REVISION GUIDE

Copy, divide, *check*

The cell cycle and its regulation

Every cell in you came from a cell that copied itself and split in two. Follow a cell around its cycle, watch mitosis hand a complete genome to each daughter cell, see how checkpoints, cyclins and kinases decide when to go, and what happens when cells stop listening.

8 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ap-biology-unit-4-cell-cycle

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	Answers	29

By the end you can

- [ ] Explain how mitosis passes a complete genome to two genetically identical daughter cells, and its roles in growth, tissue repair and asexual reproduction 4.5.B
- [ ] Describe a chromosome before and after its DNA is copied, and why chromosomes condense before mitosis 4.5.B
- [ ] Describe the stages of the cell cycle (G1, S, G2, mitosis and cytokinesis) and how a cell can leave the cycle into G0 or be held at a stage 4.5.A
- [ ] Describe prophase, metaphase, anaphase and telophase, and track the number of chromosomes and chromatids through them 4.5.B
- [ ] Compare cytokinesis in animal and plant cells 4.5.A
- [ ] Describe the G1, G2 and M checkpoints, and how cyclins and cyclin-dependent kinases control progress through the cycle 4.6.A
- [ ] Describe how disruptions to the cell cycle can lead to cancer or to apoptosis 4.6.B

Tick each one when you can do it without the book.

01

4.5.B WHY CELLS DIVIDE

One cell, two *copies*

Scrape your knee and, within a week or two, new skin has closed the gap. Every one of those new cells came from a cell that was already there, dividing in two. The cell that divides is the **parent cell**, and it ends as two **daughter cells**.

In eukaryotes, the division that makes body cells is **mitosis**. It has one job: to hand a complete copy of the cell's **genome**, every chromosome, to each of two daughter cells. So the daughters are **genetically identical** to each other and to the parent.

Organisms use that for three things. **Growth**: you began as one cell and are now tens of trillions. **Tissue repair**: the cells around a wound divide to replace the ones that were lost. **Asexual reproduction**: a yeast cell budding, a strawberry plant sending out runners or a hydra growing a bud make offspring that are copies of one parent.

The figure shows the order it all happens in. The nucleus divides first, so there is a nucleus ready for each new cell; then the cytoplasm divides between them.

KEY POINTS

- New cells come only from existing cells dividing.
- Mitosis passes a complete genome to two genetically identical daughter cells.
- It serves growth, tissue repair and asexual reproduction.

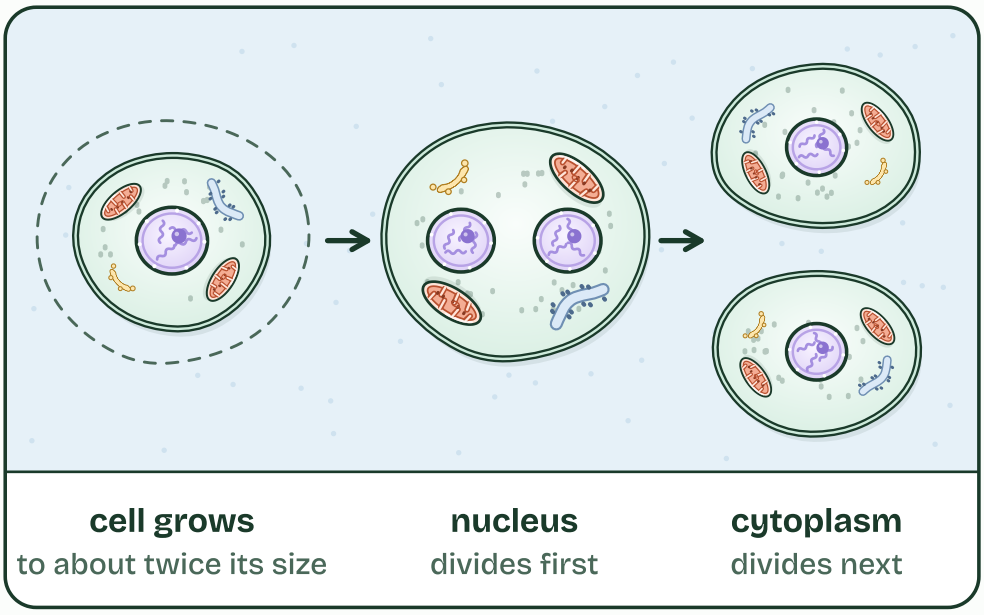
KEY TERMS

parent cell
The cell that divides. It does not survive alongside its daughters: it becomes them.

daughter cells
One of the two cells made when a parent cell divides.

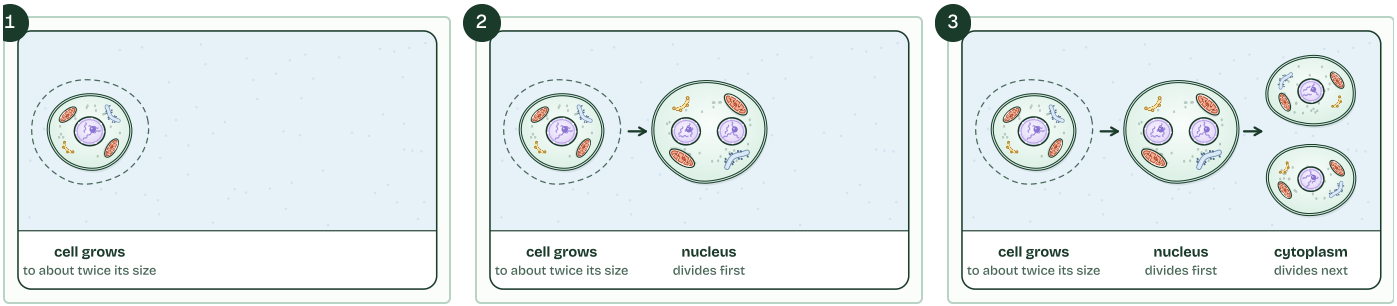
mitosis
Division of the nucleus that gives two nuclei, each with a complete copy of the parent cell's genome and the same number of chromosomes.

genome
All of the genetic information in a cell: every chromosome and the DNA it carries.



STEP BY STEP

3 STEPS



A **parent cell** grows to about twice its starting size.

Its **nucleus divides** first, so there are two.

Then the cytoplasm divides: two **daughter cells**, each with a nucleus.

WATCH OUT

Identical does not mean the same size or job. Two daughter cells carry the same DNA, but they can go on to use different genes and become different kinds of cell.

PREDICT

A gardener cuts a stem from a geranium and it roots into a new plant. How do the new plant's cells compare with the parent plant's?

(A) Each one holds half the parent's DNA, because a cutting has only one parent to inherit from

(B) They mix the parent's genes into new combinations, so the cutting is a little different from it

(C) They have the same genome as the parent, since every one was made by mitosis from its cells

Decide before you look. Answer on page 29.

02 Copied, then *coiled*

4.5.B CHROMOSOMES AND CHROMATIDS

The DNA in one of your cells would stretch about two meters if you laid it end to end. It fits into a nucleus a few micrometers across because it is wound around proteins called **histones**. DNA with its histones is **chromatin**, and for most of a cell's life it is spread loosely through the nucleus, where its genes can be read.

A **chromosome** is one long DNA molecule with its proteins. Before a cell divides it copies every one. The two copies stay joined, and each is now a **sister chromatid**, held to its twin at a narrow region called the **centromere**.

Then, as division begins, the chromatin **condenses**: it coils on itself again and again until each chromosome is short and thick enough to be seen in a light microscope. A long tangle could not be shared out without breaking; short, separate packages can be pulled apart cleanly.

KEY POINTS

- A chromosome is one DNA molecule wound around histones.
- After copying, a chromosome is two sister chromatids joined at the centromere.
- Chromosomes condense before mitosis so they can be moved without tangling.

KEY TERMS

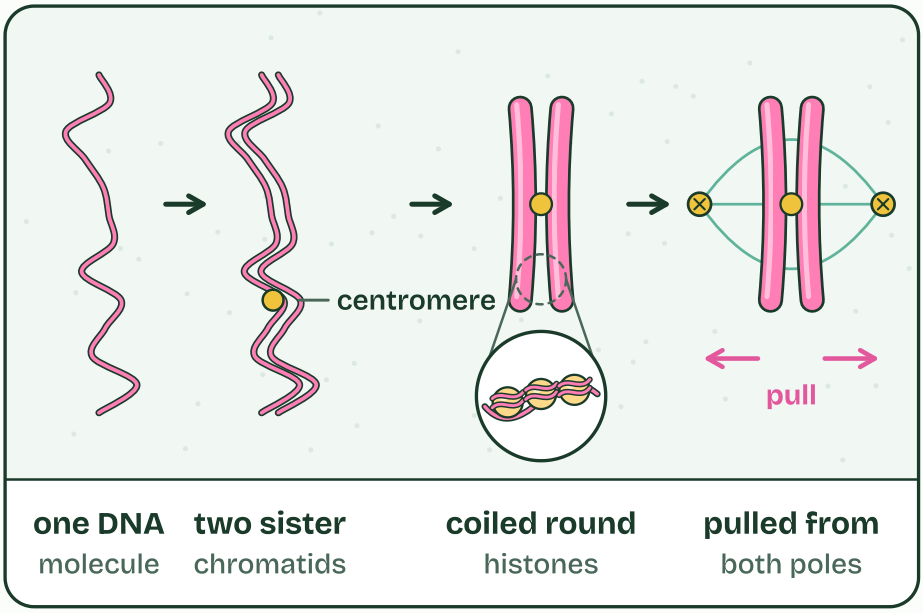
histones
Proteins that DNA winds around in a eukaryotic nucleus. They package the DNA and help it coil up tightly before division.

chromatin
DNA wound around histones. Spread out and loosely packed between divisions, it condenses into visible chromosomes before mitosis.

chromosome
One long DNA molecule with its proteins. Human body cells have 46.

sister chromatid
One of the two identical copies of a chromosome made when its DNA is replicated. Sisters stay joined at the centromere until anaphase.

centromere
The region where two sister chromatids are held together, and where spindle microtubules attach.



