YEAR 11 BIOLOGY · STUDY GUIDE

DNA, Replication & Mitosis

Year 11 Biology · a four-day study guide

From the shape of a single molecule to how one cell becomes two identical ones. Four days, in order, with a check at the end of each.

PREPARED FOR

Phoebe Fan

Year 11 Biology · "Direction & Replication"

for Phoebe — from Dad

FOUR-DAY PLAN

1. **The Structure of DNA**
   about 60 min
2. **The Cell Cycle and Interphase**
   about 65 min
3. **DNA Replication: Making an Exact Copy**
   about 70 min
4. **Mitosis and Why It Matters**
   about 70 min

How to Use This Guide

Four days, in order. Each one takes about an hour and assumes the one before it.

1

Go in order, one day at a time

Day 3 will not make much sense without Day 2. Read the explanation, study the diagram until you could redraw it from memory, then do the check at the bottom of the day.

2

Do the check without looking back

Looking up the answer while you answer teaches you nothing. Get it wrong, read why, then go back and re-read that part. Being wrong here is far cheaper than being wrong in an exam.

3

Say it out loud

At the end of each day, close the book and explain the Big Idea out loud, in your own words, using the proper terms. If you cannot say it, you do not know it yet — and that is genuinely the fastest way to find the gap.

4

Learn the vocabulary properly

Biology marks are won and lost on precise words. The glossary at the back has every term from the four days. **Chromosome** and **chromatid** are not interchangeable, and a marker will notice.

5

Finish with the final test

Once all four days are done, sit the final assessment in one go. The written questions show you exactly where each mark comes from, so you can see what a full-mark answer actually looks like.

BOXES YOU WILL SEE

- ✦ TIP — A way to remember it — a mnemonic, an analogy, or a shortcut that works.
- ⚠ COMMON MISTAKE — Where most students lose marks. Slow down and read these twice.
- ◈ EXAMPLE — The idea in something real you already know, for when the biology gets abstract.
- ⬡ EXTENSION — Beyond what you strictly need. Skip it if the basics are still wobbly.
- ⚑ IN THE EXAM — What this looks like on a real paper, and what an answer has to contain.

DAY 1

about 60 min

The Structure of DNA

THE BIG IDEA

DNA is a long chain built from just four repeating nucleotides, and because adenine always pairs with thymine and cytosine always pairs with guanine through weak hydrogen bonds, the molecule holds a uniform double-helix shape that stores information in the ORDER of its bases while still being able to split down the middle.

BY THE END OF TODAY YOU WILL BE ABLE TO

1. State the function of DNA — it stores the genetic instructions for making proteins — and identify where DNA is found in a eukaryotic cell.
2. Identify the three parts of a DNA nucleotide and name the four nitrogenous bases.
3. Describe how nucleotides join end to end to form a strand with a sugar-phosphate backbone.
4. State the complementary base pairing rules and the number of hydrogen bonds holding each pair together.
5. Explain why weak hydrogen bonds between the bases and strong covalent bonds along the backbone allow DNA to unzip without either strand breaking.
6. Sequence the levels of organisation from base pair to gene to DNA molecule to chromatin to condensed chromosome to genome, and relate each level to the one above it.
7. Apply the base-pairing rule to write the complementary strand for a given DNA base sequence.

What DNA is and what its job is

Start with the job, because the structure only makes sense once you know what the molecule has to do. DNA — deoxyribonucleic acid — is the chemical that stores the instructions a cell uses to make proteins. That matters more than it sounds, because proteins do almost all of the real work in a living thing: enzymes that speed up reactions, keratin in your hair and nails, haemoglobin that carries oxygen, receptors sitting in a membrane. If DNA carries the instructions for the proteins, then DNA effectively controls what a cell can build, what it looks like and what it can do. You do not need to know this year exactly how those instructions are read — that is a separate topic later — but you do need to be able to state the job in one clean sentence: DNA stores the genetic instructions for making proteins, and it passes those instructions on when a cell divides.

Where is it? In a eukaryotic cell — a plant, animal or fungal cell — nearly all of the DNA sits inside the nucleus, which is exactly why the nucleus is described as the control centre of the cell. (Small amounts of DNA are also found in mitochondria and, in plants, in chloroplasts.) Prokaryotes such as bacteria have no nucleus at all: their DNA is a single circular chromosome sitting free in the cytoplasm. The important point for you is that it is the same molecule, built to the same design, in every living organism on Earth. Learn the structure once and it applies to a bacterium, to a strawberry plant and to you. That universality is itself a piece of biological evidence, and it is the reason a diagram of DNA in a Year 11 textbook is never labelled human DNA or plant DNA — it is just DNA.

A useful way into the structure is to ask what this molecule has to be good at. First, it has to store an enormous amount of information: a single human body cell contains about two metres of DNA, packed into a nucleus only a few micrometres across. Second, it has to be copyable — exactly, every single time a cell divides, with no drift. Everything in today's lesson is the structural answer to those two demands. And here is the headline fact that the rest of the day builds on: DNA is a polymer. A polymer is a very long molecule made by joining many small repeating units, called monomers, in a chain — the way a paper chain is built from identical loops. The monomer of DNA is called a nucleotide, and that is where we start.

KEY TERMS

DNA

Deoxyribonucleic acid: the molecule that stores the genetic instructions for making proteins and is passed on when cells divide.

nucleus

The membrane-bound organelle of a eukaryotic cell that contains almost all of the cell's DNA.

polymer

A long molecule built by joining many small repeating units (monomers) into a chain; DNA is a polymer of nucleotides.

⚠ COMMON MISTAKE **DNA, gene and chromosome are not three different substances**

Students often write as though DNA, a gene and a chromosome are three separate materials found in different places. They are the same material, described at different sizes — the same way a letter, a sentence and a book are all ink on paper. We will rank them properly later in the lesson, but start now by refusing to treat them as synonyms or as rivals.

⚑ IN THE EXAM **One–sentence answers are worth real marks**

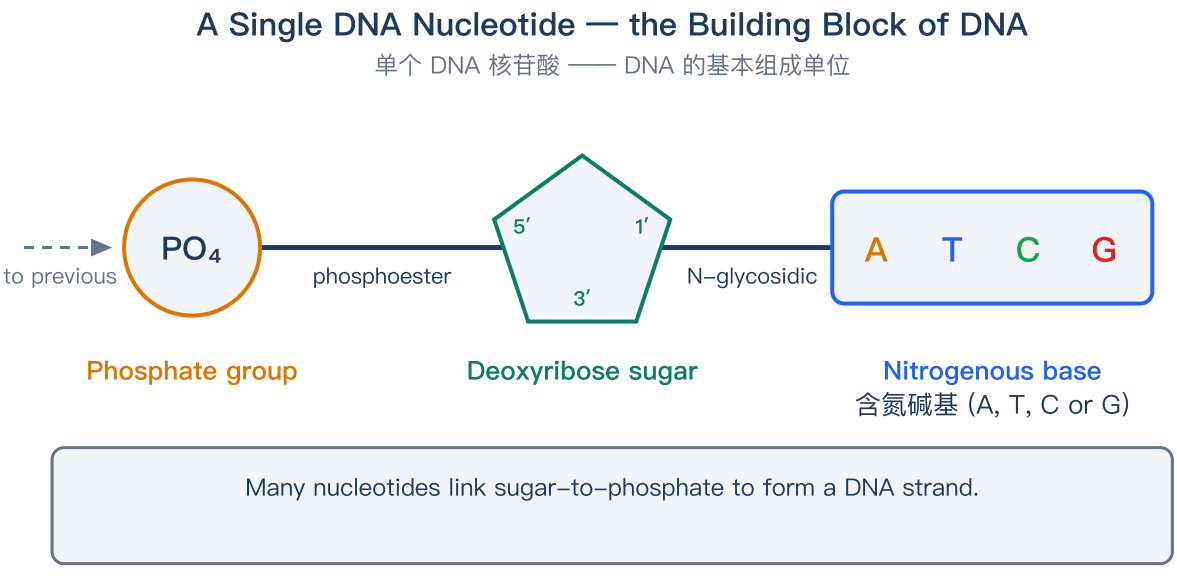
A question that says Identify the molecule that stores genetic information or State the function of DNA is a recall mark: name it and stop. Do not write a paragraph about the double helix — Identify and State earn nothing for extra detail, and you burn time you need for the Explain questions later in the paper.

◈ EXAMPLE **Think of a flat-pack instruction booklet**

Think of the instruction booklet that comes with flat-pack furniture. It tells you exactly which panel meets which screw, but it never lifts a single panel — the building is done by you, the Allen key and the screws. DNA works the same way. It stores the instructions for making proteins, and the proteins are what actually do the work: enzymes speeding up reactions, keratin in your hair, haemoglobin carrying oxygen. So when a question asks what DNA does, the answer is that it stores the genetic instructions for making proteins — not that it carries oxygen or speeds up reactions, because those are the jobs of particular proteins built from those instructions. Where it breaks down, in two places. The booklet only tells you how to assemble parts that already exist, whereas DNA's instructions are instructions for building the workers themselves — every protein doing a job in you was built from a length of your DNA. And you throw the booklet out once the shelf is standing, whereas DNA is kept permanently and copied in full every time the cell divides.

The nucleotide: the repeating building block

Every nucleotide has exactly three parts, and you should be able to name all three without hesitating: a phosphate group, a deoxyribose sugar, and one nitrogenous base. Look at the diagram and trace them with your finger. Notice how they are arranged — the deoxyribose sugar sits in the middle and acts as the connecting piece: the phosphate group attaches to one side of the sugar and the base attaches to the other side. That arrangement is not decoration, it is the whole reason the molecule can build a backbone on the outside and hold the bases on the inside. Exam papers frequently show an unlabelled nucleotide and ask you to label the three components, so learn it as a picture as well as a list. If you are ever unsure which shape is which in a diagram, the sugar is the one in the middle with two neighbours.



A single DNA nucleotide: a phosphate group bonded to a deoxyribose sugar at the 5' carbon, and a nitrogenous base (A, T, C or G) bonded at the 1' carbon.

There are only four bases in DNA: adenine (A), thymine (T), cytosine (C) and guanine (G). Now the key idea. The phosphate group is identical in every nucleotide, and the deoxyribose sugar is identical in every nucleotide. The only thing that differs from one nucleotide to the next is which of the four bases is

attached. So there are only four kinds of nucleotide in the entire molecule, and a strand of DNA is a message written in a four-letter alphabet.

Nucleotides join up in a line: the sugar of one nucleotide bonds to the phosphate group of the next, over and over, for millions of units. That produces a continuous chain of alternating sugar–phosphate–sugar–phosphate running down the outside of the molecule, and it is called the sugar-phosphate backbone. Two things to lock in about it. First, these joins are strong covalent bonds — remember that, because tomorrow the contrast between these strong bonds and some much weaker ones becomes the whole point. Second, the bases are not part of the backbone; they hang off the side of it, pointing inwards. If you picture a single strand as one half of a ladder that has been sawn down the middle, the backbone is the upright side rail and the bases are half-rungs sticking out sideways, each one waiting for a partner.

KEY TERMS

nucleotide

The repeating monomer of DNA, made of a phosphate group, a deoxyribose sugar and one nitrogenous base.

phosphate group

The part of a nucleotide that attaches to its sugar and links to the sugar of the neighbouring nucleotide, so that sugars and phosphates alternate along the backbone.

deoxyribose sugar

The five-carbon sugar in the middle of a nucleotide; it carries the phosphate on one side and the base on the other.

nitrogenous base

The part of a nucleotide that varies: adenine, thymine, cytosine or guanine. Its order along the strand carries the information.

sugar–phosphate backbone

The continuous alternating chain of sugars and phosphate groups, joined by strong covalent bonds, that runs along the outside of each strand.

✦ TIP **Memory aid: P—S—B, sugar in the middle**

Say it as three beats in order: Phosphate – Sugar – Base. The sugar is always the middle beat because it is the piece that holds the other two. If you can say P–S–B and point to each one on a diagram, you have the label question in the bag.

⚠ COMMON MISTAKE **A base is not a nucleotide**

A very common slip is to write DNA is made of A, T, C and G. Strictly, DNA is made of nucleotides, and the base is only one of the three parts of each nucleotide. Markers notice the difference. Say DNA is a polymer of nucleotides, each containing one of four bases.

EXTENSION

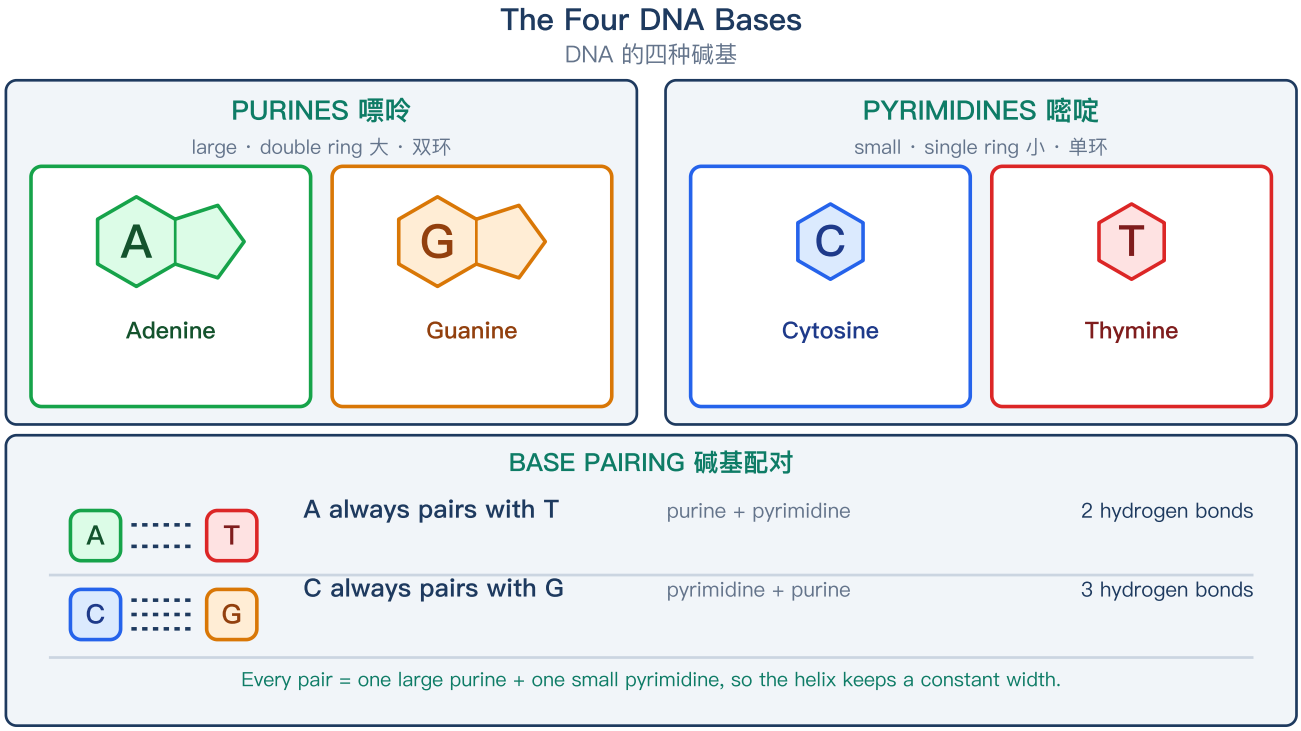
Extension: the sequence is the information, and why four letters is enough

The information is not stored in the chemicals themselves — every organism uses the same four bases — it is stored in the ORDER in which the bases appear along the strand, the same way star and rats are built from the same letters but mean different things. Only four letters sounds limiting until you count the combinations. A stretch of just 10 bases can be arranged in 4 to the power of 10 ways — 1,048,576 different sequences. A gene is hundreds or thousands of bases long, so the storage capacity is effectively unlimited. You will sometimes see the strong covalent joins along the backbone given a longer chemical name in other textbooks. Ignore it — 'strong covalent bonds in the sugar-phosphate backbone' is all any Australian marker wants.

