

$\psi_w = \psi_s + \psi_p$: as the cell loses water, ψ_p falls to zero and ψ_w becomes more negative (illustrative values).

Exam tip: In pure water a turgid cell reaches $\psi_w = 0$ because ψ_p becomes equal and opposite to ψ_s . Always state values with their signs and units, and compare water potentials, not solute concentrations, when using this model.

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?
5. **HL only** What is the water potential of pure water at atmospheric pressure and 20°C?

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.

Gene expression

1. Transcription, translation and the function of the protein product (such as an enzyme).
2. A protein that binds to a specific base sequence in DNA, such as a promoter or enhancer, to regulate transcription.
3. It represses transcription of the gene downstream.
4. They have identical genomes, but different environments change their epigenetic tags and so their gene expression.

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.
5. Zero (0 kPa).