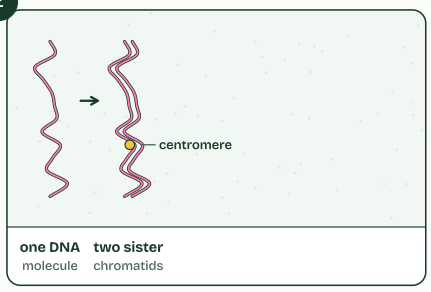
STEP BY STEP
4 STEPS

1



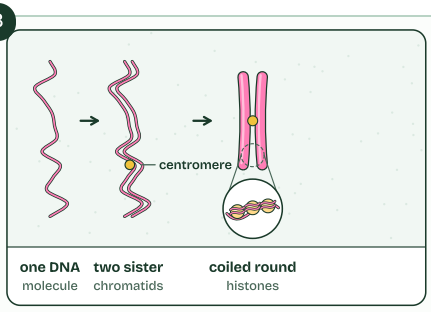
Before it is copied, a chromosome is **one DNA molecule**, long and thin.

2



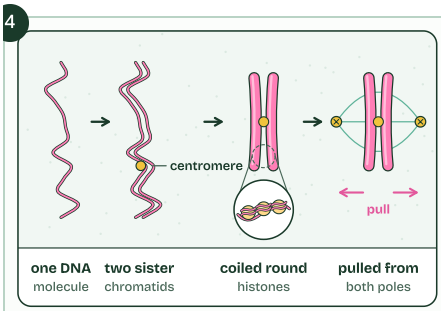
After copying it is **two sister chromatids**, joined at the centromere.

3



As division begins the DNA winds around **histones** and coils into a short, thick chromosome.

4



Microtubules from both poles attach at the centromere and pull.

WATCH OUT

Copying the DNA does not double the chromosome number. Count centromeres: a copied chromosome has one, so it is still one chromosome, made of two chromatids. A human cell about to divide has 46 chromosomes and 92 chromatids.

PREDICT

A cell has 8 chromosomes before it copies its DNA. How many DNA molecules are in its nucleus as mitosis begins?

(A) 16, because each of the 8 chromosomes is now two sister chromatids

(B) 8, because the number of chromosomes stays the same until the cell has divided

(C) 4, because the DNA has to be halved before it can be shared between two cells

Decide before you look. Answer on page 29.

03 Around the *cycle*

4.5.A THE CELL CYCLE

A dividing cell goes through the same sequence again and again, the **cell cycle**. Most of it is **interphase**, in three stages. In **G1** the cell grows, making proteins and organelles. In **S** (synthesis) it copies its DNA. In **G2** it grows more and makes what it needs to divide. Then comes **mitosis**, which divides the nucleus, and **cytokinesis**, which divides the cytoplasm. Each daughter cell starts again in G1.

Not every cell keeps going round. A cell can leave the cycle from G1 into **G0**, where it carries on with its job but does not divide. Most nerve cells and mature muscle cells stay there for life. Others wait in G0 until they are needed: liver cells rarely divide, but after part of the liver is damaged or removed they reenter the cycle and the organ grows back. A cell can also be **held** at a stage, waiting until conditions are right to go on.

KEY POINTS

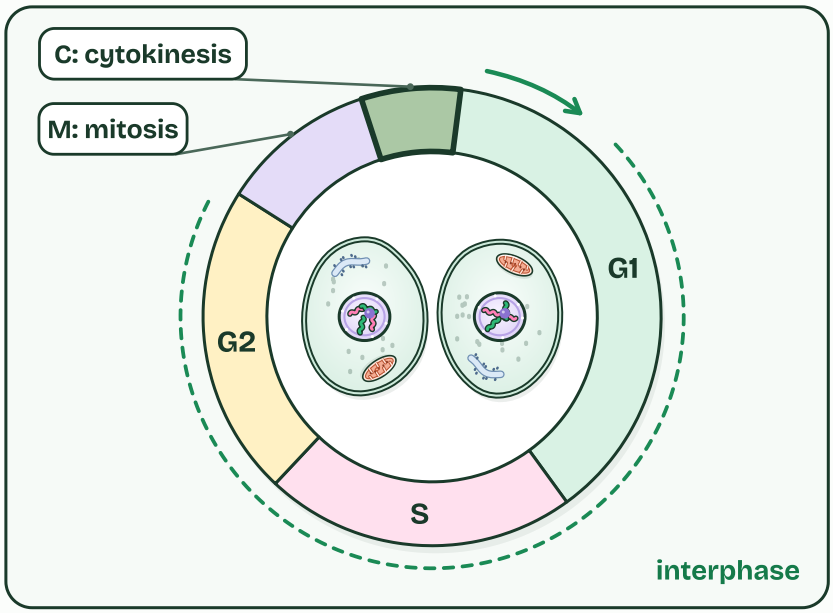
- Interphase is G1, S and G2; then mitosis and cytokinesis.
- The DNA is copied in S phase, before mitosis.
- G0: alive and working, not dividing; some cells can return to the cycle.

KEY TERMS

cell cycle
The sequence of stages from one cell division to the next: interphase (G1, S and G2), then mitosis and cytokinesis.

interphase
The part of the cell cycle between divisions, made of G1, S and G2. The cell grows, makes proteins and organelles, and copies its DNA.

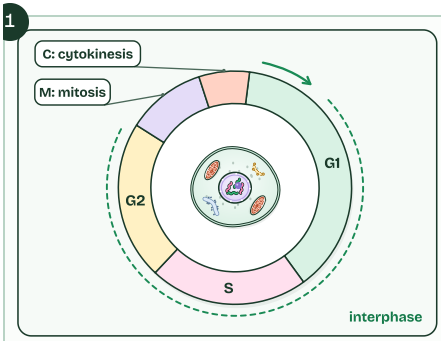
G0
A state outside the cell cycle where a cell is alive and working but no longer dividing. Some cells can leave it again when the right signal arrives.



STEP BY STEP

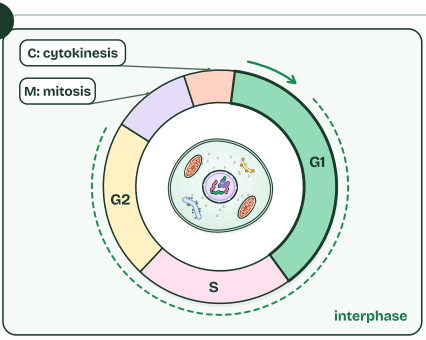
6 STEPS

1



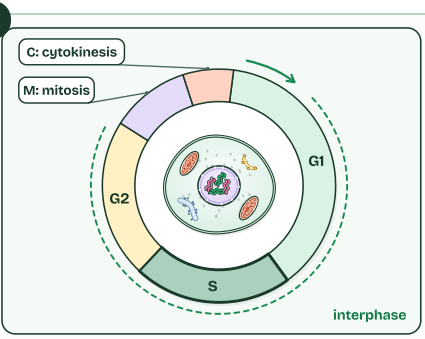
The **cell cycle**: one turn is one division.

2



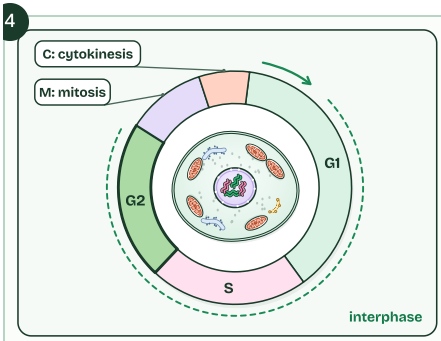
G1: the cell grows and makes proteins and organelles.

3



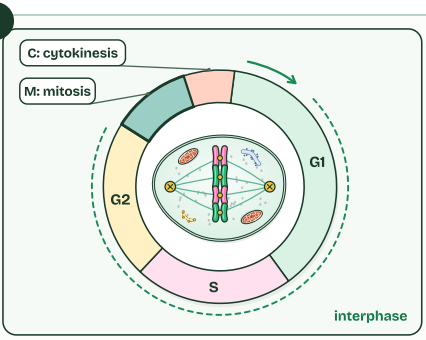
S: the DNA is copied.

4



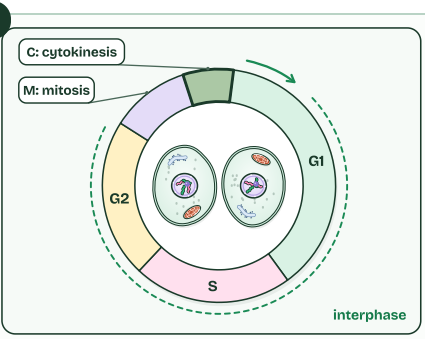
G2: more growth and preparation for division.