EXAMPLE

Think of a row of people linking arms

Picture a long row of people standing side by side. Each person hooks their left arm through the arm of the person on their left, and holds a lettered card out in front with their free right hand. Each person is a nucleotide: the body in the middle is the deoxyribose sugar, the single hooking arm is the phosphate group — exactly one per person, joining that person's body to their neighbour's — and the card is the nitrogenous base. Two things follow. The chain running down the row is made from the people themselves, not from a separate rope they are all holding — that is exactly what we mean when we say the sugar-phosphate backbone forms because the sugar of one nucleotide bonds to the phosphate of the next, giving one continuous alternating sugar–phosphate–sugar–phosphate line. And the cards stay out in front, which is where the bases sit: off the side of the backbone, never part of it. Where it breaks down: arms come apart the moment someone lets go, while those sugar-phosphate joins are strong covalent bonds that hold even when the two strands separate.

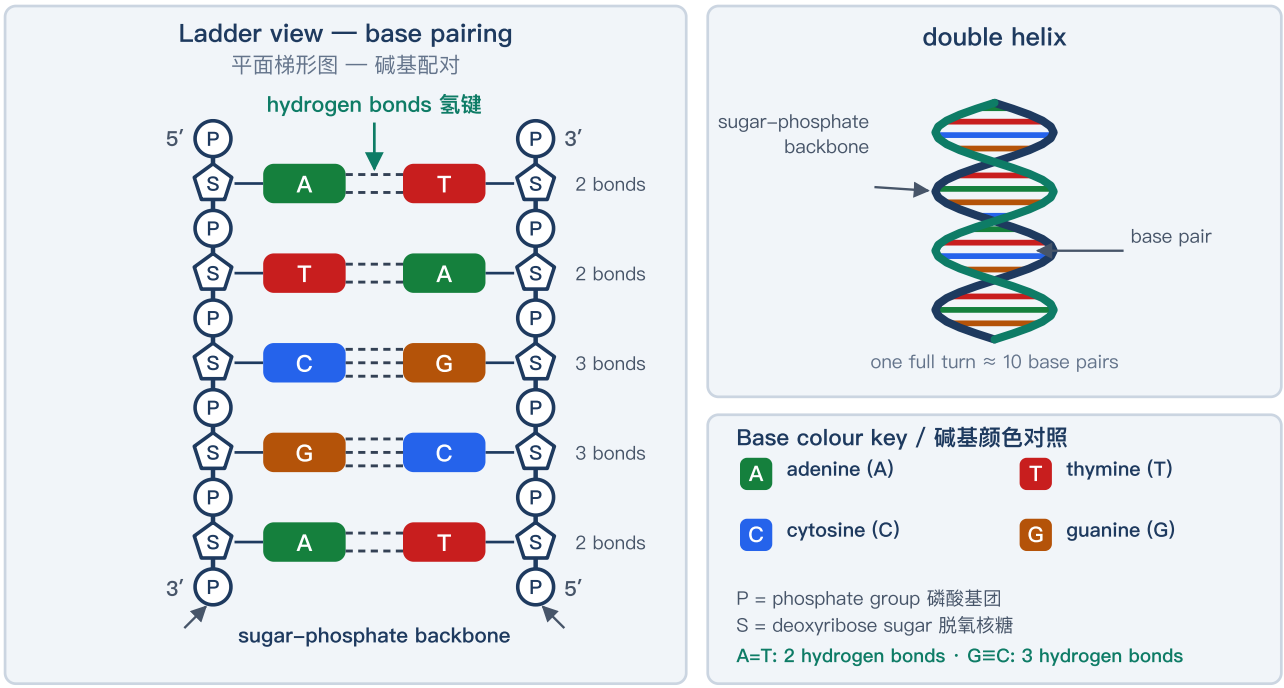


The four DNA bases: purines A and G are large double-ring molecules, pyrimidines C and T are small single-ring molecules, and A always pairs with T (2 hydrogen bonds) while C always pairs with G (3 hydrogen bonds).

Base pairing and the double helix

A real DNA molecule is two strands, not one. They lie alongside each other with their backbones on the outside and their bases facing each other in the middle. The bases are what hold the two strands together, and they do it by a fixed rule called complementary base pairing: adenine always pairs with thymine (A–T), and cytosine always pairs with guanine (C–G). No other combination occurs. Stop on the consequence, because it is the most useful fact in the whole topic — if you know the base order of one strand, you can work out the other strand exactly. A strand reading A–T–G–C must be facing T–A–C–G. The two strands are not identical; they are complementary, each one a mirror-image record of the other. That is precisely what makes an exact copy possible.

DNA: Double Helix and Base Pairing



DNA structure: a ladder view showing two antiparallel sugar–phosphate backbones with A–T pairs held by two hydrogen bonds and C–G pairs by three, alongside the twisted double-helix form.

The pairs are joined by hydrogen bonds, and NESA-style questions want the numbers: two hydrogen bonds between A and T, three hydrogen bonds between C and G. A single hydrogen bond is weak — far weaker than the covalent bonds running along each backbone. But a DNA molecule contains millions of base pairs, and millions of weak bonds added together hold the two strands together firmly. This combination is the cleverest thing about the structure, and it is worth writing out as a full sentence in your notes: the two strands are held together by many weak hydrogen bonds that can be broken one at a time, while each strand itself is held together by strong covalent bonds that stay intact. That is exactly why DNA can be unzipped down the middle without either strand falling to pieces — and why the zipper analogy works so well.

Finally, the whole thing is twisted. The two strands wind around each other into a spiral shape called a double helix, the model published by Watson and Crick in 1953, built on X-ray diffraction images produced by Rosalind Franklin and Maurice Wilkins. The two strands also run in opposite directions to each other; the word for that is antiparallel, and at Year 11 level you only need to state it, not explain it. Because the pairing rule is fixed, the helix stays the same width all the way along, like a spiral staircase whose steps are all the same length. The twisted-ladder analogy is a good one to hold in your head — the two sugar-phosphate backbones are the side rails and each base pair is a rung. Just be clear about where it breaks down: a real ladder rung is one solid piece of wood, whereas each rung of DNA is two half-rungs held together by nothing stronger than two or three hydrogen bonds (two for A–T, three for C–G), which is the entire reason the molecule can open.

KEY TERMS

complementary base pairing

The fixed rule that adenine pairs only with thymine and cytosine pairs only with guanine, so each strand determines the sequence of the other.

hydrogen bond

A weak bond holding paired bases together: two between A and T, three between C and G. Many together hold the strands, but each can be broken individually.

double helix

The three-dimensional shape of DNA: two strands wound around each other in a spiral of constant width.

antiparallel

Describes the two strands of DNA running in opposite directions to each other.

⚠ COMMON MISTAKE **Unzipping breaks hydrogen bonds, not the backbone**

Two errors are penalised again and again. First, writing that the strands separate by breaking the sugar-phosphate backbone — they do not; the backbone is covalent and stays intact, and only the hydrogen bonds between the paired bases break. Second, pairing A with G or C with T. There is no such pair. And do not describe base pairs as being held by covalent bonds: within a nucleotide the bonds are covalent, but BETWEEN the paired bases they are hydrogen bonds.

⬡ EXTENSION **Extension: purines, pyrimidines and constant width**

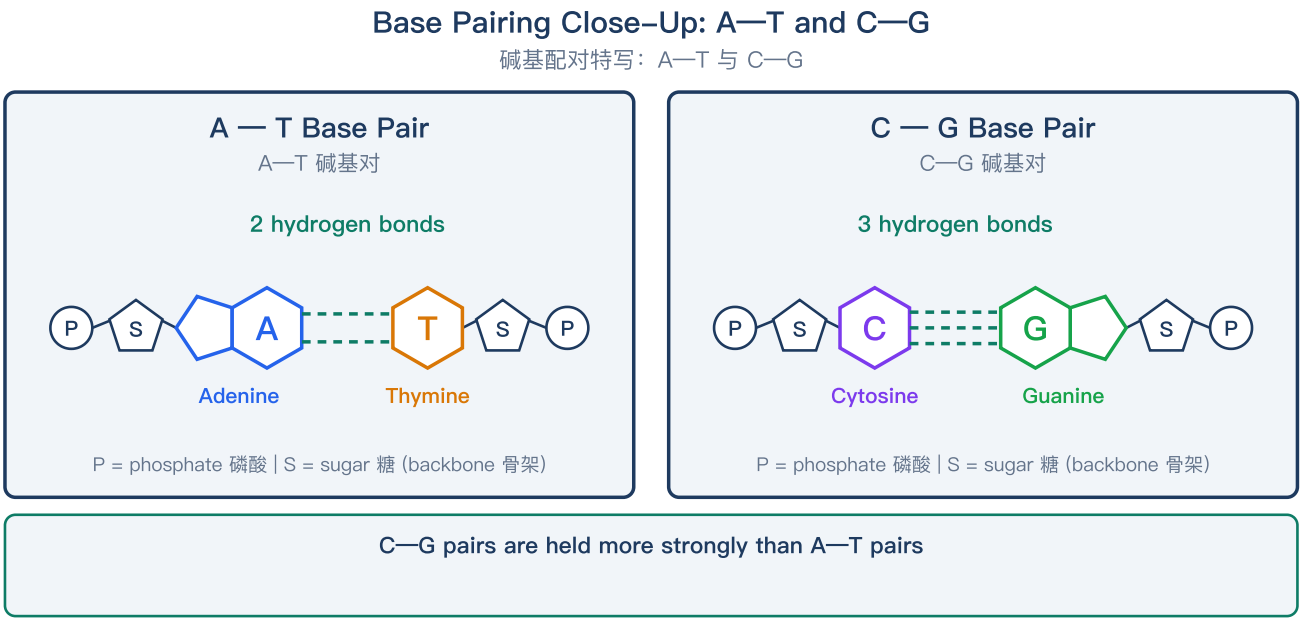
The four bases come in two sizes. Adenine and guanine are purines — large, double-ring molecules. Cytosine and thymine are pyrimidines — smaller, single-ring molecules. Because A–T and C–G each pair a large purine with a small pyrimidine, every rung of the ladder is the same total length, so the helix keeps a constant width of about 2 nanometres. If two purines ever paired the helix would bulge; if two pyrimidines paired it would pinch in. Size is only half the story, though. Adenine and cytosine are also a purine and a pyrimidine, yet they never pair. The bases only pair when their hydrogen-bonding sites line up, and only A with T and only C with G have their bonding groups in matching positions. So size explains why the helix keeps a constant width, and hydrogen bonding explains why the pairing rule is specific.

⬡ EXTENSION **Extension: what antiparallel actually means**

Each strand has two chemically different ends, labelled 5 prime and 3 prime. In a double helix the 5 prime end of one strand lines up with the 3 prime end of the other, so the strands run in opposite directions — like the two carriageways of a divided highway. For Year 11 you state that the strands are antiparallel and stop there; the 5-prime-to-3-prime machinery of copying belongs to Year 12.

◈ EXAMPLE **Think of a shell pressed into wet sand**

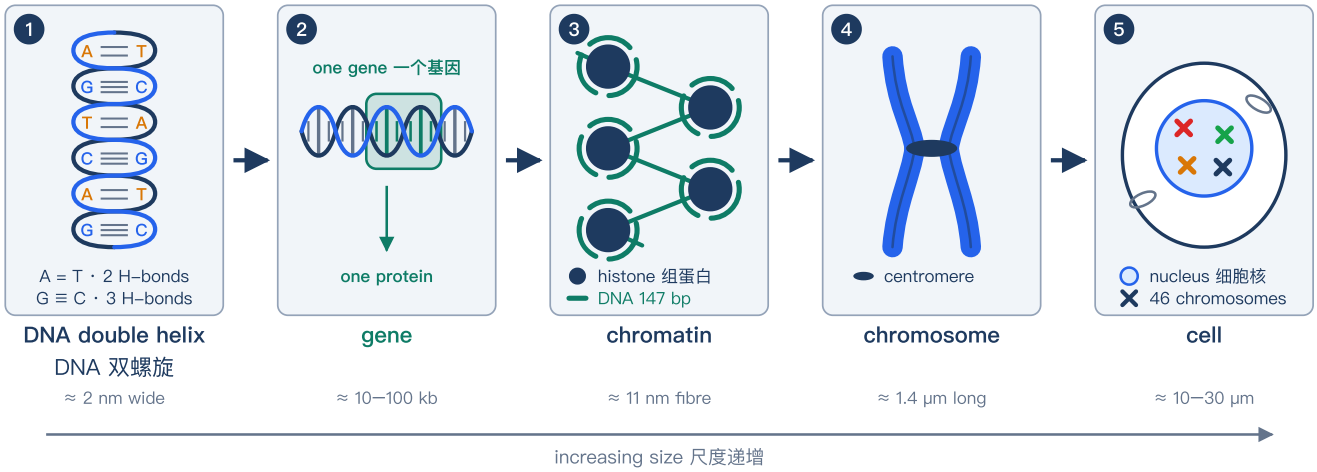
Press a shell into wet sand and lift it off. What you leave behind is not another shell — every ridge on the shell is a groove in the sand, every bump a dip. It is the opposite of the shell, and yet it holds every detail of it; you could pick that shell out of a pile from the print alone. That is what complementary means. The strand facing A–T–G–C is not A–T–G–C, it is T–A–C–G, each base replaced by its one fixed partner. The two strands are opposites that carry the same information, which is why knowing one strand tells you the other exactly. Where it breaks down: sand blurs and records the shape only once, whereas base pairing is exact and works both ways — either strand specifies the other, letter for letter, every time. And a print is sand, not shell, whereas both strands of DNA are ordinary DNA of exactly the same kind; neither one is the real strand and the other a mere impression of it.