5



Mitosis: the nucleus divides.

6



Cytokinesis: the cytoplasm divides, giving two cells, each back in G1.

REMEMBER IT

The order of the cycle: Giraffes Sing, Gorillas Make Chili

G Giraffes	S Sing	G Gorillas	M Make	C Chili
G1 proteins and organelles	**S phase** the DNA is copied	**G2** ready to divide	**Mitosis** the nucleus divides	**Cytokinesis** the cytoplasm divides

WATCH OUT

Interphase is not a resting stage. The cell is growing, making new proteins, membranes and organelles, and copying all of its DNA. A typical dividing cell spends about nine tenths of its cycle in interphase.

PREDICT

Compare a cell in G2 with the same cell earlier, in G1. What does it have in G2?

(A) The same amount of DNA, but more cytoplasm and more mitochondria than it had in G1

(B) Twice the DNA, because every chromosome has been copied into two chromatids

(C) Half the DNA, because some of its chromosomes have already been pulled to the poles

Decide before you look. Answer on page 29.

04 4.5.B MITOSIS
A complete genome, *twice*

Mitosis is one smooth process. Biologists split it into four phases to talk about it, but the cell does not pause between them. Watch the film through once without stopping, and keep your eye on one chromosome.

The whole process is built around one fact: each chromosome arrives as two identical sister chromatids. The cell builds a **spindle** of microtubules from two poles, attaches every chromosome to both poles, lines them all up, and then pulls the two chromatids of each chromosome in opposite directions. One copy of every chromosome ends up at each end of the cell.

That is why mitosis gives **genetically identical** nuclei. Nothing is shuffled and nothing is halved: each daughter nucleus gets one chromatid of every chromosome, and the two chromatids were copies of each other. A human cell with 46 chromosomes makes two daughter cells with 46 each.

In the cell cycle, mitosis alternates with interphase: copy the DNA, divide, copy, divide. A cell never goes through mitosis twice without copying its DNA in between.

KEY POINTS

- A spindle attaches every chromosome to both poles.
- Sister chromatids are pulled to opposite poles: one copy of each chromosome to each end.
- Daughter nuclei are identical to each other and to the parent.

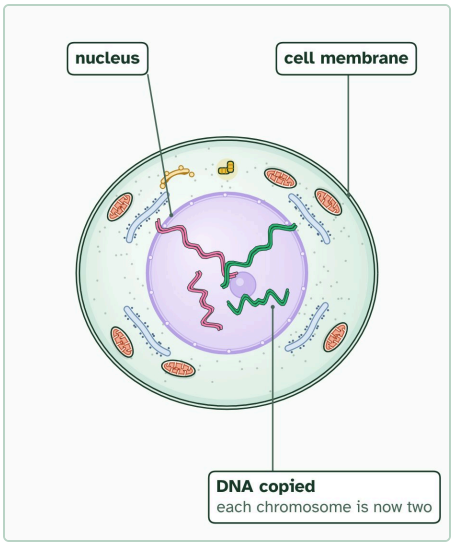
KEY TERMS

spindle
A framework of microtubules that grows from the two poles of a dividing cell, attaches to the chromosomes and moves them.

ANIMATION · MITOSIS, ONE PHASE AT A TIME

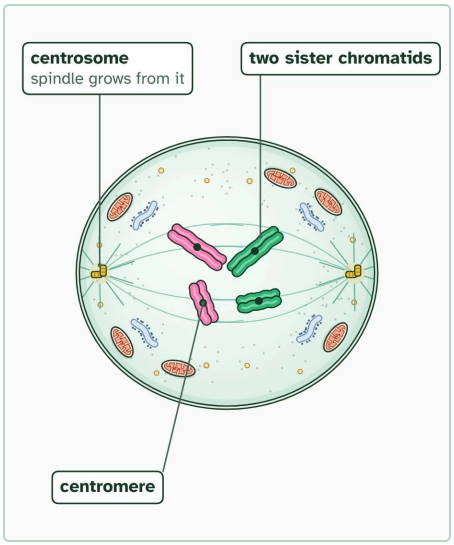
7 MOMENTS

1 INTERPHASE



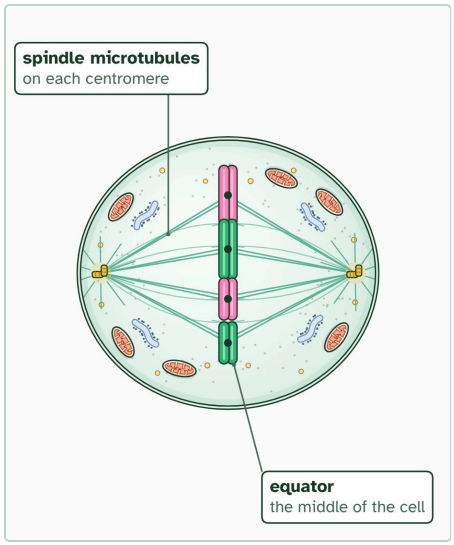
After copying, each chromosome is **two DNA molecules**, the sister chromatids, held together at the centromere.

2 PROPHASE



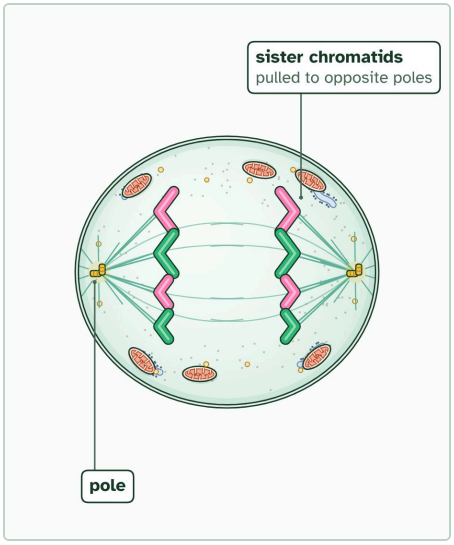
The **nuclear membrane** breaks down and the centrosomes move apart. **Spindle microtubules** grow from them.

3 METAPHASE



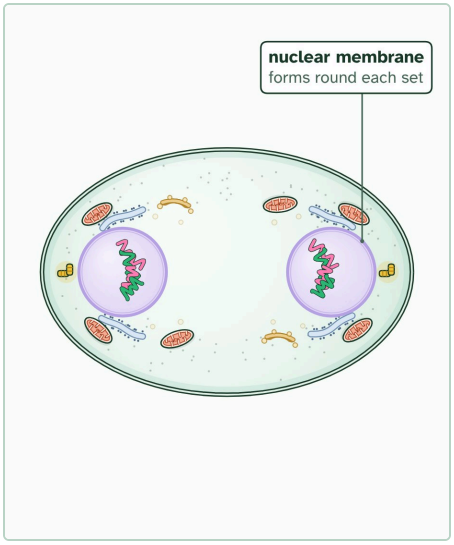
Metaphase. Microtubules from both poles attach to each centromere and line the chromosomes up on the **equator**.

4 ANAPHASE



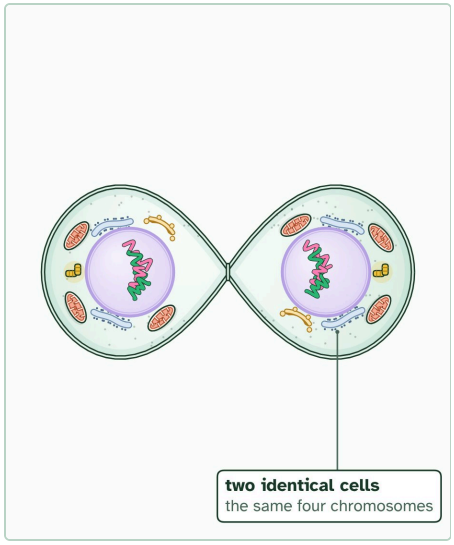
Anaphase. The centromeres split. Microtubule motors pull the **sister chromatids** to opposite poles.

5 TELOPHASE



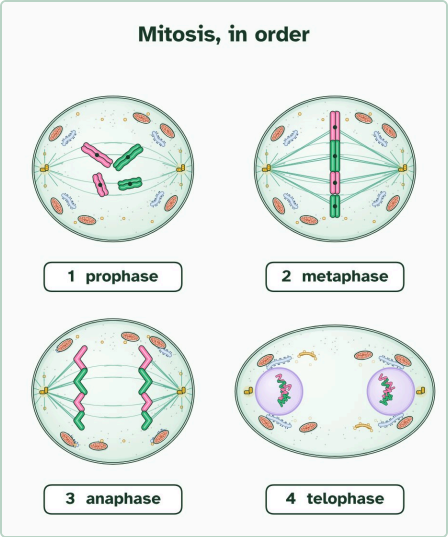
Telophase. A nuclear membrane forms round each group, the chromosomes uncoil and the spindle breaks down.