Close-up of the two DNA base pairs: A—T is joined by two hydrogen bonds while C—G is joined by three, with each base attached to its sugar and phosphate on the backbone.

From base pair to genome: getting the sizes in order

This is where students lose marks that are genuinely easy to keep, because they use DNA, gene and chromosome as if the words were interchangeable. They are not interchangeable, and they are not three different substances either — they are the same material described at different levels of size, and you must be able to rank them and say how each relates to the next. Try the cookbook picture first: the individual letters are the bases, one recipe is a gene, one whole volume is a chromosome, and the complete set of volumes on the shelf is the genome. That picture is excellent for the ranking. Do not push it further than that, though — a cookbook has only one recipe per page and is read straight through, while a cell reads only the few genes it needs at any moment and ignores the rest.



The size hierarchy of genetic material: DNA double helix to gene, chromatin, chromosome and finally the cell nucleus.

Now the real terms, smallest first. A base pair is one rung of the ladder: two bases joined by hydrogen bonds. A gene is a length of DNA — typically hundreds or thousands of base pairs long — that carries the instructions for making one protein. A DNA molecule is one enormously long double helix carrying many genes along its length.

Most of the time that molecule is not the neat X-shaped chromosome you see in textbooks. Wrapped around packaging proteins called histones, it exists as chromatin: long, thin, tangled threads spread throughout the nucleus. Only when a cell prepares to divide does the chromatin coil and fold up tightly into a condensed chromosome, thick and short enough to be visible under a light microscope. The genome is the complete set of DNA in a cell or organism. Each level sits inside the next: base pairs make up a gene, genes sit along a DNA molecule, the DNA molecule is packaged as a chromosome, chromosomes sit inside the nucleus, and the nucleus sits inside the cell.

Some numbers will anchor the scale for you. A human somatic (body) cell contains 46 chromosomes, arranged as 23 pairs, which is what we mean when we call the cell diploid. Note the word body cell. Egg and sperm cells are not diploid — they are haploid, carrying just 23 chromosomes, one from each pair. So 'every human cell has 46 chromosomes' is wrong; every human body (somatic) cell does. How haploid cells are made is a later topic. One complete set — the human genome — is about three billion base pairs long and carries roughly 20,000 protein-coding genes; a body cell holds two such sets, which is the two metres of DNA mentioned earlier, folded into a nucleus only a few micrometres across. So if an exam asks where a gene is found, the full-mark answer walks down the levels: a gene is a section of a DNA molecule, that DNA molecule is packaged with proteins as a chromosome, the chromosomes are inside the nucleus, and the nucleus is inside the cell. Practise saying that chain out loud until it is automatic.

KEY TERMS

gene

A length of DNA, made of hundreds or thousands of base pairs, that carries the instructions for making one protein (at this level, treat one gene as coding for one protein).

chromatin

DNA wound around packaging proteins called histones in its normal, uncondensed state: long, thin threads spread through the nucleus.

chromosome

One long DNA molecule packaged with proteins; it becomes short, thick and visible under a microscope when the chromatin condenses before cell division.

genome

The complete set of DNA in a cell or organism.

diploid

Having two complete sets of chromosomes, one from each parent; human body cells are diploid with 46 chromosomes (23 pairs).

haploid

Having one complete set of chromosomes; human gametes (egg and sperm) are haploid with 23 chromosomes.

⚠ COMMON MISTAKE **A chromosome is not always X–shaped**

Textbook pictures show the X shape so often that students believe DNA always looks like that. It does not. For most of a cell's life the DNA is chromatin — thin, uncondensed threads you cannot see individually. Chromosomes only become visible when they condense before division, and an unreplicated chromosome is a single thread, not an X. The X shape appears only after the DNA has been copied. We will name those two halves (sister chromatids, joined at the centromere) in a later lesson.

✦ TIP **Say the ladder of sizes out loud**

base pair, then gene, then DNA molecule, then chromatin, then condensed chromosome, then genome. Six steps, always in that order. Then add the containers: chromosomes sit in the nucleus, the nucleus sits in the cell.

⚑ IN THE EXAM **Distinguish between a gene and a chromosome**

Distinguish means give one explicit point of difference. A full-mark answer states the relationship, not just two separate definitions: a gene is a short section of DNA coding for one protein, whereas a chromosome is an entire DNA molecule packaged with proteins and carrying many genes. The word whereas is doing real work there — use it.

◈ EXAMPLE **Think of a charging cable wound up before a flight**

Loose in your bag, a charging cable is a long thin thread that loops around everything and is impossible to trace end to end. Wind it tightly into a bundle before a flight and it becomes short and thick — you can take it in at a glance and move it without it snagging on anything. Nothing has been added and nothing has been cut: it is the same cable, with the same amount of wire in it, just packed into far less space. That is the difference between chromatin and a condensed chromosome — the same DNA in two states, not two substances found in two kinds of cell. Only when the cell prepares to divide does the chromatin coil and fold until it is short and thick enough to be seen under a light microscope and moved cleanly. Where it breaks down: a coiled cable has nothing inside the coil, whereas DNA is already wound around packaging proteins called histones even as loose chromatin. Condensing coils that histone-wrapped thread up further; it does not add the histones.

How to answer your worksheet boxes

Your class worksheet has a box labelled DNA, with the prompt telling you it is made of NUCLEOTIDES. A box like that is asking for a compact definition, not an essay, and the marks sit in specific words. Write something close to this: DNA (deoxyribonucleic acid) is the molecule that stores the genetic instructions for making proteins. It is a polymer made of repeating units called nucleotides. Each nucleotide is made of a phosphate group, a deoxyribose sugar and one of four nitrogenous bases (A, T, C or G). The nucleotides join into two strands with a sugar-phosphate backbone on the outside, and the two strands are twisted into a double helix. That is four sentences and it covers function, monomer name, the three components, the four bases and the overall shape — every idea a marker could be looking for.

The second box is labelled BASE PAIRING, with the prompt that the strands are held together by base pairing. Careful here, because the prompt itself is where most students stop, and stopping there loses the mark. Write: The two strands are held together by complementary base pairing. Adenine always pairs with thymine (A–T) and cytosine always pairs with guanine (C–G). Each pair is joined by weak hydrogen bonds — two between A and T, three between C and G. There are millions of these bonds, so together they hold the helix firmly, but because each one is weak they can be broken so the strands can separate. Notice what that adds to the prompt: the name of the rule, the two specific pairs, the bond type, the numbers, and the weak-but-many point. Held together by base pairing on its own is just repeating the question back.

Two habits will lock this in tonight. First, cover both model answers, write them from memory, then compare word by word and circle anything you left out — missing words are almost always the technical ones (nucleotide, complementary, hydrogen, backbone). Second, drill the pairing rule until it is reflex:

write out a random strand such as T–A–C–G–G–A–T–C and produce its complementary partner, then check every letter. If you can produce both worksheet answers from memory and complete a complementary strand without pausing, you have Day 1. One last warning about wording: never say the strands are held together by the backbone. The backbone runs along each strand separately and holds that strand together; it is base pairing that holds the two strands to each other.

⚑ IN THE EXAM **The verb ladder for this topic**

Identify the parts of a nucleotide — name them, nothing more. Describe the structure of DNA — give the features in an organised account (monomer, backbone, pairing, helix) with no causal reasoning needed. Explain why DNA can unzip without breaking — now you must link cause to effect using because, so that and therefore. Same content, three different answers. Read the verb before you write a single word.

✦ TIP **Write structure answers in the same fixed order**

Always go outside-in and small-to-large: nucleotide (three parts) → strand and sugar-phosphate backbone → base pairing and hydrogen bonds → double helix. Using one fixed running order every time means you never leave a component out under exam pressure, and the marker can find each point immediately.

⚠ COMMON MISTAKE **Do not answer with the analogy alone**

Twisted ladder and zipper are learning tools, not answers. A response that says DNA looks like a twisted ladder and unzips like a zip earns almost nothing. Convert every analogy into technical wording before it goes on the page: rails become sugar-phosphate backbones, rungs become base pairs, unzipping becomes the breaking of hydrogen bonds between complementary bases.

DAY 1 RECAP

- DNA stores the genetic instructions for making proteins, and it is a polymer built from repeating nucleotides.
- One nucleotide = a phosphate group + a deoxyribose sugar + one nitrogenous base (A, T, C or G), with the sugar in the middle.
- Nucleotides join sugar-to-phosphate by strong covalent bonds, forming the sugar-phosphate backbone along the outside of each strand, with the bases pointing inwards.
- Complementary base pairing is fixed: A always pairs with T (2 hydrogen bonds) and C always pairs with G (3 hydrogen bonds), so one strand determines the other exactly.
- Hydrogen bonds are individually weak but there are millions of them, so the helix is held firmly yet can still be unzipped at the bases without breaking either backbone.
- The two strands wind into a double helix, run in opposite directions (antiparallel) and keep a constant width all the way along.
- Size order to recite: base pair → gene → DNA molecule → chromatin → condensed chromosome → genome; chromosomes sit in the nucleus, and human body cells are diploid with 46 chromosomes (23 pairs), while gametes are haploid with 23.

Check Yourself — Day 1

1 **What is the function of DNA, and where is almost all of it found in a eukaryotic cell? (1 mark)**

a) It stores the genetic instructions for making proteins; it is found in the nucleus

b) It stores the genetic instructions for making proteins; it is found in the cell membrane

c) It speeds up the chemical reactions of the cell; it is found in the nucleus

d) It carries oxygen around the body; it is found in the cytoplasm

2 **Which of the following correctly lists the three parts of a single DNA nucleotide? (1 mark)**

a) A phosphate group, a deoxyribose sugar and one nitrogenous base

b) A phosphate group, a deoxyribose sugar and two nitrogenous bases

c) Adenine, thymine and cytosine

d) A sugar-phosphate backbone, a hydrogen bond and a base pair

3 **A section of one DNA strand has the base sequence A–G–C–T–T–C. Writing your answer in the same left-to-right order, what is the base sequence of the complementary strand? (1 mark)**

a) A–G–C–T–T–C

b) T–C–G–A–A–G

c) G–A–T–C–C–T

d) G–A–A–G–C–T

4 **Which statement about the bonds in a DNA molecule is correct? (1 mark)**

a) Base pairs are joined by strong covalent bonds and the backbone is held together by hydrogen bonds

b) Every base pair is held together by two hydrogen bonds

c) A–T pairs are held by two hydrogen bonds and C–G pairs by three, while the sugar-phosphate backbone is held by strong covalent bonds

d) The two strands are held to each other by the sugar-phosphate backbone

5 **Which list is in the correct order from smallest to largest? (1 mark)**

a) gene → base pair → DNA molecule → chromosome → genome

b) base pair → DNA molecule → gene → chromosome → genome

c) base pair → gene → genome → chromosome → DNA molecule

d) base pair → gene → DNA molecule → chromosome → genome

6 **When the two strands of a DNA molecule are separated, which bonds are broken? (1 mark)**

a) The covalent bonds between the sugar and the phosphate along each backbone

b) The bonds joining each base to its own sugar

c) The hydrogen bonds between the paired bases

d) All the bonds in the molecule, which is why the strands come apart

7 **Describe the structure of a DNA molecule. Use the terms nucleotide, sugar-phosphate backbone, complementary base pairing and double helix. (4 marks)**

8 **Explain why it is important that the two strands of DNA are held together by weak hydrogen bonds rather than by strong covalent bonds. (4 marks)**

9 **Distinguish between a gene and a chromosome. (2 marks)**

10 **Draw a simple diagram of two nucleotides joined together in one DNA strand. Label the phosphate group, the deoxyribose sugar, the nitrogenous base and the sugar-phosphate backbone. (4 marks)**

ANSWERS

Write your answer out first. A question you have read the answer to is not practice.

1. **a) It stores the genetic instructions for making proteins; it is found in the nucleus**

2. **a) A phosphate group, a deoxyribose sugar and one nitrogenous base**

3. **b) T–C–G–A–A–G**

4. **c) A–T pairs are held by two hydrogen bonds and C–G pairs by three, while the sugar-phosphate backbone is held by strong covalent bonds**

5. **d) base pair → gene → DNA molecule → chromosome → genome**

6. **c) The hydrogen bonds between the paired bases**

7. DNA is a polymer made of repeating units called nucleotides. Each nucleotide consists of a phosphate group, a deoxyribose sugar and one of four nitrogenous bases (adenine, thymine, cytosine or guanine). The sugar of one nucleotide bonds to the phosphate group of the next by strong covalent bonds, forming a sugar-phosphate backbone along the outside of each strand, with the bases pointing inwards. Two strands lie side by side and are held together by complementary base pairing: adenine pairs with thymine (two hydrogen bonds) and cytosine pairs with guanine (three hydrogen bonds). The two strands run in opposite directions (antiparallel) and are twisted into a double helix of constant width.

8. Because hydrogen bonds are weak, they can be broken individually without much energy, so the two strands can be separated (the helix can unzip) whenever the information in the DNA needs to be accessed or copied. At the same time, each strand is held together internally by strong covalent bonds in its sugar-phosphate backbone, so the strands stay intact while they are separated and each one can still act as a complete record of the base sequence. There are millions of hydrogen bonds along a DNA molecule, so collectively they still hold the double helix together firmly. If the strands were joined by covalent bonds instead, separating them would require breaking the molecule apart, and the DNA could not be copied.

9. A gene is a relatively short section of a DNA molecule, hundreds or thousands of base pairs long, that carries the instructions for making one protein, whereas a chromosome is an entire DNA molecule packaged

with proteins that carries many genes along its length. They are not different substances: genes are located on chromosomes, so a chromosome is the larger structure containing many genes.