6 CYTOKINESIS



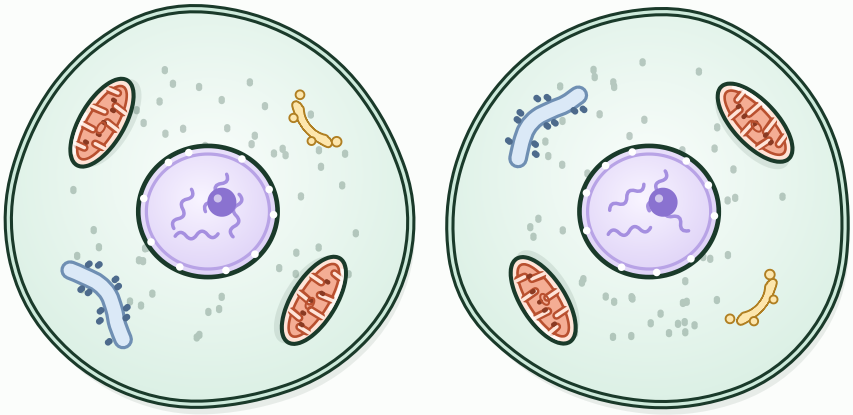
Cytokinesis. A ring of actin and myosin pinches the cell in two. Each daughter nucleus has one copy of every chromosome: they are **genetically identical**.

7 THE FOUR PHASES



Prophase, metaphase, anaphase, telophase: make up your own way to remember the order.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-4-cell-cycle#mitosis



one cell, then two

The short version, on a loop: chromosomes line up on the spindle, the chromatids are pulled apart, and one cell becomes two.

WATCH OUT

In mitosis each chromosome lines up on its own. Matching chromosomes from the two parents do not pair up; that happens only in meiosis, which makes gametes (Unit 5).

PREDICT

A dog's body cells have 78 chromosomes. A skin cell divides by mitosis. How many chromosomes does each daughter cell have?

(A) 39, because the chromosomes are shared out between the two daughter cells

(B) 156, because the chromosomes were all copied before the skin cell divided

(C) 78, because each daughter cell gets one chromatid of every chromosome

Decide before you look. Answer on page 29.

05 Four phases, one *at a time*

4.5.B THE PHASES OF MITOSIS

Prophase. The chromosomes condense and become visible, each as two sister chromatids. The nuclear envelope breaks down, and the spindle starts to grow from the two poles. **Metaphase.** Microtubules from both poles attach at each centromere, and the chromosomes line up in a single row across the middle of the cell. **Anaphase.** The centromeres split and the sister chromatids are pulled to opposite poles; from this moment, each chromatid counts as a chromosome of its own. **Telophase.** A nuclear envelope forms around each group, the chromosomes uncoil and the spindle breaks down.

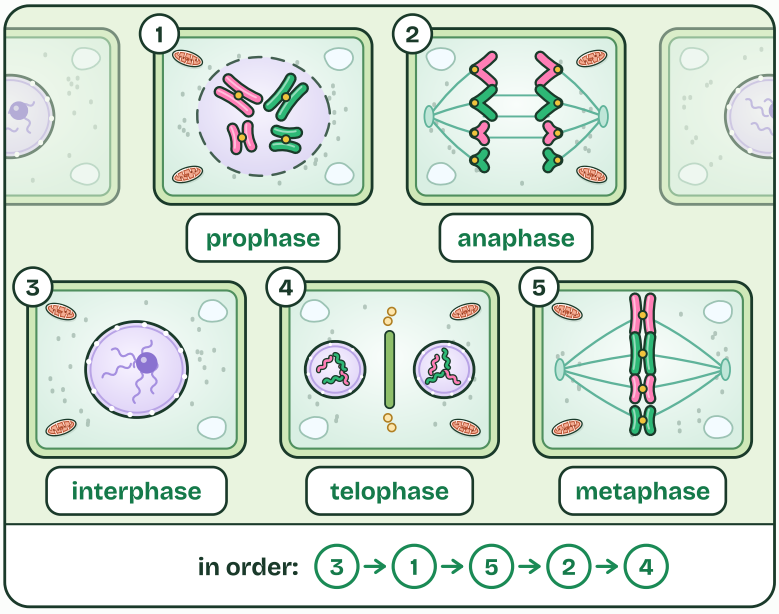
Keep count as you go. The number of chromosomes is the number of centromeres, so it only changes in anaphase, when the centromeres split, and again when the cell divides.

A human body cell through the cycle (DNA: molecules)

Stage	Chromosomes	Chromatids	DNA
G1	46	not yet copied	46
G2 to metaphase	46	92	92
Anaphase	92	separated	92
Each daughter cell	46	not yet copied	46

KEY POINTS

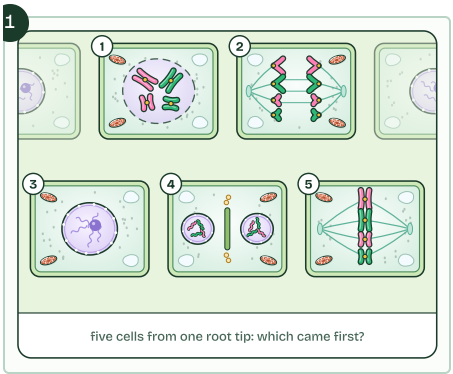
- Prophase: condense, envelope breaks down, spindle forms.
- Metaphase: chromosomes in one row on the middle of the spindle.
- Anaphase: sister chromatids separate. Telophase: two new nuclei.



STEP BY STEP

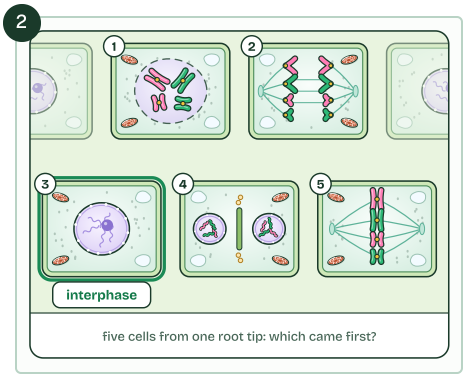
7 STEPS

1



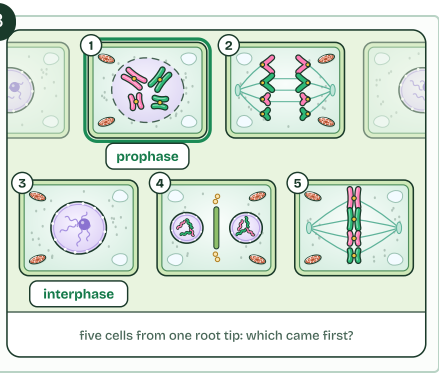
Five drawn cells from a root tip. **Name each one** before you go on.

2



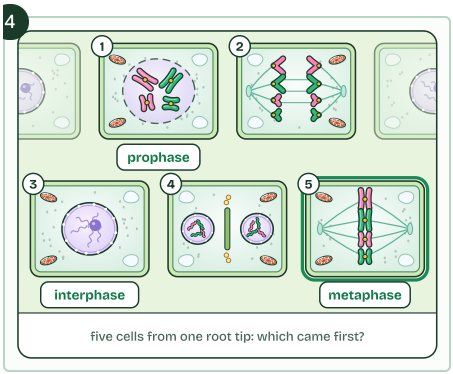
Interphase: a round nucleus and a dark nucleolus.

3



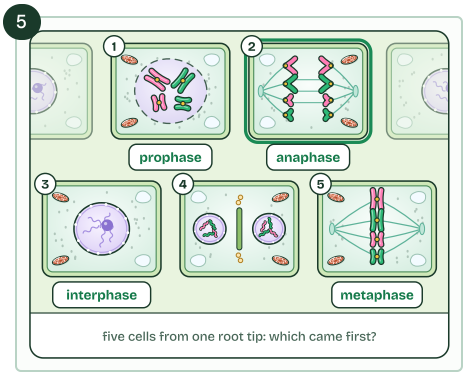
Prophase: thick threads, the nuclear envelope going.

4



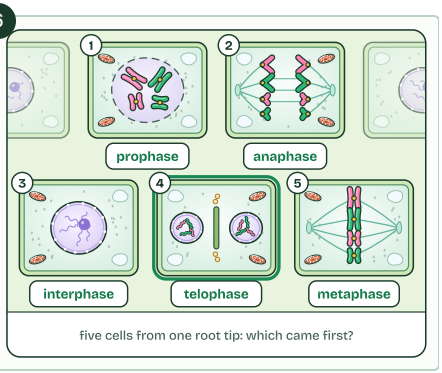
Metaphase: chromosomes in a line across the middle.

5



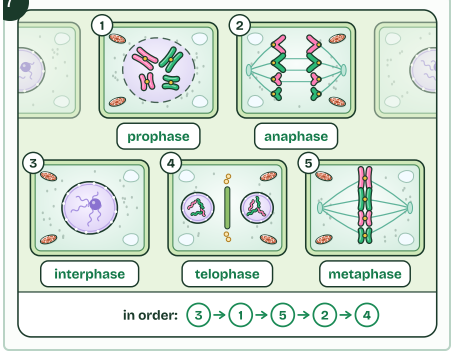
Anaphase: chromatids pulled to opposite ends.

6



Telophase: two nuclei and a new cell plate.

7



In the order of the process: 3, 1, 5, 2, 4.

REMEMBER IT

The four phases, in order: Penguins March Across Town

P	M	A	T
Penguins	March	Across	Town
Prophase	**Metaphase**	**Anaphase**	**Telophase**
condense; envelope goes	a line across the middle	chromatids pulled apart	two nuclei form

WATCH OUT

Two separate small cells side by side are not in telophase. In telophase the two new nuclei are still inside one cell, which is only starting to divide.

PREDICT

The drug colchicine stops microtubules forming. Root tip cells are soaked in it for a few hours. Where do the dividing cells get stuck?

(A) Condensed, as in early metaphase, but never lined up or pulled apart

(B) In anaphase, with the sister chromatids apart but unable to reach the two poles

(C) In interphase, because without microtubules the cell can no longer copy its DNA

Decide before you look. Answer on page 29.

06

4.5.A CYTOKINESIS

Splitting the *cytoplasm*

Mitosis leaves one cell with two nuclei. **Cytokinesis** finishes the job by dividing the cytoplasm, usually starting while telophase is still under way. Animal and plant cells do it in different ways, because a plant cell is boxed in by a rigid wall.

In an **animal cell**, a ring of actin and myosin filaments forms just inside the membrane around the middle of the cell. The ring tightens like a drawstring, and the membrane is pulled in to make a groove, the **cleavage furrow**, until the cell is pinched in two.

A **plant cell** cannot be pinched, because its wall will not bend. Instead, vesicles from the Golgi carry membrane and wall material to the middle of the cell and fuse into a flat **cell plate**. The plate grows outward until it meets the old wall, and becomes two new membranes with a new wall between them.

Each daughter cell needs more than a nucleus. Mitochondria (and chloroplasts in a plant) are made only by existing ones dividing, so each daughter must get some. Most cytokinesis is equal, so the two daughter cells are about the same size.

KEY POINTS

- Mitosis divides the nucleus; cytokinesis divides the cytoplasm.
- Animal cells: a ring of actin and myosin makes a cleavage furrow.
- Plant cells: vesicles fuse into a cell plate that becomes a new wall.

KEY TERMS

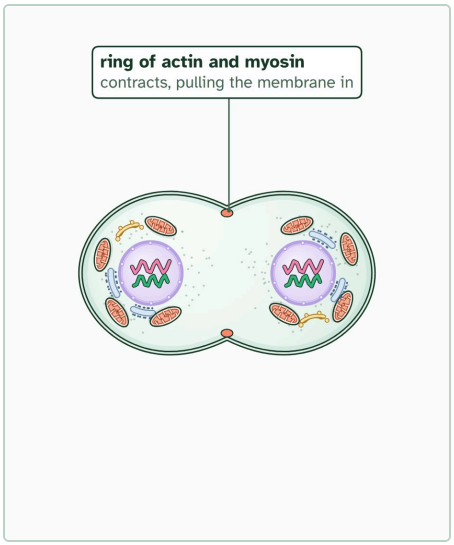
cytokinesis
Division of the cytoplasm into two daughter cells. It follows mitosis and usually begins during telophase.

cleavage furrow
The groove that forms around the middle of a dividing animal cell as a ring of actin and myosin tightens and pinches it in two.

cell plate
A disk of fused vesicles that forms across the middle of a dividing plant cell and grows outward to become two new membranes and a new wall between the daughter cells.

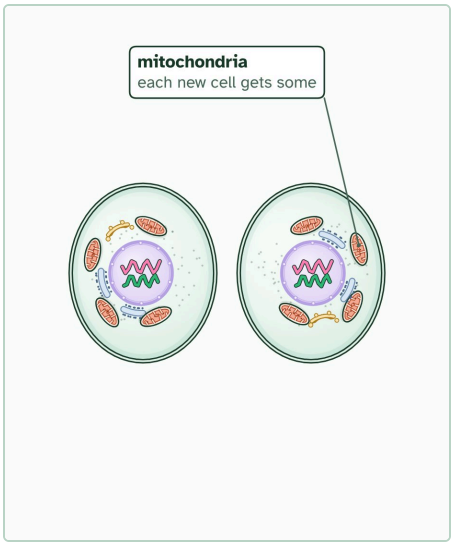
ANIMATION · SPLITTING THE CYTOPLASM
7 MOMENTS

1 AN ANIMAL CELL



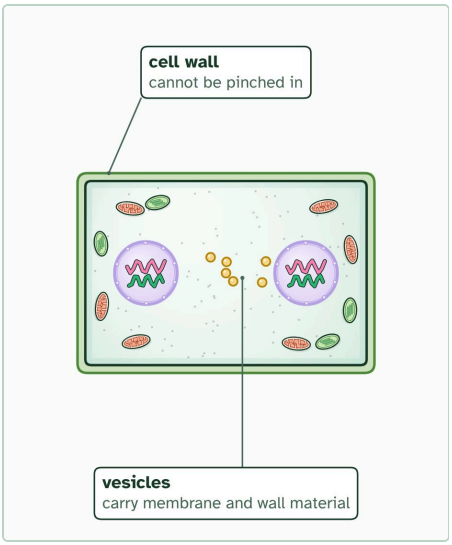
In an **animal cell**, a ring of **actin and myosin** just inside the membrane contracts and pinches the cell in two.

2 AN ANIMAL CELL



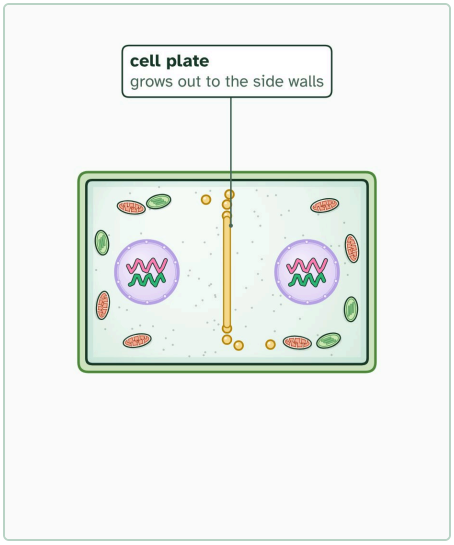
Mitochondria are only made by dividing old ones, so **each daughter cell must get at least one**.

3 A PLANT CELL



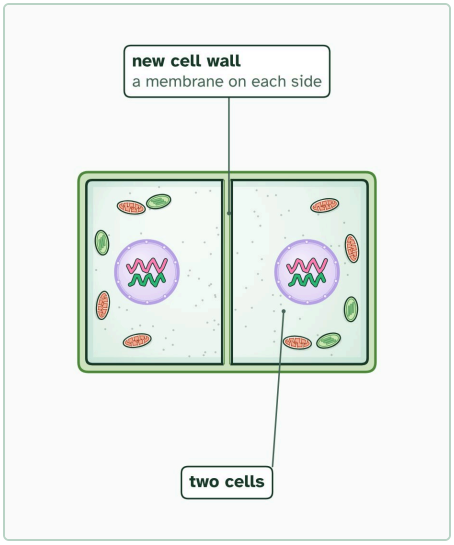
A **plant cell** has a wall, so it cannot be pinched. Vesicles carry membrane and wall material to the equator.

4 A PLANT CELL



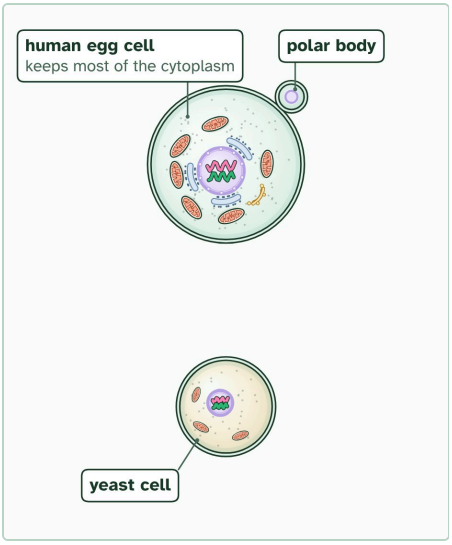
The vesicles fuse into a **cell plate**, which grows outwards until it meets the side walls.

5 A PLANT CELL



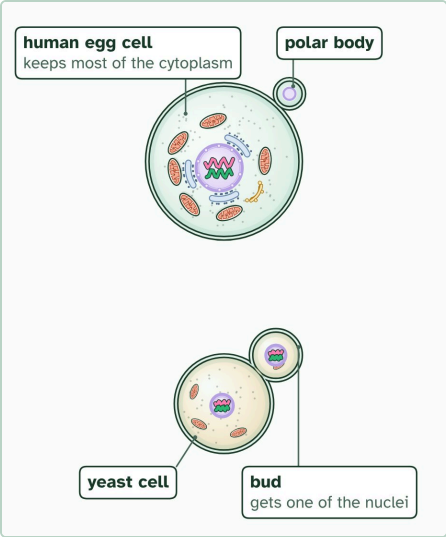
The plate becomes two membranes with **new cell wall** between them: two cells.

6 UNEQUAL DIVISION



Cytokinesis is usually equal, but not always. A human **egg cell** keeps almost all the cytoplasm and pinches off a tiny **polar body**.

7 UNEQUAL DIVISION



Yeast divides by **budding**: a small bud grows out, one nucleus moves into it, and it pinches off.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-4-cell-cycle#cytokinesis

WATCH OUT

Cytokinesis is not a fifth phase of mitosis. Mitosis is the division of the nucleus; cytokinesis is a separate step that divides the rest of the cell.

PREDICT

A drug stops actin filaments forming but leaves microtubules alone. What happens when an animal cell treated with it divides?