10. Each nucleotide is drawn as three shapes: a phosphate group joined to one side of a deoxyribose sugar, and a nitrogenous base joined to the other side. The sugar of the first nucleotide is joined to the phosphate group of the second, and the line running phosphate–sugar–phosphate–sugar is labelled as the sugar-phosphate backbone. The two bases point sideways off the backbone, in the same direction as each other.

DAY 2

about 65 min

The Cell Cycle and Interphase

THE BIG IDEA

A cell cannot simply split in two and hope for the best: it first spends a long, busy interphase — growing in G1, replicating its DNA in S phase, and checking and preparing in G2 — because mitosis can only separate copies that already exist, so the copying must be finished before division begins.

BY THE END OF TODAY YOU WILL BE ABLE TO

1. Explain why cells divide, referring to growth, repair and replacement, and the limit that the surface area to volume ratio places on cell size.
2. Outline the cell cycle as a repeating sequence of interphase (G1, S and G2) followed by M phase (mitosis and cytokinesis).
3. Describe the events of G1, S and G2, and state in which sub-phase DNA is replicated.
4. Justify why DNA replication must be completed during interphase, before mitosis begins.
5. Interpret a cell cycle diagram or a set of phase durations, and calculate the percentage of the cycle spent in interphase.
6. Distinguish between the cell cycle and mitosis, and between a chromosome before and after S phase.

Why cells divide at all

Before you learn the steps of the cell cycle, you need a reason for the cycle to exist at all. Cells divide for three reasons, and you should be able to name all three without hesitating. The first is growth: you began as a single fertilised egg and you are now built from trillions of cells, and that happened because cells divided again and again. An organism grows mainly by making MORE cells, not by inflating the cells it already has. The second is repair and replacement: damaged tissue is rebuilt, and worn-out cells are replaced. The third is asexual reproduction, in which a whole new organism is produced from one parent by cell division alone — budding in yeast and Hydra, or a strawberry plant sending out a runner. Growth and repair are the two you will be asked about most often, and we come back to all three when we look at the roles of mitosis later in the topic.

Repair and replacement is the one that catches students out, because it is easy to assume division stops once you have finished growing. It does not. The outer layer of your skin is shed constantly and replaced by cells dividing deeper in the epidermis. The lining of your gut is replaced every few days, because digestion

is chemically brutal on it. Mature red blood cells have no nucleus and cannot divide at all, so replacements are produced by the division of precursor cells in your bone marrow. Wound healing is the same process concentrated in one place: cells at the edges of a cut divide until the gap is closed. Right now, as you read this sentence, millions of your cells are somewhere in the middle of a cell cycle.

That leaves an obvious question: why divide at all — why not simply let one cell grow bigger? The limit is geometric. Everything a cell needs (oxygen, glucose) and everything it must get rid of (carbon dioxide, wastes) has to cross the cell surface membrane, so surface area is the cell's supply line, while the volume of cytoplasm inside is the demand. As a cell enlarges, its volume grows faster than its surface area, so the surface area to volume ratio falls and each unit of cytoplasm is served by less membrane. The distance from the membrane to the centre also increases, and diffusion over longer distances is slow. Past a certain size the cell simply cannot supply its own interior. So instead of continuing to grow, it divides — and the two smaller daughter cells each have a healthier surface area to volume ratio again.

KEY TERMS

surface area to volume ratio

The ratio of a cell's outer surface area to the volume of cytoplasm inside it; it falls as a cell grows larger, limiting how big a cell can become.

tissue repair

Replacement of damaged or worn-out cells by cell division, for example in wound healing, skin and the lining of the gut.

asexual reproduction

Production of new individuals from a single parent by cell division, without gametes or fertilisation; the offspring are genetically identical to the parent. Examples include budding in yeast and Hydra, and a strawberry plant reproducing by runners.

EXTENSION **Extension: do the cube arithmetic yourself**

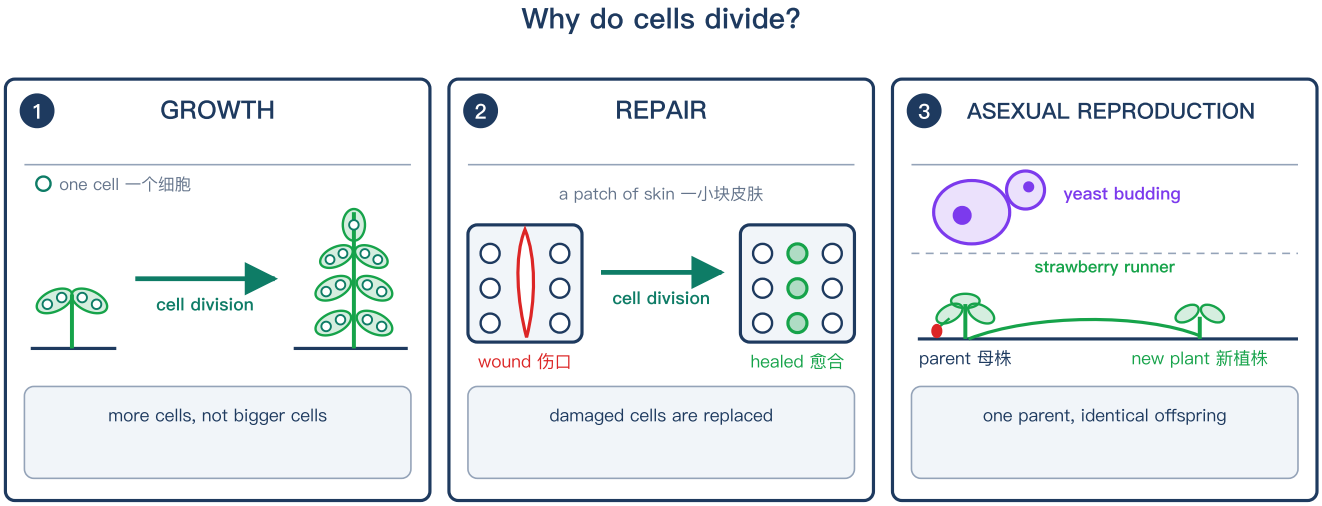
Model a cell as a cube. A cube with 1 cm sides has a surface area of 6 cm2 (six faces, each 1 cm2) and a volume of 1 cm3, giving a surface area to volume ratio of 6:1. Double the sides to 2 cm and the surface area becomes 24 cm2 while the volume becomes 8 cm3 — a ratio of only 3:1. At 3 cm sides it is 54 cm2 to 27 cm3, or 2:1. The supply line has not kept up with the demand. Real cells are not cubes, and some cells get around the problem with a flattened or branched shape, but the arithmetic is exactly why most cells stay microscopic and divide instead of swelling.

⚠ COMMON MISTAKE **Cell division is not only for growing children**

Students often write that cell division happens 'while an organism is growing', as though an adult's cells have stopped. Adults are not finished: skin, gut lining and blood are replaced continuously throughout life, and wound healing can start at any age. If a question asks for the roles of cell division, growth alone is a partial answer — name replacement and repair as well.

◈ EXAMPLE **Think of a thick hot chip**

Put a thin chip and a thick potato wedge in the same oven for the same time. The thin one cooks through. The wedge browns on the outside while the middle is still raw, because heat only gets in across the surface and then has to travel inwards. A cell has the same problem, in two parts. Everything it needs crosses the cell surface membrane, so surface area is the supply line and the cytoplasm inside is the demand — and as the wedge gets thicker, its volume climbs faster than its surface does, so the surface area to volume ratio falls. The second part is distance: the centre of a wedge is further from any surface, and diffusion over longer distances is slow. Where it breaks down: leave the wedge in the oven longer and the middle does eventually cook, but a cell cannot solve its problem by waiting, because its demand for oxygen and glucose never stops and its wastes keep building — the supply across the membrane has to keep up continuously. And a wedge cannot turn itself into two thin chips, which is precisely what a cell does instead of growing.

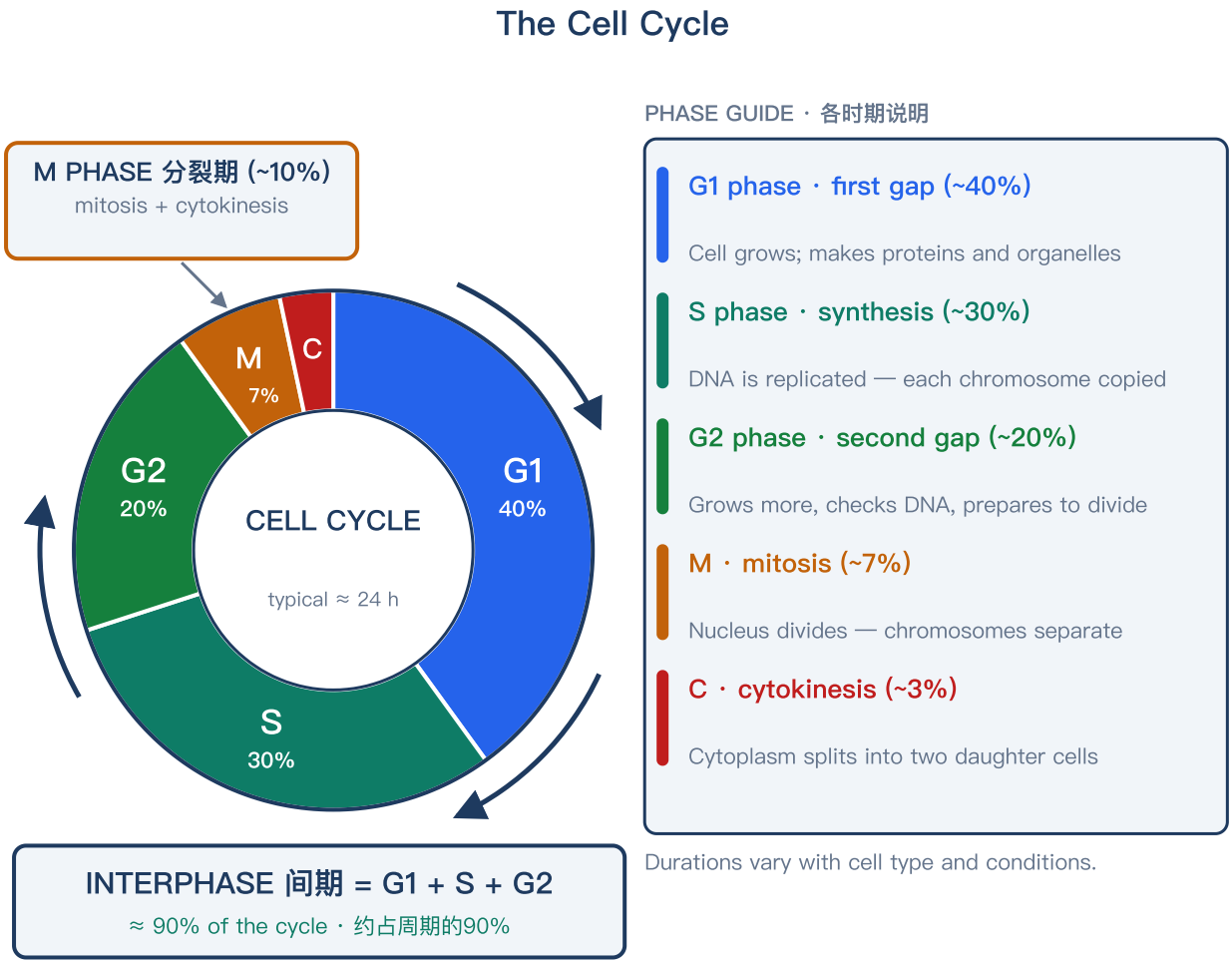


Cells divide for three reasons: to grow, to repair damage, and to reproduce asexually.

The cell cycle: one loop with two very unequal parts

The cell cycle is the ordered, repeating sequence of events that runs from the moment a cell is produced to the moment it divides to produce two cells of its own. It has two main parts, and getting the naming right here will earn you marks all year. The first part is interphase, which is divided into three sub-phases in this order: G1, S and G2. The second part is M phase, which is made up of mitosis — the division of the nucleus

— followed by cytokinesis, the division of the cytoplasm into two separate cells. Notice what that sentence does not say. Interphase is not a stage of mitosis; it is the part of the cell cycle that comes before mitosis. Mitosis itself has exactly four stages, and you meet them on Day 4.



The cell cycle: a long interphase (G1, S, G2 — about 90% of the cycle) followed by a short M phase of mitosis and cytokinesis, proceeding clockwise.

Now look at the diagram and pay attention to the sizes of the slices, because they are not decoration. In almost every cell you will meet, interphase occupies roughly 90 per cent or more of the cycle. In the standard textbook example of a rapidly dividing human cell grown in the laboratory, one full cycle takes about 24 hours, of which M phase is roughly one hour — everything else is interphase. Different sources quote slightly different breakdowns, so always work from the figures the question gives you rather than a memorised percentage. Your lessons spend most of their time on mitosis because mitosis has lots of named stages and diagrams to learn, and that gives students a badly distorted mental picture of the timing. In terms of time, mitosis is the brief event at the end of a long preparation, not the main event of a cell's life.

Two more features of the diagram matter. First, it is a cycle: the arrow goes all the way round, so each of the two daughter cells produced at cytokinesis begins its own G1 and the whole sequence starts again. Second, the length of a cycle is not fixed — it varies enormously between cell types and organisms. Some human cells, such as those lining the gut, divide roughly once a day, while others may go months or years

between divisions. When a question says Construct or Label a cell cycle diagram, draw interphase as the large arc, subdivide it G1 to S to G2 in that order, keep M phase as a thin wedge, subdivide M into mitosis and cytokinesis, and write the words DNA replication next to S phase. Those labels are where the marks sit.

KEY TERMS

cell cycle

The ordered, repeating sequence of events from the formation of a cell to its division into two daughter cells; made up of interphase and M phase.

interphase

The part of the cell cycle before M phase, consisting of G1, S and G2; the longest and metabolically busiest part of the cycle.

M phase

The division part of the cell cycle: mitosis (division of the nucleus) followed by cytokinesis (division of the cytoplasm).

mitosis

Division of the nucleus, in which the sister chromatids of each chromosome are separated into two identical nuclei.

cytokinesis

Division of the cytoplasm after mitosis, producing two separate daughter cells.