(A) The chromosomes never separate, because actin is what pulls the chromatids to the two poles

(B) Mitosis finishes, but no furrow forms, leaving one cell with two nuclei

(C) The cell builds a cell plate instead, the way a plant cell does when it cannot be pinched

Decide before you look. Answer on page 29.

07 Stop, or *go*

4.6.A CHECKPOINTS, CYCLINS AND CDKS

A cell does not drift from one stage to the next. At **checkpoints** it checks its own state and goes on only if all is well. The **G1 checkpoint** asks whether the cell is big enough, has the nutrients and signals it needs, and has undamaged DNA; a cell that fails it may wait or move into G0. The **G2 checkpoint** asks whether all the DNA has been copied, without damage. The **M checkpoint**, or spindle checkpoint, in metaphase, holds off anaphase until every chromosome is attached to the spindle from both poles.

The go signals are two kinds of protein working as a pair. **Cyclin-dependent kinases** (CDKs) are present all the time, but a CDK on its own is inactive. It works only when bound to a **cyclin**, and cyclins come and go: each kind is made through part of the cycle and then broken down. When enough cyclin has built up, it binds and activates its CDK. The active CDK phosphorylates target proteins, the same kind of switch you met in signal transduction, and those proteins start the next stage. Then the cyclin is destroyed and the CDK falls quiet again.

The tool follows a cell line for four days with two cyclins against a threshold. Turn the growth signal off, damage the DNA or mutate a gene, and watch the cyclins and the number of cells.

KEY POINTS

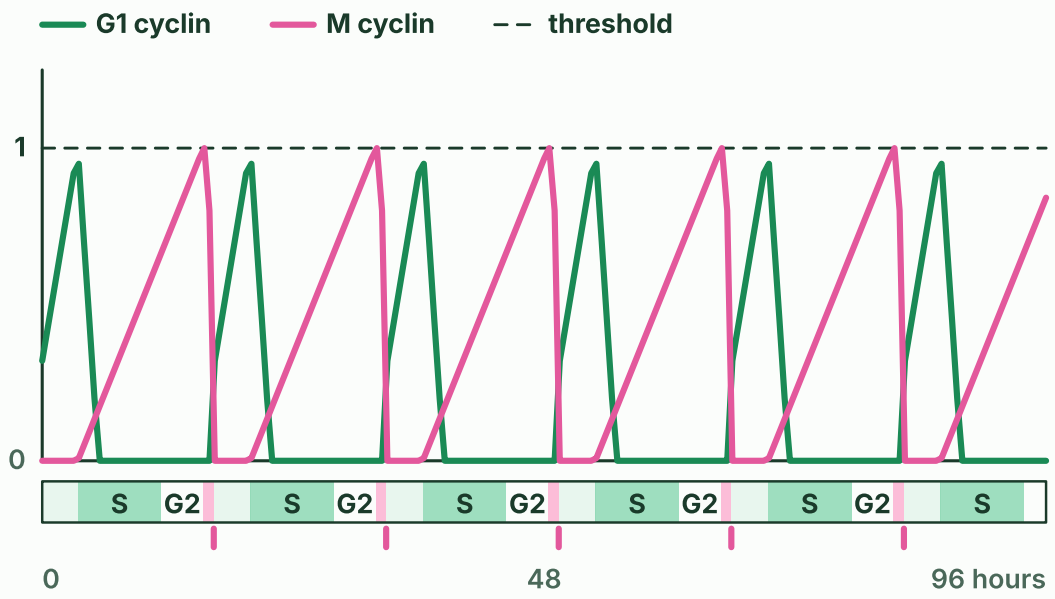
- Checkpoints at G1, G2 and M let the cell go on only when conditions are right.
- CDKs are always present; cyclins rise and fall.
- A cyclin activates its CDK, which phosphorylates proteins that drive the next stage.

KEY TERMS

checkpoints
A point in the cell cycle where the cell goes on only if conditions are right, such as its DNA being undamaged or fully copied.

Cyclin-dependent kinases
Enzymes that add phosphate groups to target proteins. They are present all through the cell cycle but are active only when bound to a cyclin.

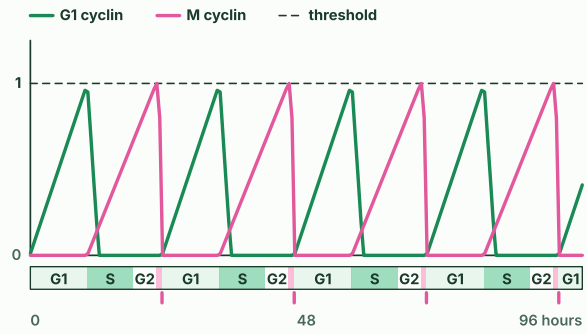
cyclin
A protein whose concentration rises and falls through the cell cycle. Bound to a cyclin-dependent kinase, it activates it.



Four days of one cell and its daughters. Switch the growth signal, a mutated gene or DNA damage, and read each cyclin against its threshold. Try the four tasks.

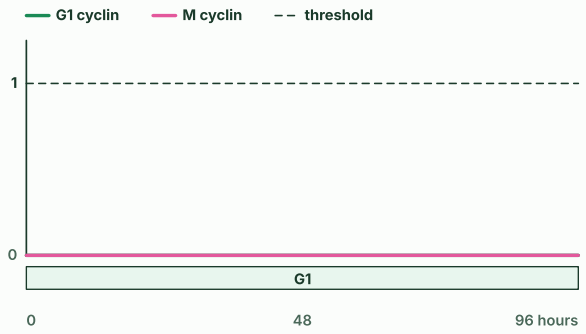
STEP BY STEP 3 STEPS

1



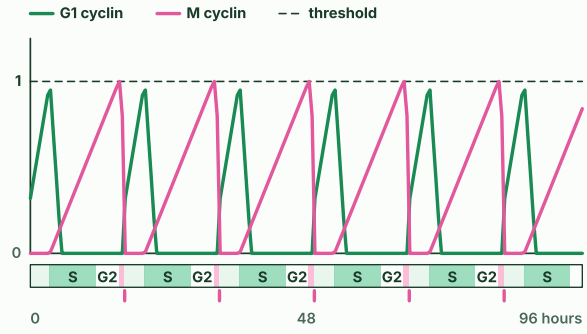
A normal cell: each cyclin rises to its **threshold**, the cell passes that **checkpoint**, and the cyclin is broken down. Four divisions in four days.

2



No growth signal: the G1 cyclin is never made, so the cell stays in **G1** and does not divide.

3



An **oncogene**: the G1 cyclin builds up fast with no signal at all, so the cell divides again and again.

REMEMBER IT

What each checkpoint checks

G Grown?	G Genome copied?	M Moored?
G1 checkpoint	**G2 checkpoint**	**M checkpoint**
size, signals, DNA undamaged	all the DNA copied, no damage	every chromosome tied to both poles

WATCH OUT

It is the cyclins that come and go, not the CDKs. The kinase is there the whole time; what changes is whether a cyclin is bound to switch it on.

PREDICT

A cell makes a mutant cyclin, the kind that drives mitosis, that cannot be broken down. What would you expect?

(A) The cell races through mitosis and back into G1 much faster than usual, then divides again

(B) The cell skips S phase the next time around, because its cyclin is already high enough

(C) The cell enters mitosis but gets stuck there, unable to finish dividing

Decide before you look. Answer on page 29.

08 When cells *ignore* the rules

4.6.B DISRUPTIONS TO THE CELL CYCLE

Two kinds of gene keep the cycle under control. **Proto-oncogenes** make proteins that push a cell to divide when it is signaled to. A mutation can turn one into an **oncogene**, stuck on like an accelerator taped down. **Tumor suppressor genes** make the brakes: proteins that hold a cell at a checkpoint when its DNA is damaged. A mutation that breaks one removes a brake.

Cancer is cells that divide when they should not and pass checkpoints they should fail. It is rarely one mutation. A cell usually needs several, in genes that drive the cycle and genes that brake it, building up over years as it divides, which is one reason cancer is more common with age. The mass of cells that results is a tumor. A benign tumor stays where it formed; a malignant one invades the tissue around it and can spread through the blood.

The planned alternative is **apoptosis**. A cell with damage it cannot repair takes itself apart in an orderly way, and its pieces are cleared up by other cells. Apoptosis also shapes the body: in a human embryo, the cells between the fingers die this way, separating them. Many cancer cells have lost the ability to trigger it.

KEY POINTS

- Oncogenes push the cycle on; lost tumor suppressors fail to stop it.
- Cancer usually takes several mutations, in both kinds of gene.
- Apoptosis removes damaged or unneeded cells in an orderly way.