⚠ COMMON MISTAKE **Interphase is a phase of the CELL CYCLE, not a phase of mitosis**

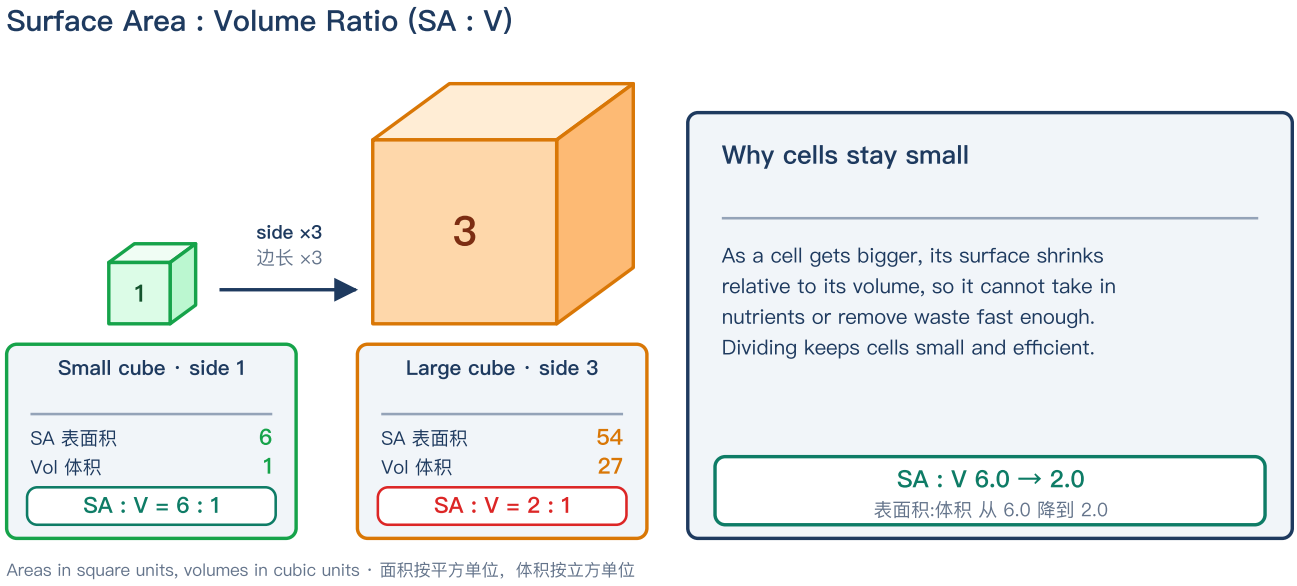
A very common error is to list interphase as a fifth stage of mitosis, alongside prophase, metaphase, anaphase and telophase. Mitosis has four stages, full stop. Interphase belongs to the cell cycle and finishes before prophase begins. If a question asks you to name the stages of mitosis and you include interphase, you have shown the marker exactly which idea you have muddled.

⚠ COMMON MISTAKE **Do not read the pie diagram backwards**

Because lessons and textbook pages devote most of their space to mitosis, students often draw or interpret the cell cycle circle as though mitosis takes up most of the cycle. Time spent teaching a phase has nothing to do with how long the phase lasts. On a correctly drawn diagram the M phase wedge is thin and interphase is the overwhelming majority of the circle.

TIP Four words for four phases

Say it out loud until it is automatic: G1 grow, S copy, G2 check, M divide. Then add the tail: and cytokinesis splits the cytoplasm. That single line gives you the sequence, the key event of each phase, and reminds you that cytokinesis is separate from mitosis. And keep the two words apart: mitosis is the division of the NUCLEUS only, while 'cell division' means mitosis PLUS cytokinesis. Writing 'mitosis' when you mean the whole of cell division loses marks.



A cube of side 1 has a surface area to volume ratio of 6:1, but a cube of side 3 has only 2:1 — as a cell grows, its surface falls behind its volume, which is why cells divide instead of getting bigger.

Inside interphase: G1, S and G2

G1 stands for the first gap — and it is a 'gap' only in the sense that it sits between the last division and the start of DNA synthesis, because nothing about it is idle. During G1 the newly formed cell grows back towards a normal size, synthesises proteins, and builds new organelles such as ribosomes and mitochondria, so that there will eventually be two working sets of machinery to hand on. It is also getting on with its ordinary job: a liver cell in G1 is still processing chemicals, a leaf cell is still photosynthesising. For most cells G1 is the longest sub-phase, and it is where a cell spends most of its ordinary working life.

S stands for synthesis, and this is the one phase you must never misplace: S phase is when the DNA is replicated. Every chromosome is copied, so the cell now holds two identical copies of every chromosome — a complete second copy of its entire genome. The structural consequence is the sentence that turns up in exam answers again and again: a chromosome that was a single thread of DNA now consists of two identical sister chromatids, joined at a region called the centromere. Read the next line carefully, because it is where marks are won and lost. The amount of DNA in the nucleus has doubled, but the chromosome number has NOT changed. A human body cell still has 46 chromosomes at the end of S phase — it simply has 92 chromatids. How the copying is actually carried out is tomorrow's lesson.

G2 is the second gap, and it works like a pre-flight check. The cell keeps growing, duplicates the remaining organelles, and synthesises the proteins that the division itself will need — including the protein subunits that will later be assembled into spindle fibres, the protein cables that attach to each chromosome's centromere during mitosis and pull the chromatids apart. Just as importantly, the newly copied DNA is checked and repairable errors are repaired, so the cell does not carry a damaged copy into division. Only when G2 is complete does the cell enter M phase. If you can produce one accurate sentence about each sub-phase — G1: the cell grows and makes organelles and proteins; S: the DNA is replicated so each chromosome becomes two sister chromatids joined at a centromere; G2: the cell grows further, checks the copied DNA and makes the proteins needed for division — you can answer almost any Describe question on interphase.

KEY TERMS

G1 phase

The first sub-phase of interphase, in which the cell grows, synthesises proteins and makes new organelles while carrying out its normal functions.

S phase

The sub-phase of interphase in which DNA is replicated, so that each chromosome comes to consist of two identical sister chromatids joined at a centromere.

G2 phase

The final sub-phase of interphase: further growth, checking and repair of the replicated DNA, and synthesis of proteins needed for division, including spindle components.

sister chromatid

One of the two identical copies of a replicated chromosome, joined to its partner at the centromere.

centromere

The region that holds sister chromatids together and to which spindle fibres attach during mitosis.

⚠ COMMON MISTAKE **Interphase is NOT a resting phase**

Older books and lazy summaries call interphase the resting stage, and students then write that 'the cell rests before dividing'. That answer scores zero. Interphase is the longest and most metabolically active part of the cycle: the cell is growing, building organelles and proteins, doing its everyday job and copying an entire genome. If you are tempted to write 'rest', write G1, S and G2 with one event each instead.

⚠ COMMON MISTAKE **DNA is not replicated at the start of mitosis**

'The DNA copies itself during prophase' is one of the most heavily penalised errors in this topic. Replication is finished before mitosis begins — that is precisely why the chromosomes that become visible in prophase already appear as two chromatids. If replication happened during prophase, there would be nothing for the spindle to separate at anaphase.

⚠ COMMON MISTAKE **A chromosome does not always look like an X**

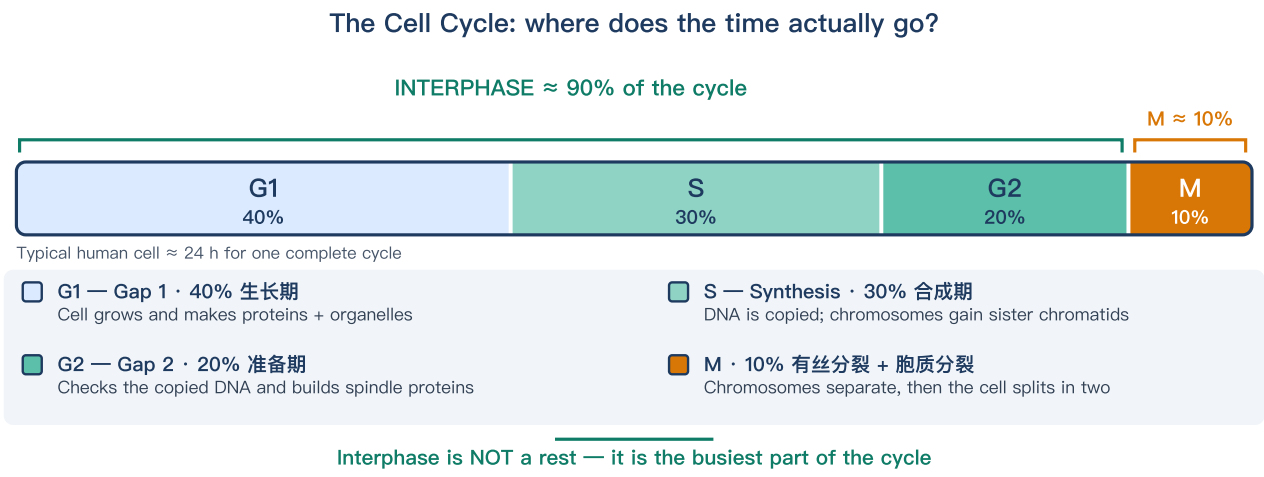
Textbook diagrams almost always draw the replicated, X-shaped chromosome, so students assume every chromosome has two chromatids all of the time. It does not. Throughout G1 — which is most of a cell's life — each chromosome is a single unreplicated thread with one chromatid and one centromere. The two-chromatid X form exists only from the end of S phase until anaphase, when the centromere divides and each chromatid becomes a chromosome in its own right. Remember too that these condensed, drawable shapes are only visible during division; for the whole of interphase the same DNA is present as long, uncondensed threads.

⬡ EXTENSION **Extension: G0, the cells that step off the cycle**

Not every cell keeps cycling. Some leave the cycle after G1 and enter a state called G0, where they carry out their function without preparing to divide. Mature neurons and cardiac muscle cells are normally in G0 permanently, which is part of why nerve and heart damage does not heal the way a cut in your skin does, while liver cells sit in G0 but can re-enter the cycle if the organ is damaged. This is extension in all three states — useful background, not a required dot point.

◈ EXAMPLE **Think of a stapled handout**

A teacher gives out a two-page worksheet, stapled in the corner, to 46 students. How many handouts left the room? Forty-six — not ninety-two — even though ninety-two sheets of paper did. You count staples, not sheets. That is exactly the count at the end of S phase. Every chromosome has been replicated, so each one is now two identical sister chromatids held together at a single centromere, and the centromere is the staple. The cell holds twice the DNA but still 46 chromosomes, because one centromere means one chromosome. The number only becomes 92 at anaphase, when each centromere divides and every chromatid gains one of its own. Where it breaks down, in two places: the two pages of a handout say different things, whereas sister chromatids carry identical DNA — and that identity is the entire point of copying. And a staple is a separate object clipped on afterwards, whereas the centromere is not added to the chromosome — it is a region of the chromosome's own DNA, copied during S phase along with everything else.



Interphase is NOT a rest — it is the busiest part of the cycle

The key question: why must the DNA be copied BEFORE mitosis?

This is the question your class asked, and it deserves a proper answer rather than 'because it just has to'. Start from what mitosis actually does. Mitosis is a separation process, not a copying process. Spindle fibres attach at the centromere of each chromosome and pull the two sister chromatids apart, one to each pole — and that is the whole of what mitosis is able to do. It has no mechanism for manufacturing new genetic material. So if the copies are not already sitting there when mitosis begins, there is nothing to separate, and no amount of careful dividing can invent the missing DNA.

Do the counting and it becomes obvious. A human body cell is diploid and has 46 chromosomes. During S phase every chromosome is replicated, so the cell enters mitosis with 46 chromosomes made up of 92 chromatids. At anaphase the centromeres divide and one chromatid from each pair travels to each pole, so each new nucleus receives 46 chromosomes — a complete set, and identical to the set in the other nucleus. Now imagine the cell had skipped S phase. It would enter mitosis with 46 single-chromatid chromosomes, and the spindle could do nothing except share those 46 out between the two poles, giving roughly 23 each: a random, incomplete half-set. Those daughter cells would be missing the genes for essential proteins, so they could not function, and a second division would strip out more again. Copying first is what makes the daughter cells both complete and genetically identical.

Why does the copying happen during interphase rather than during mitosis itself? Two reasons you can quote. First, DNA can only be copied while it is uncoiled and accessible — long, loose threads of DNA and protein called chromatin — which is exactly its state throughout interphase; from prophase onwards it is coiled up tightly for transport and is not being read or copied. Second, replication takes time, and the new copy has to be checked before it is separated — which is precisely the job of G2. So the order of the cycle is not arbitrary. Replicate in S, check in G2, separate in M. Learn to say the whole chain in one breath: DNA is replicated in S phase, so each chromosome consists of two identical sister chromatids joined at a centromere; at anaphase the centromeres divide and one chromatid of each pair moves to each pole; therefore each daughter nucleus receives one complete, identical copy of every chromosome.

KEY TERMS

DNA replication

The copying of a DNA molecule during S phase so that two identical molecules are produced, one for each future daughter cell.

chromatin

The long, uncondensed threads of DNA and protein in which the genetic material exists throughout interphase; DNA can only be replicated and read in this accessible form.

diploid

Having two complete sets of chromosomes, one from each parent; human body cells are diploid with 46 chromosomes (23 pairs).

daughter cell

Either of the two cells produced when a parent cell completes mitosis and cytokinesis.

genetically identical

Carrying exactly the same DNA sequence; the daughter cells of mitosis are genetically identical to each other and to the parent cell.

⚑ IN THE EXAM **Model answer: 'Justify why DNA replication must occur before mitosis'**

Justify needs evidence plus a stated conclusion. Try this shape: 'Mitosis separates the sister chromatids of each chromosome; it does not copy DNA. If the DNA were not replicated first, there would be no sister chromatids to separate, so the parent cell's 46 chromosomes could only be shared between the two poles, giving each daughter cell an incomplete set that is missing essential genes. Because DNA replication in S phase produces two identical chromatids per chromosome, mitosis can deliver one complete identical set to each daughter cell. Replication must therefore be completed before mitosis begins.' Three moves: what mitosis does, what would go wrong, conclusion.

⚠ COMMON MISTAKE **'The DNA is shared evenly between the two cells' earns nothing**

This is the single most common weak answer in the whole topic. Fair sharing of the original DNA would give each daughter cell half a genome, not a whole one. The identity and completeness of the daughter cells comes from the COPYING step in S phase, not from careful division. If your sentence does not contain the word replicated or copied, it is not yet an explanation.