KEY TERMS

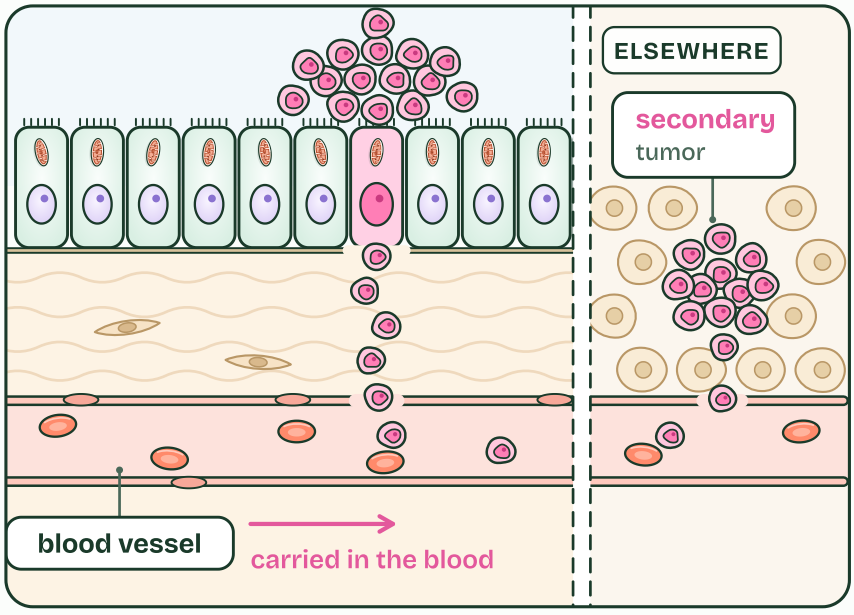
Proto-oncogenes
A gene whose protein pushes the cell cycle on, for example by passing on a signal to divide. A mutated, overactive version is an oncogene.

oncogene
A mutated proto-oncogene that pushes the cell to divide even when it has no signal to.

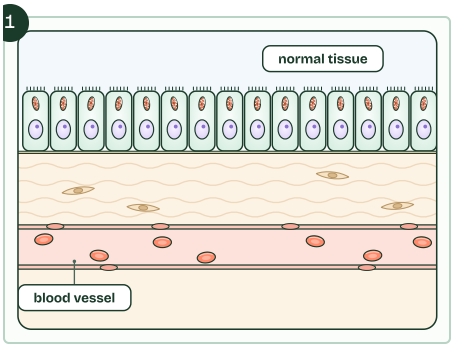
tumor suppressor genes
A gene whose protein stops the cell cycle, for example at a checkpoint when DNA is damaged. Losing it removes a brake.

cancer
A disease in which cells divide out of control, ignoring checkpoints and signals, and can invade other tissues.

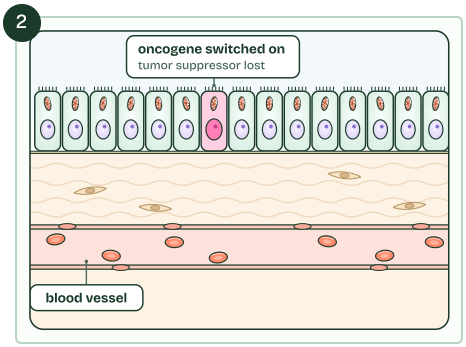
apoptosis
Programmed cell death: a cell dismantles itself in an orderly way, and its pieces are taken up by other cells, without harming its neighbors.



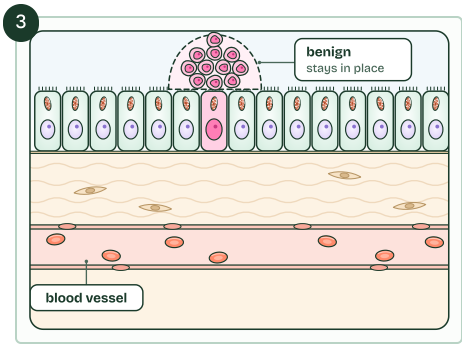
STEP BY STEP 5 STEPS



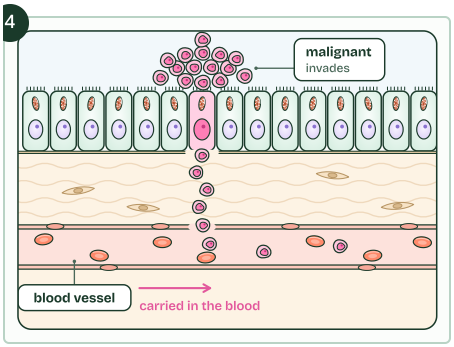
Normal tissue: cells divide only when signaled, and damaged cells are stopped.



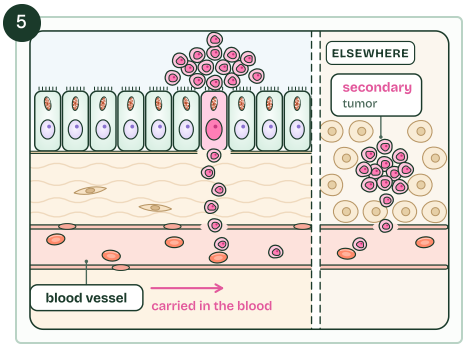
One cell gains an **oncogene** and loses a **tumor suppressor**.



Its descendants divide out of control: a **benign** tumor that stays in place.



A **malignant** tumor invades: here, into a blood vessel.



Cells carried away grow into a **secondary tumor** elsewhere.

WATCH OUT

Cancer is not one mutation. One mutated gene seldom makes a cell cancerous; it takes several, which is why most cancers appear later in life.

PREDICT

A skin cell's DNA is badly damaged by sunlight and cannot be repaired. For the rest of the body, what is the best thing that cell can do?

(A) Die by apoptosis, so that none of its daughter cells inherit the damage

(B) Divide as quickly as it can, so that healthy copies of it replace the damaged skin around it

(C) Pass the G1 checkpoint and copy its DNA, since copying the DNA again will repair the damage

Decide before you look. Answer on page 30.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

apoptosis 08
Programmed cell death: a cell dismantles itself in an orderly way, and its pieces are taken up by other cells, without harming its neighbors.

cancer 08
A disease in which cells divide out of control, ignoring checkpoints and signals, and can invade other tissues.

cell cycle 03
The sequence of stages from one cell division to the next: interphase (G1, S and G2), then mitosis and cytokinesis.

cell plate 06
A disk of fused vesicles that forms across the middle of a dividing plant cell and grows outward to become two new membranes and a new wall between the daughter cells.

centromere 02
The region where two sister chromatids are held together, and where spindle microtubules attach.

checkpoints 07
A point in the cell cycle where the cell goes on only if conditions are right, such as its DNA being undamaged or fully copied.

chromatin 02
DNA wound around histones. Spread out and loosely packed between divisions, it condenses into visible chromosomes before mitosis.

chromosome 02
One long DNA molecule with its proteins. Human body cells have 46.

cleavage furrow 06
The groove that forms around the middle of a dividing animal cell as a ring of actin and myosin tightens and pinches it in two.

cyclin 07
A protein whose concentration rises and falls through the cell cycle. Bound to a cyclin-dependent kinase, it activates it.

Cyclin-dependent kinases 07
Enzymes that add phosphate groups to target proteins. They are present all through the cell cycle but are active only when bound to a cyclin.

cytokinesis 06
Division of the cytoplasm into two daughter cells. It follows mitosis and usually begins during telophase.

daughter cells 01
One of the two cells made when a parent cell divides.

G0 03
A state outside the cell cycle where a cell is alive and working but no longer dividing. Some cells can leave it again when the right signal arrives.

genome 01
All of the genetic information in a cell: every chromosome and the DNA it carries.

histones 02
Proteins that DNA winds around in a eukaryotic nucleus. They package the DNA and help it coil up tightly before division.

interphase 03
The part of the cell cycle between divisions, made of G1, S and G2. The cell grows, makes proteins and organelles, and copies its DNA.

mitosis 01
Division of the nucleus that gives two nuclei, each with a complete copy of the parent cell's genome and the same number of chromosomes.

oncogene 08

A mutated proto-oncogene that pushes the cell to divide even when it has no signal to.

parent cell 01

The cell that divides. It does not survive alongside its daughters: it becomes them.

Proto-oncogenes 08

A gene whose protein pushes the cell cycle on, for example by passing on a signal to divide. A mutated, overactive version is an oncogene.

sister chromatid 02

One of the two identical copies of a chromosome made when its DNA is replicated. Sisters stay joined at the centromere until anaphase.

spindle 04

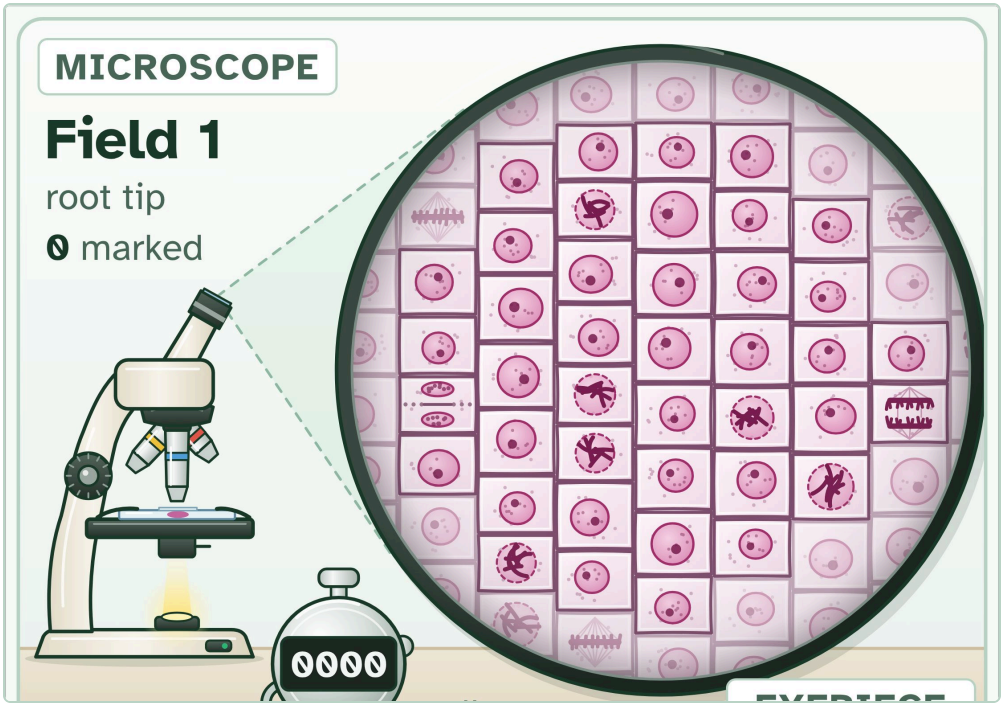
A framework of microtubules that grows from the two poles of a dividing cell, attaches to the chromosomes and moves them.

tumor suppressor genes 08

A gene whose protein stops the cell cycle, for example at a checkpoint when DNA is damaged. Losing it removes a brake.