⚠ COMMON MISTAKE **S phase doubles the DNA, not the chromosome number**

After S phase a human cell has 46 chromosomes and 92 chromatids — not 92 chromosomes. A replicated chromosome is still ONE chromosome, because it still has one centromere; it simply now has two chromatids. Count centromeres, not arms. The chromosome number changes only at anaphase: when the centromeres divide, each chromatid gains its own centromere and so becomes a chromosome in its own right, and the cell momentarily contains 92 chromosomes. These are then shared equally between the two poles, so each new nucleus again receives 46 single-chromatid chromosomes — exactly the number the parent cell started with. Each daughter nucleus therefore ends up with the same chromosome number as the parent: in mitosis the chromosome number is never halved.

Writing about the cell cycle: verbs, numbers, diagrams and quality control

Most marks in this topic are lost to the verb, not to the biology, so match your answer to what is being asked. Outline the events of the cell cycle wants a short sequence in general terms: interphase (G1 growth, S DNA replication, G2 preparation and checking), then mitosis, then cytokinesis. Describe what occurs during S phase wants characteristics and features with no reasoning attached: DNA is replicated, so that each chromosome comes to consist of two identical sister chromatids joined at a centromere. Explain and Justify want the cause-and-effect links, with every sentence tied to the next by because, so that or therefore. A description dressed up as an explanation earns description marks only — and that is where the difference between a good answer and a top answer usually sits.

You will also be handed numbers, and the arithmetic is straightforward as long as you show it. If a cell completes one full cycle in 24 hours and M phase takes about 1 hour, then the time in interphase is 24 minus 1 equals 23 hours, and the percentage is 23 divided by 24, times 100, which is 95.8 per cent. Write the working and the per cent sign; Calculate questions award both. The reasoning also runs backwards: if a diagram or table shows that a phase occupies a large slice of the cycle, that phase lasts a long time. This is why a correctly drawn cell cycle circle has an enormous interphase arc and a thin M phase wedge, and why a circle drawn as four equal quarters is marked wrong even when every label on it is correct.

Finally, build the habit of using technical vocabulary without being prompted. Under exam pressure the default answer is 'the cell splits in two', which earns nothing at all, because it names no phase, no structure and no process. Train yourself to include all three in every answer, like this: 'During S phase of interphase the DNA is replicated, so each chromosome comes to consist of two identical sister chromatids joined at a centromere.' That one sentence contains a phase, a process, a structure and a consequence. Keep this working vocabulary live for the rest of the topic: interphase, G1, S phase, G2, M phase, mitosis, cytokinesis, replicated, sister chromatid, centromere, chromatin, diploid, daughter cell, genetically identical.

KEY TERMS

checkpoint

(Extension) A control point in the cell cycle at which conditions are assessed before the cell is allowed to continue to the next phase.

EXTENSION

Extension: checkpoints — the cell cycle's quality control

The cycle is not a free-running loop; a cell is only allowed to proceed when conditions are right, and this is assessed at checkpoints. At the G1/S checkpoint the cell effectively asks: am I big enough, are nutrients and growth signals available, and is my DNA undamaged? Only then does it commit to S phase. At the G2/M checkpoint: has all of my DNA been replicated, and is the copy free of damage? Only then does mitosis begin. At the spindle (M) checkpoint, during metaphase, the cell checks that every chromosome is attached to spindle fibres at its centromere before anaphase is allowed to start. Cell cycle regulation is required content for VCE Unit 1; for NSW and QLD treat it as valuable extension. You do not need the molecules that run the checkpoints.

EXTENSION

Extension: what happens when control is lost

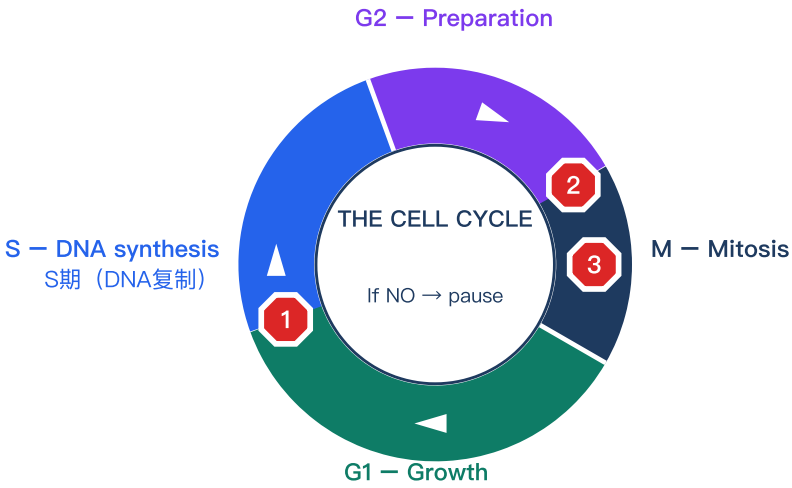
If checkpoints fail, cells can divide when they should not, and can carry damaged DNA into division instead of pausing to repair it. Uncontrolled, repeated division produces a growing mass of cells — a tumour — and these cells divide more often than normal cells, ignore signals to stop, and may lose their normal specialised function. This is the required consequence in VCE Unit 1 (loss of cell cycle regulation and cancer) and a strong extension for NSW and QLD. Keep the answer at this level: link cancer to a FAILURE OF CELL CYCLE CONTROL rather than describing it vaguely as 'cells growing wrongly'.

IN THE EXAM

Which parts of today does your course actually assess?

Everything in the five main sections is core for NSW Module 5 and for VCE Unit 1. In QCAA Unit 1 the cell cycle appears mainly as background to stem cells and differentiation, and the detail is assessed in Unit 4 — so treat today as core preparation either way. The state differences show up at the edges: VCE Unit 1 requires the sub-phases of the cell cycle plus checkpoints, loss of regulation and cancer, but for S phase it asks only that 'DNA is replicated' — the mechanism belongs to Unit 3. NSW Module 5 and QCAA Unit 4 want the replication detail itself, which is tomorrow's lesson. If you are unsure which applies to you, learn the core plus the checkpoint idea: it is required in one state and useful background everywhere else.

Cell Cycle Checkpoints — Quality Control Before Dividing



1 G1/S Checkpoint
G1/S 检查点

Is the cell big enough?
Is the DNA undamaged?

2 G2/M Checkpoint
G2/M 检查点

Was the DNA copied completely and correctly?

3 Spindle Checkpoint

Are all chromosomes attached to the spindle?

If a checkpoint fails and division continues anyway, cells can divide out of control — **this is the link to cancer.**

The cell cycle wheel (G1 → S → G2 → M) with its three quality-control checkpoints — G1/S, G2/M and the spindle checkpoint — and why failed checkpoints are linked to cancer.

DAY 2 RECAP

- Cells divide for growth, for repair and replacement of worn-out cells, and for asexual reproduction (for example budding in yeast and Hydra, or a strawberry runner) — and division continues throughout adult life in skin, gut lining and blood.
- A cell cannot just keep growing: as it enlarges, volume increases faster than surface area, so the surface area to volume ratio falls and the membrane can no longer supply the interior — so the cell divides instead.
- The cell cycle = interphase (G1, S, G2) followed by M phase (mitosis, then cytokinesis), and it repeats: each daughter cell starts again at G1. Mitosis is nuclear division only; cell division = mitosis + cytokinesis.
- Interphase is the longest and busiest part of the cycle — roughly 90 per cent or more of it — and it is NOT a resting phase and NOT a stage of mitosis.
- G1 grow (proteins and organelles); S copy (DNA replicated, so each chromosome becomes two identical sister chromatids joined at a centromere); G2 check the copy and make the proteins needed for division, including spindle components.
- S phase doubles the amount of DNA but not the chromosome number: a human cell still has 46 chromosomes, now made of 92 chromatids. Count centromeres, not arms — and remember that for most of a cell's life a chromosome is a single unreplicated thread, not an X.
- Replication must finish before mitosis because mitosis only SEPARATES existing sister chromatids — without a prior copy, each daughter cell would receive an incomplete half-set and could not function. The identity of daughter cells comes from copying, not from fair sharing.

Check Yourself — Day 2

1 **Which statement about interphase is correct?**

a) It is the resting stage of the cell cycle, during which the cell is metabolically inactive.

b) It is the longest part of the cell cycle, during which the cell grows, replicates its DNA and prepares for division.

c) It is the first stage of mitosis, occurring immediately before prophase.

d) It is the stage in which sister chromatids are separated and moved to opposite poles.

2 **During which phase of the cell cycle is DNA replicated?**

a) G1 phase

b) S phase

c) G2 phase

d) Prophase

3 **A human body cell contains 46 chromosomes. Immediately after S phase is complete, the cell contains:**

a) 46 chromosomes and 46 chromatids

b) 46 chromosomes and 92 chromatids

c) 92 chromosomes and 92 chromatids

d) 23 chromosomes and 46 chromatids

4 **(Extension) A cube-shaped model cell with sides of 1 cm grows until its sides are 2 cm long. What happens to its surface area to volume ratio, and why does this matter?**

a) It stays the same, because both surface area and volume increase together.

b) It increases from 3:1 to 6:1, so exchange across the membrane becomes easier.

c) It decreases from 6:1 to 3:1, so each unit of cytoplasm is served by less membrane for exchange.

d) It decreases from 6:1 to 3:1, but this does not matter because the diffusion distance to the centre is unchanged.

5 **Which statement about cell division in a fully grown adult is correct?**

a) Cell division has stopped, because the body has finished growing.

b) Cell division continues, but only at the site of an injury.

c) Cell division continues throughout life to replace worn-out cells, for example in the skin, the lining of the gut and the blood.

d) Cell division continues, but only in order to produce gametes.

6 **Which sequence correctly describes one turn of the cell cycle?**

a) G1 → S → G2 → mitosis → cytokinesis

b) Interphase → prophase → metaphase → S phase → anaphase → telophase

c) S → G1 → G2 → cytokinesis → mitosis

d) G1 → G2 → S → mitosis → cytokinesis

7 **Describe what occurs during S phase of interphase. (3 marks)**

8 **Justify why DNA replication must be completed before mitosis begins. (3 marks)**

9 **A rapidly dividing human cell in culture completes one full cell cycle in 24 hours, and M phase (mitosis and cytokinesis) takes approximately 1 hour. Calculate the percentage of the cycle spent in interphase, and state what your answer tells you about how a cell cycle diagram should be drawn. (3 marks)**

ANSWERS

Write your answer out first. A question you have read the answer to is not practice.

1. **b) It is the longest part of the cell cycle, during which the cell grows, replicates its DNA and prepares for division.**

2. **b) S phase**

3. **b) 46 chromosomes and 92 chromatids**

4. **c) It decreases from 6:1 to 3:1, so each unit of cytoplasm is served by less membrane for exchange.**

5. **c) Cell division continues throughout life to replace worn-out cells, for example in the skin, the lining of the gut and the blood.**

6. **a) G1 → S → G2 → mitosis → cytokinesis**

7. During S phase the DNA of the cell is replicated, so that two identical copies of every chromosome are produced. As a result, each chromosome now consists of two identical sister chromatids joined together at the centromere. The amount of DNA doubles, but the chromosome number stays the same (a human cell still has 46 chromosomes, now made up of 92 chromatids). The verb is Describe, so do not explain why replication must come first — and do not omit that the chromosome number is unchanged, which is usually the second mark. With three marks available, credit is given separately for (i) DNA is replicated, (ii) each chromosome now consists of two identical sister chromatids joined at a centromere, and (iii) the amount of DNA doubles while the chromosome number does not change.

8. Mitosis is a separation process, not a copying process: spindle fibres attach at the centromere and pull the two sister chromatids of each chromosome to opposite poles. If the DNA had not already been replicated in S phase, there would be no sister chromatids to separate, so the parent cell's chromosomes could only be shared out between the two poles and each daughter cell would receive an incomplete set missing essential genes, making it non-functional. Because replication in S phase gives every chromosome two identical chromatids, mitosis can deliver one complete and identical set of chromosomes to each daughter cell. Replication must therefore be completed before mitosis begins. Structure the answer in three moves — what mitosis does, what would go wrong without replication, and the conclusion — linking the sentences with because, so that or therefore.

9. Time in interphase = 24 - 1 = 23 hours. Percentage = 23 / 24 x 100 = 95.8% (about 96%). This tells you that interphase must be drawn as by far the largest part of a cell cycle diagram, with M phase as a thin wedge; a

circle divided into equal quarters would misrepresent the timing, even if all the labels were correct. Calculate questions award the working and the per cent sign separately, and the final 'so the diagram must be drawn this way' statement is the third mark. Note that other sources quote breakdowns such as G1 40%, S 30%, G2 20%, M 10% — always calculate from the data you are given rather than from a memorised percentage.

DAY 3

about 70 min

DNA Replication: Making an Exact Copy

THE BIG IDEA

Before a cell can divide it copies its entire DNA, unzipping the double helix and building a new partner strand against each old one, so every new DNA molecule is half old and half new — and that copying step, not fair sharing, is why daughter cells end up genetically identical.

BY THE END OF TODAY YOU WILL BE ABLE TO

1. Identify S phase of interphase as the only stage of the cell cycle in which DNA replication occurs.
2. Describe the sequence of events in DNA replication, from the unwinding of the double helix to the formation of two complete DNA molecules.
3. Explain why replication is described as semi-conservative, and why the hydrogen bonds break while the sugar-phosphate backbone stays intact.
4. Construct the complementary strand for a given template strand sequence using the base-pairing rules A-T and C-G.
5. Distinguish a replicated chromosome (two identical sister chromatids joined at a centromere) both from a single unreplicated chromosome and from a homologous pair of chromosomes.
6. Justify why DNA replication must be completed before mitosis begins, referring to the consequences for chromosome number in the daughter cells.

1. Where and when replication happens: S phase

Yesterday you met the cell cycle: a long interphase made of G1, S and G2 — the busiest part of the cycle, not a rest — followed by a short M phase of mitosis and cytokinesis. Today we zoom right into the S sitting in the middle of interphase. S stands for synthesis, and what is being synthesised is DNA. This is the single moment in the whole cycle when the cell makes a complete second copy of every DNA molecule it owns. Before S phase, a human somatic cell has 46 chromosomes, each one a single DNA molecule. After S phase it still has 46 chromosomes, but each one now contains two identical DNA molecules held together. Hold onto that sentence — the number does not change, the content doubles. We will come back to it at the end of the lesson.