Dry lab: *Count the cells*

Fields of view down a microscope, from an onion root tip, from further back along the root, from normal tissue and from two tumors. Mark every cell that is dividing by its phase, calculate the mitotic index as a percentage, and find out where cells divide fastest.



Run it online: change the variables, run the trials, and the table and graph fill in as you go. biologybybradford.com/guides/ap-biology-unit-4-cell-cycle#lab

Your question

How does the percentage of cells in mitosis differ between the tip of a root and the region behind it, and between normal tissue, a benign tumor and a malignant tumor? Make a prediction for each before you count.

What you can change

The sample and the field of view. Each field is a new set of cells from the same sample, so counting several fields of one sample is how you repeat. Mark it for me fills a field in for you once you can name the phases by eye.

What to record

For each field: the sample, the number of whole cells, the number in each phase of mitosis and the mitotic index, the cells in mitosis as a percentage of all the cells counted. At least three fields for each sample, then the mean. The fields are drawn and their rates invented to show the method.

Find out

- **Name them by eye.** In the first root tip field, mark every dividing cell by its phase yourself, then Count this field and see which of your marks were right.
- **Tip or further back?** Count at least three fields from the root tip and three from 1 cm behind it. Where are cells dividing, and why there?
- **Which phase is longest?** Add up the cells in each phase across all your root tip fields. Which phase holds the most cells, and what does that say about how long each phase lasts?
- **Tumors.** Count three fields each of normal tissue, a benign tumor and a malignant tumor. Rank them by mean mitotic index.
- **Back to the cell cycle.** Use your results to explain why the root tip and the malignant tumor have high mitotic indices, and the root 1 cm back and normal tissue low ones.

Record

- For each field: the sample, the number of whole cells, the cells in each phase, and the mitotic index as a percentage to one decimal place.
- Mitotic index (%) = cells in mitosis ÷ all cells counted × 100.
- A mean mitotic index for each sample, and the range. The graph shows each field as a point and the mean as a bar.
- Describe the pattern in one sentence per comparison, quoting the means. Do the ranges overlap? Download the CSV to keep your table.

Your question How does the percentage of cells in mitosis differ between the tip of a root and the region behind it, and between normal tissue, a benign tumor and a malignant tumor? Make a prediction for each before you count.**What you can change**The sample and the field of view. Each field is a new set of cells from the same sample, so counting several fields of one sample is how you repeat. Mark it for me fills a field in for you once you can name the phases by eye.**What to record**For each field: the sample, the number of whole cells, the number in each phase of mitosis and the mitotic index, the cells in mitosis as a percentage of all the cells counted. At least three fields for each sample, then the mean. The fields are drawn and their rates invented to show the method.

Back to the cell cycle

Use your results to explain why the root tip and the malignant tumor have high mitotic indices, while the root 1 cm back and normal tissue have low ones.

QUESTIONS ON THE LAB

QUESTION 1

A field of view from a tumor holds 250 cells, and 30 of them are in mitosis. What is the mitotic index?

(A) 30 percent, as 30 of the cells in this field of view were caught in the middle of dividing

(B) 12 percent, because 30 out of 250 is 0.12 of all the cells counted

(C) 8.3 percent, since there are about 8.3 cells in the whole field for every one in mitosis

Answer on page 30.

QUESTION 2

The root tip fields have a mitotic index of around 15 percent, and the fields 1 cm back have almost none. What explains the difference?

(A) Cells further back divide just as often, but finish mitosis too quickly for any to be caught

(B) The stain only soaks into the tip of the root, so dividing cells further back are hard to see

(C) Cells divide in a zone near the tip; further back they stop and grow longer

Answer on page 30.

QUESTION 3

Across all your root tip fields, prophase holds the most dividing cells and anaphase the fewest. What can you conclude?

(A) That prophase takes the longest and anaphase is over the fastest

(B) That some of the cells skip anaphase and go straight from metaphase on to telophase

(C) That cells in anaphase take up less of the stain and so are missed when you count

Answer on page 30.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on 4.5 and 4.6 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?program=ap&units=U4&ced=4.5,4.6&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 A gardener cuts a stem from a geranium and it roots into a new plant. How do the new plant's cells compare with the parent plant's?

C **They have the same genome as the parent, since every one was made by mitosis from its cells**

The same genome. A cutting grows only by mitosis, and mitosis copies every chromosome into each daughter cell, so the new plant is a clone of the old one. New combinations of genes need sexual reproduction, which is Unit 5.

02 A cell has 8 chromosomes before it copies its DNA. How many DNA molecules are in its nucleus as mitosis begins?

A **16, because each of the 8 chromosomes is now two sister chromatids**

16. Copying turns each of the 8 chromosomes into two sister chromatids, and each chromatid is one DNA molecule. There are still 8 chromosomes, because there are still 8 centromeres.

03 Compare a cell in G2 with the same cell earlier, in G1. What does it have in G2?

B **Twice the DNA, because every chromosome has been copied into two chromatids**

Twice the DNA. S phase comes between G1 and G2, so by G2 every chromosome has been copied into two sister chromatids. The cell has usually grown and made more organelles too.

04 A dog's body cells have 78 chromosomes. A skin cell divides by mitosis. How many chromosomes does each daughter cell have?

C **78, because each daughter cell gets one chromatid of every chromosome**

78. The DNA was copied first, so the cell had 78 chromosomes of two chromatids each. Mitosis separates the chromatids, and each daughter gets one of every pair of sisters: 78 chromosomes, the same as the parent.

05 The drug colchicine stops microtubules forming. Root tip cells are soaked in it for a few hours. Where do the dividing cells get stuck?

A **Condensed, as in early metaphase, but never lined up or pulled apart**

With no spindle, the chromosomes still condense, but nothing attaches to them, so they are never lined up properly or pulled apart. The cells pile up with short, thick chromosomes, which is exactly why colchicine is used to prepare cells for counting chromosomes.

06 A drug stops actin filaments forming but leaves microtubules alone. What happens when an animal cell treated with it divides?

B **Mitosis finishes, but no furrow forms, leaving one cell with two nuclei**

The spindle is made of microtubules, so mitosis still separates the chromatids and two nuclei form. But the contractile ring needs actin, so no furrow forms and the cell is left with two nuclei in one cytoplasm. Animal cells have no way to build a cell plate.

07 A cell makes a mutant cyclin, the kind that drives mitosis, that cannot be broken down. What would you expect?

C **The cell enters mitosis but gets stuck there, unable to finish dividing**

It gets stuck. The cyclin's fall is part of the signal to finish: destroying it switches the CDK off, which lets the chromatids separate and the cell leave mitosis. Experiments with cyclins that cannot be broken down show cells held in mitosis.

Q8 A skin cell's DNA is badly damaged by sunlight and cannot be repaired. For the rest of the body, what is the best thing that cell can do?

A Die by apoptosis, so that none of its daughter cells inherit the damage

Apoptosis. Every daughter of a damaged cell would inherit the damage, and copying damaged DNA adds more mistakes. Killing itself in an orderly way removes the risk, and neighboring cells divide to fill the gap. A cell whose tumor suppressors are broken may skip this and keep dividing.

QUESTIONS ON THE DRY LAB

Q1 A field of view from a tumor holds 250 cells, and 30 of them are in mitosis. What is the mitotic index?

B 12 percent, because 30 out of 250 is 0.12 of all the cells counted

12 percent: 30 ÷ 250 = 0.12, and 0.12 × 100 = 12. The index divides by every cell counted, dividing or not, so it is the share of cells caught in mitosis.

Q2 The root tip fields have a mitotic index of around 15 percent, and the fields 1 cm back have almost none. What explains the difference?

C Cells divide in a zone near the tip; further back they stop and grow longer

A root grows from a small region of dividing cells just behind its tip. The new cells it leaves behind stop dividing (many enter G0) and elongate instead, pushing the tip on through the soil. That is why the cells further back are longer and almost none are in mitosis.

Q3 Across all your root tip fields, prophase holds the most dividing cells and anaphase the fewest. What can you conclude?

A That prophase takes the longest and anaphase is over the fastest

The cells were caught at random moments, so the share in each phase matches how long that phase lasts. If a cycle takes 24 hours and 2 percent of the cells are in anaphase, anaphase lasts about 2 percent of 24 hours: around half an hour.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.