Replication takes place inside the nucleus, because that is where the chromosomes are. It needs three things present at once: the DNA itself, a supply of free nucleotides floating in the nucleus, and the enzymes that do the work. Those free nucleotides are already there — the cell built up a stock of them during G1, before S phase began, as part of its ordinary metabolism, and keeps topping the supply up while replication runs. This matters more than it sounds, because a very common student picture is of an enzyme manufacturing each new nucleotide to order, one at a time, like a chef cooking a dish only once the customer asks for it. Nothing so clever is going on. The ingredients are already in the pot; the process simply selects the correct one at each position by complementary base pairing.

One more timing point that markers reward every year: replication is finished before mitosis starts. By the end of S phase every chromosome has been duplicated. G2 is then spent growing further, checking the copy, and building the proteins that will later form spindle fibres. Only after all of that does prophase begin. If you write in an exam that DNA replicates during prophase, or at the start of mitosis, you lose the mark immediately — and worse, the rest of your answer becomes impossible to follow, because mitosis contains no copying step anywhere in it.

KEY TERMS

S phase
The middle sub-phase of interphase, during which every DNA molecule in the nucleus is replicated.

free nucleotides
Ready-made nucleotide units already present in the nucleus, used as the raw material for building new DNA strands. Each one is a phosphate group, a deoxyribose sugar and one nitrogenous base (A, T, C or G).

somatic cell
Any ordinary body cell that is not a gamete; in humans these are diploid, with 46 chromosomes.

⚠ COMMON MISTAKE **"DNA copies itself during mitosis"**

This is the most persistent error in the whole topic. Mitosis only SEPARATES chromatids that already exist. The copying happened earlier, in S phase of interphase. Train yourself to say 'replicated in S phase, separated at anaphase' as a single unit.

⚑ IN THE EXAM **Command verb watch: Describe vs Explain**

'Describe what occurs during S phase' wants features and events (DNA is replicated; each chromosome becomes two identical sister chromatids joined at a centromere). 'Explain why replication must occur before mitosis' wants cause and effect linked with 'so that', 'because', 'therefore'. Same content, different structure — read the verb before you write.

2. Semi-conservative: what 'half old, half new' really means

The word semi-conservative describes the outcome of replication, and it is worth pinning down exactly, because there are two wrong versions of it that students write every single year. Semi-conservative means this: each of the two new DNA molecules consists of one complete original strand and one complete newly built strand. The original molecule is neither destroyed nor kept whole — it is separated down the middle, and each of its two strands ends up in a different daughter molecule, partnered with a brand new strand. 'Conserve' means keep; 'semi' means half; so half of each new molecule has been kept from the parent.

Wrong version one: 'each new strand is half old and half new'. No. Each STRAND is entirely old or entirely new; it is each MOLECULE that is half and half. Wrong version two: 'one molecule is completely old and the other is completely new'. That is called the conservative model, and it is not what happens. A good habit is to draw it. Draw the parent molecule as two lines, colour one blue and one black. Then draw the two products. Each must show one blue line and one black line. If your drawing ends up with a blue-blue molecule sitting next to a black-black molecule, you have drawn the conservative model by mistake and you can catch yourself before an exam does.

Why does this matter biologically, rather than just as vocabulary? Because keeping one original strand in each product is exactly what guarantees accuracy. The old strand is the template — it dictates, base by base, what the new strand must be. If both original strands were thrown away and DNA were built from scratch, there would be no instruction to follow and no way to know whether the copy was right. Semi-conservative replication is therefore not merely a description of a pattern; it is the reason the copy is faithful. That link — old strand acts as template, therefore the copy is accurate, therefore the daughter cells are identical — is the causal chain markers are hunting for in extended-response answers.

KEY TERMS

semi–conservative replication

Replication in which each new DNA molecule contains one original (parent) strand and one newly synthesised strand.

template strand

An original DNA strand whose base sequence determines the base sequence of the new strand built against it.

daughter strand

The newly synthesised DNA strand built by complementary base pairing against a template strand.

✦ TIP **The two–colour test**

Draw the parent molecule with one blue strand and one black strand. Every correct product molecule must show exactly one blue and one black. Any molecule that comes out a single colour means you have slipped into the conservative model.

EXTENSION **Extension: how do we actually know it is semi-conservative?**

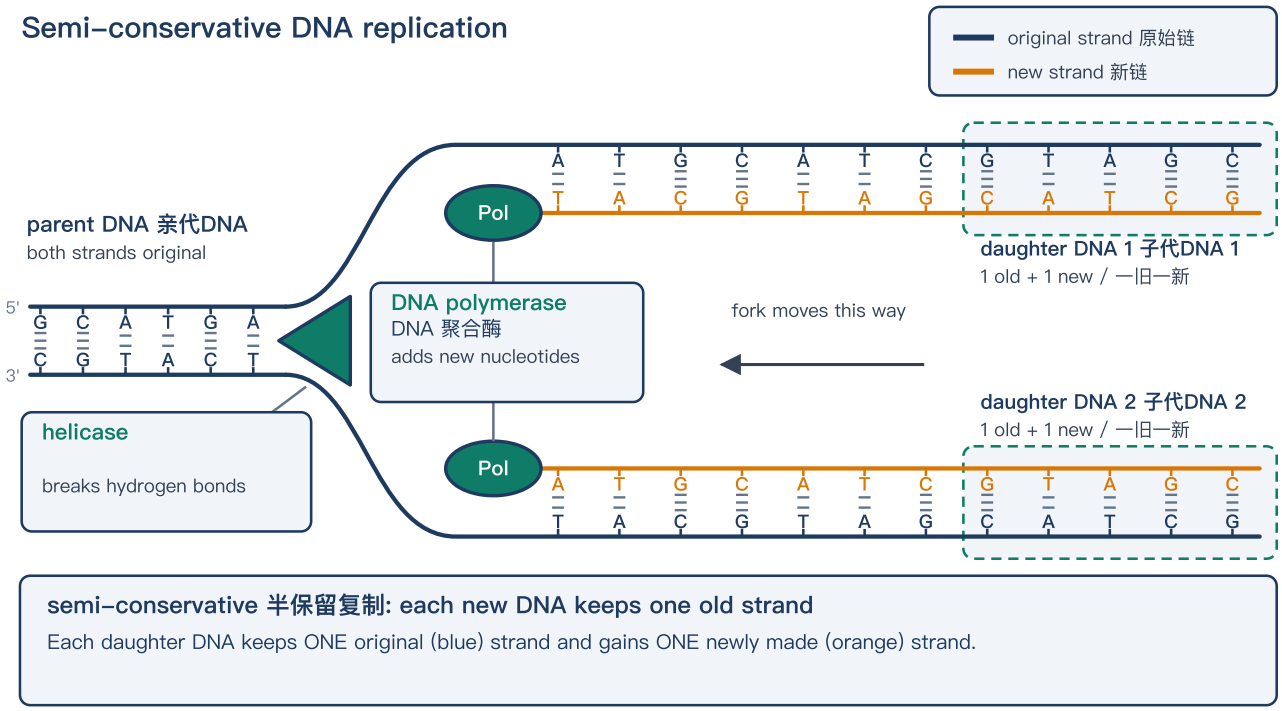
After Watson and Crick proposed the double helix, biologists debated three possible models of replication: conservative, semi-conservative, and dispersive (new and old material mixed along each strand). Meselson and Stahl settled it by growing bacteria in a medium containing a heavier isotope of nitrogen (15N), so that the nitrogen in their DNA was 'heavy', then transferring them to a medium containing ordinary nitrogen (14N) and separating the DNA by density after each round of division. The logic is what matters, not the technique. After one round, every molecule had an intermediate density — that rules out the conservative model, which predicts one heavy molecule and one light one. After two rounds, the population was a mixture of intermediate and light molecules — that rules out the dispersive model. Only semi-conservative replication predicts both results. You are not expected to reproduce the experimental detail; you are expected to appreciate that the model rests on evidence rather than assertion.

EXAMPLE **Think of two dance partners**

Picture two people who have been dance partners all night. They split up, and each is immediately partnered by someone new. You now have two couples on the floor, and every couple is one original person plus one newcomer. That is semi-conservative replication: each couple is a new DNA molecule, containing one complete original strand and one complete newly synthesised strand. Now notice what is not half and half — the people. Nobody walked away as half of themselves. Each strand is entirely original or entirely new, exactly as each dancer is entirely one person; it is the molecule, the couple, that is the mixture. Where it breaks down, in two places. First, dancers choose, and could pair with anyone in the room; a template strand has no choice, because its base sequence dictates the new strand base by base. Second, the newcomer does not arrive ready-made: a new strand is not a finished partner walking in off the street, it is built up one free nucleotide at a time against the template.

3. The steps of replication, in order

Step 1 — the helix unzips. An enzyme called helicase moves along the DNA and breaks the hydrogen bonds holding each base pair together. Because those bonds are weak, they can be broken without damaging anything else, and the two strands peel apart. Now read that again and notice what is NOT broken: the sugar-phosphate backbone. The strong covalent bonds running along each backbone stay completely intact. This is precisely the design feature you met on Day 1 — strong bonds along the strands, weak bonds across the middle — and this is the moment it pays off. If you write that the backbone breaks, you have described a shattered chromosome, not a replicating one. The Y-shaped region where the strands have come apart and copying is under way is called the replication fork — a term you need if you sit NSW Module 5, and one you can simply recognise if you sit VCE Unit 1.



A replication fork: helicase unzips the parent double helix and DNA polymerase pairs new nucleotides onto each exposed template strand, so every daughter molecule keeps one original strand and one new one.

Step 2 — each old strand becomes a template. With the bases now exposed, each single strand carries a readable instruction: a strand reading A-T-G-C can only ever be partnered by T-A-C-G. Step 3 — free nucleotides move in and pair up. The nucleotides already floating in the nucleus line up against the exposed bases, and only the complementary one fits and bonds: adenine with thymine (two hydrogen bonds), cytosine with guanine (three hydrogen bonds). This is where the accuracy comes from. It is not that an enzyme 'remembers' the sequence; it is that only the correct base can form the right hydrogen bonds in the right place, so the correct base is the one that stays.

Step 4 — the new nucleotides are joined up. DNA polymerase bonds each newly arrived nucleotide to the one before it, building a continuous new sugar-phosphate backbone along each template. Step 5 — two complete molecules re-wind. Each template strand now has a full new partner, and each pair twists back into a double helix. Where there was one DNA molecule there are now two, and by the rule from section 2, each contains one old strand and one new one. The photocopier analogy is useful here — one page in, two identical pages out — but notice exactly where it breaks down: a photocopier keeps the original intact and produces a separate copy, which is the conservative model. DNA does not work that way. A zipper being opened, with each half then growing a new set of teeth, is closer to the truth, though no real zipper does that either.

KEY TERMS

helicase

The enzyme that breaks the hydrogen bonds between paired bases, unwinding and separating the two DNA strands.

DNA polymerase

The enzyme that joins free nucleotides together into a new continuous strand along each template strand.

replication fork

The Y-shaped region of a DNA molecule where the two strands have separated and new strands are being built. Named and assessed in NSW Module 5; recognition only for VCE Unit 1.

hydrogen bond

A weak bond holding complementary bases together across the helix: two between A and T, three between C and G.

⚠ COMMON MISTAKE **"The strands separate because the backbone breaks"**

The sugar-phosphate backbone is held by strong covalent bonds and stays whole throughout replication. Only the weak hydrogen bonds between the paired bases are broken. That contrast is the entire reason DNA can be opened and closed repeatedly without falling apart.

⬡ EXTENSION **Extension: leading and lagging strands**

Because the two strands of a double helix run in opposite directions (antiparallel), the two new strands cannot be assembled in exactly the same way at a replication fork. One new strand is built as a single continuous piece as the fork opens; the other is built as a series of short pieces that are then joined together by the enzyme ligase. You may see these labelled the leading and lagging strands. This is genuinely beyond Year 11 core in all three states — recognise it so a textbook diagram does not confuse you, but do not spend memory on the detail. No Year 11 question requires it.

✦ TIP **Which enzyme names do I actually need?**

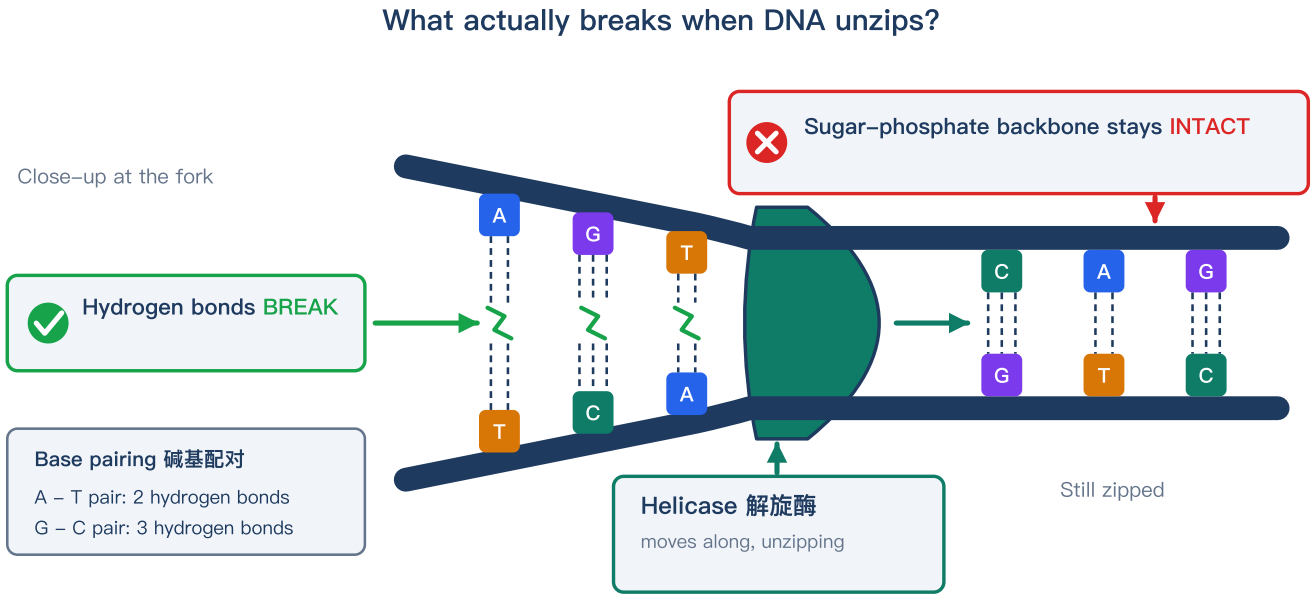
Helicase, DNA polymerase and ligase (which joins short pieces of new DNA together — see the extension callout above) are named and assessed in the NSW Module 5 course, which is the Year 12 (HSC) course, and they are Year 12 material in Queensland too. If you are studying VCE Units 1 and 2, S phase is simply 'DNA is replicated' — the enzymes belong to Unit 3. Learn the five steps regardless of which state you are in; learn the enzyme names according to the course you actually sit. Either way, you must be able to state what unzips (the hydrogen bonds between the bases) and what does not (the sugar-phosphate backbone).

IN THE EXAM Model the process (NESA command verb)

The NSW Module 5 dot point uses the verb 'Model'. That signals a labelled diagram or annotated sequence, not prose alone. Practise drawing a diagram of replicating DNA (a replication fork, if your course uses the term) with these labels: original strand, new strand, free nucleotides, hydrogen bonds broken, sugar-phosphate backbone intact, helicase, DNA polymerase. The marks sit on the labels.

EXAMPLE Think of your fridge door

Think of the fridge door at home. Push a sheet of paper against it and it slides off; push a magnet against it and it stays. The door is not choosing anything — it has no idea what you brought. Only the things that can actually hold on are still there a second later. Free nucleotides work the same way. They drift around the nucleus, constantly bumping into the exposed bases on the template strand. One that cannot form the right hydrogen bonds in the right place drifts away again; only the complementary one — A with T, C with G — holds on long enough for DNA polymerase to join it into the growing new strand. That is where the accuracy comes from: not an enzyme remembering the sequence, but only the correct base staying put. Where it breaks down, in two places. First, a magnet sticks anywhere on the door, while each base can bond with only one specific partner. Second, a magnet's grip is strong and permanent, whereas a base pair is held by just two or three weak hydrogen bonds — weak enough for helicase to break open again next time this DNA is replicated. What actually locks the new nucleotide into the strand is the covalent bond DNA polymerase makes along the sugar-phosphate backbone, not the hydrogen bonds across the middle.



Close–up of a replication fork: helicase snaps only the hydrogen bonds holding the base pairs together, while the two sugar–phosphate backbones remain whole and unbroken.

4. Worked example: building the complementary strand

If you sit NSW Module 5 or QCAA Unit 4, this is the most reliably examinable skill in the whole topic, and it is free marks once the habit is automatic. VCE students meet it formally in Unit 3 — practise it anyway, because everything later in genetics rests on it. The task: given the base sequence of one strand, write the sequence of the strand that will be built against it. The only rule you need is complementary base pairing — A pairs with T, C pairs with G. Work along the sequence one base at a time and write each partner directly underneath. Do not try to do it in your head, and do not reverse the order of the letters.

Worked example. Template strand: 5'-T A C G G A T C-3'. Take them one at a time. T pairs with A. A pairs with T. C pairs with G. G pairs with C. G pairs with C. A pairs with T. T pairs with A. C pairs with G. So the new complementary strand is 3'-A T G C C T A G-5'. Now check your work two ways. First, count: eight bases in, eight bases out — if the lengths differ you have skipped one. Second, scan for illegal pairs: any A sitting opposite a G, or any C opposite a T, is an error. Those two specific wrong pairings are the ones students actually produce under time pressure, so they are worth checking for deliberately.

About those 5' and 3' labels. You will see them on exam diagrams and on the strands in your textbook, and at this level they simply record that the two strands run in opposite directions — that is what antiparallel means. At Year 11 level you are expected to state that the strands are antiparallel and to notice that the complementary strand's labels are flipped. You are NOT expected to explain the chemistry of the 3' and 5' carbons of deoxyribose, or to reason about the direction in which synthesis proceeds. If a question gives you 5'-...-3' and asks for the complementary strand, write your answer as 3'-...-5' and move on to the next question.

One extra habit worth building now: if a question gives you a sequence and asks how many hydrogen bonds hold the resulting double-stranded segment together, count 2 for every A-T pair and 3 for every C-G pair. In the worked example above there are four A-T pairs and four C-G pairs, giving (4 x 2) + (4 x 3) = 20 hydrogen bonds. NSW markers like this style of question because it checks whether you genuinely know which pair carries which bond count, rather than just reciting the letters of the pairing rule.

KEY TERMS

complementary base pairing

The rule that adenine always pairs with thymine and cytosine always pairs with guanine, joined by hydrogen bonds.

antiparallel

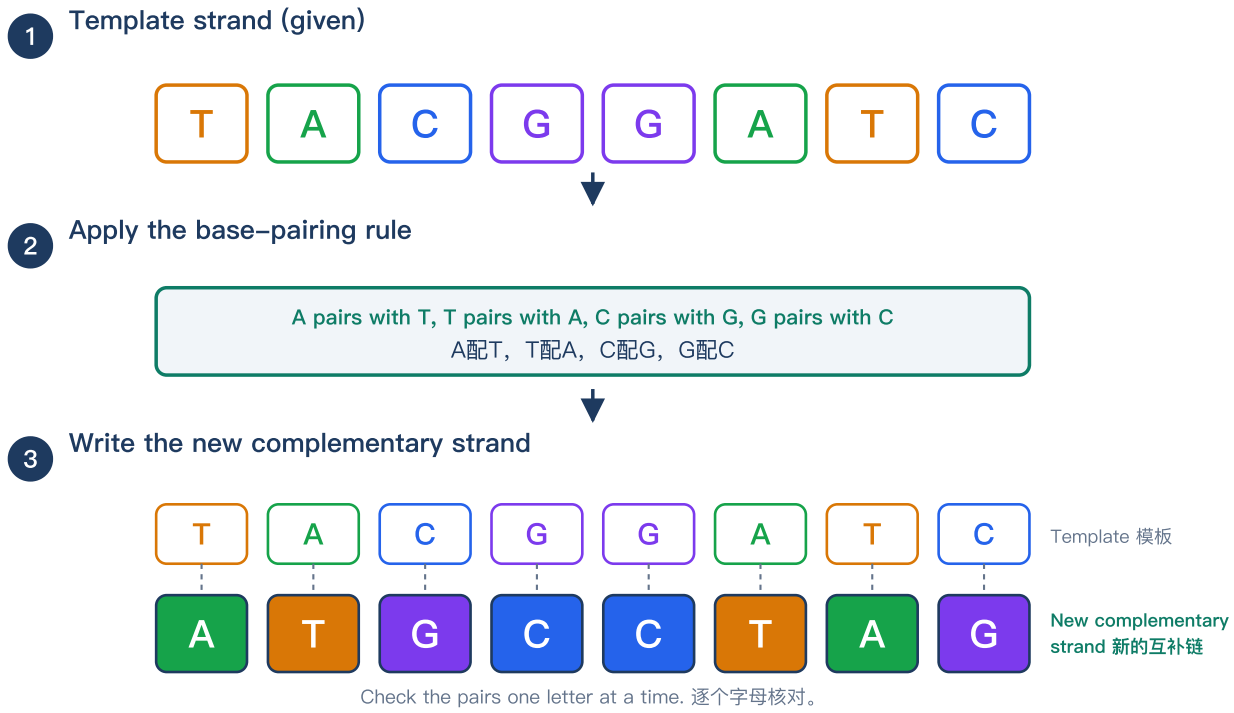
A description of the two strands of a DNA double helix as running in opposite directions to each other.

✦ TIP **Two letters, two shapes**

A and T are both drawn with straight lines; C and G are both drawn with curves. Straight goes with straight, curved goes with curved. It is purely a memory hook with no biological meaning — it is about the shapes of the letters as you write them, not the shapes of the molecules, which pair according to hydrogen bonding (see the next box) — but under exam pressure it stops you writing A-G.

⚠ COMMON MISTAKE **"Bases fit together because of their shape, and are held by covalent bonds"**

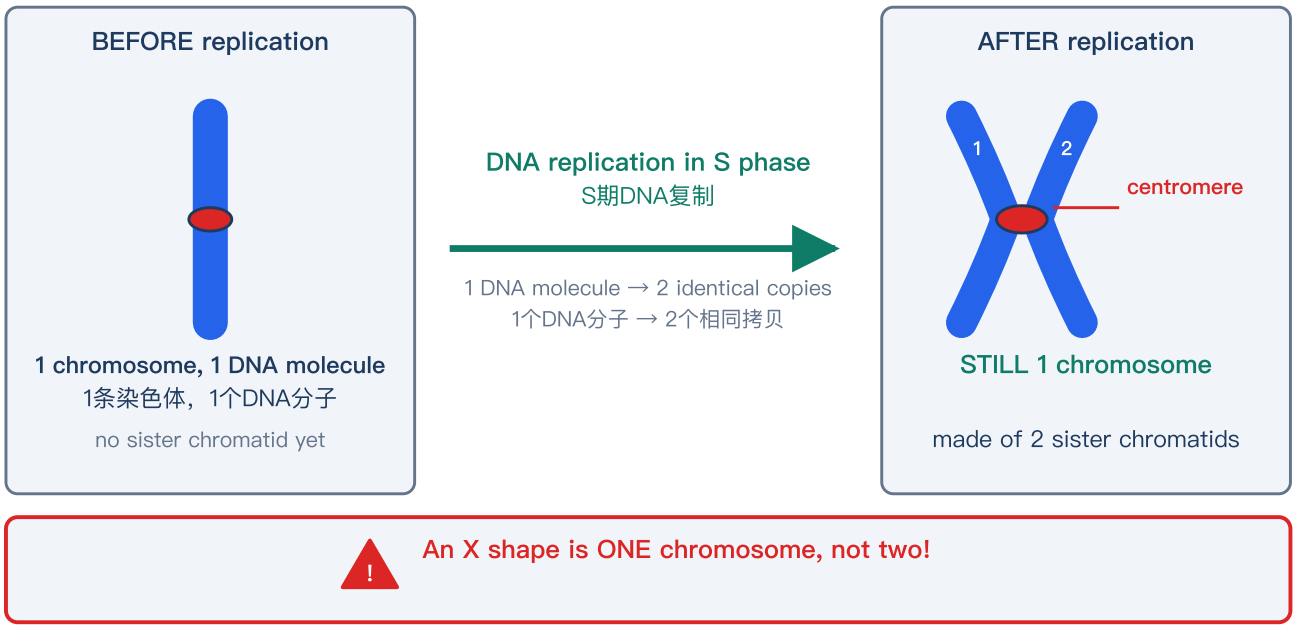
Size and shape do play a part, but the specific pairing is determined by which bases can form hydrogen bonds with one another — and those bonds are weak, not covalent. If base pairs were joined by covalent bonds, the helix could not unzip for replication at all.



Worked example: from the template strand T A C G G A T C, apply the base–pairing rule (A—T, C—G) to write the new complementary strand A T G C C T A G.

5. After replication: sister chromatids and the X shape

Now connect the molecule back to the structure you can actually see down a microscope. Before S phase, a chromosome is a single long DNA molecule wrapped up with protein — one thread carrying one copy of the genes on that chromosome. After replication in S phase, that same chromosome contains two identical DNA molecules. When the chromosome later condenses during prophase, those two copies become visible as two rods lying side by side, joined at a narrow waist. Each rod is a chromatid, and because the two are exact copies of one another we call them sister chromatids. The point at which they are held together is the centromere. Joined this way, they produce the familiar X shape you see in every textbook diagram.



Before and after DNA replication: one rod-shaped chromosome becomes an X shape that is still ONE chromosome, made of two identical sister chromatids joined at the centromere.

Here is the sentence that earns and loses the most marks in this entire topic: an X-shaped structure is still ONE chromosome. It is one chromosome made of two sister chromatids. It is not two chromosomes. A human cell that has just finished S phase still has 46 chromosomes, not 92 — it has 46 chromosomes and 92 chromatids. Later, when the centromeres divide at anaphase and the chromatids are pulled apart, each separated chromatid is from that moment called a chromosome in its own right. The count per cell doubles only momentarily at anaphase, when the centromeres divide, and cytokinesis then gives each daughter cell 46 — the same number the parent cell started with, so the ploidy of the cell never changes. Replication itself never doubled the chromosome number. Students who believe the number doubles at prophase and halves at anaphase have imported meiosis logic into mitosis, and the whole answer collapses around that one error.

Two more traps to close off. First, a chromosome does not always look like an X. For most of a cell's life it is unreplicated and uncondensed chromatin — a single thin thread you cannot even distinguish as a separate structure under a light microscope. The X shape is only visible once the replicated chromosome condenses in prophase, and it lasts only until the centromeres divide at anaphase. Between the end of S phase and prophase the chromosome is already replicated but still an uncondensed chromatin thread — replicated does not mean visibly X-shaped. Second, do not confuse sister chromatids with homologous chromosomes. Sister chromatids are two identical copies of the SAME chromosome, produced by replication and joined at a centromere. Homologous chromosomes are a matching pair of separate chromosomes, one inherited from each parent, carrying the same genes in the same order but not necessarily identical versions of those genes — and they are never joined at a centromere.

Finally, the causal chain. This is the assessed skill, so learn it as one connected sequence rather than four separate facts. DNA is replicated semi-conservatively in S phase, so each chromosome now consists of two identical sister chromatids joined at a centromere. At anaphase the centromeres divide and one chromatid of each pair is pulled to each pole. Therefore each daughter nucleus receives one complete, identical copy of

every chromosome, and the two daughter cells are genetically identical to each other and to the parent cell — they are clones. Both are still diploid: they carry two copies of every chromosome, 46 in total, arranged as 23 homologous pairs. Only gametes carry a single set, and they are not made by mitosis. Notice what happens if you delete the first step: without prior copying, mitosis would simply share out the existing chromosomes and the number would halve at every division. That is your justification for why replication must come first.

KEY TERMS

sister chromatid

One of two identical copies of a single chromosome, produced by DNA replication and joined at the centromere.

centromere

The constricted region holding sister chromatids together, and where spindle fibres attach during mitosis.

chromatin

The uncondensed, thread-like form of DNA and protein present in the nucleus for most of the cell cycle.

genetically identical

Having exactly the same DNA base sequence; used to describe the daughter cells produced by mitosis.

⚠ COMMON MISTAKE **"An X–shaped chromosome is two chromosomes"**

Count centromeres, not rods. One centromere means one chromosome, however many chromatids hang off it. A human cell at the end of S phase has 46 chromosomes and 92 chromatids — the chromosome number has not changed.

⚠ COMMON MISTAKE **"Daughter cells are identical because the DNA is shared out evenly"**

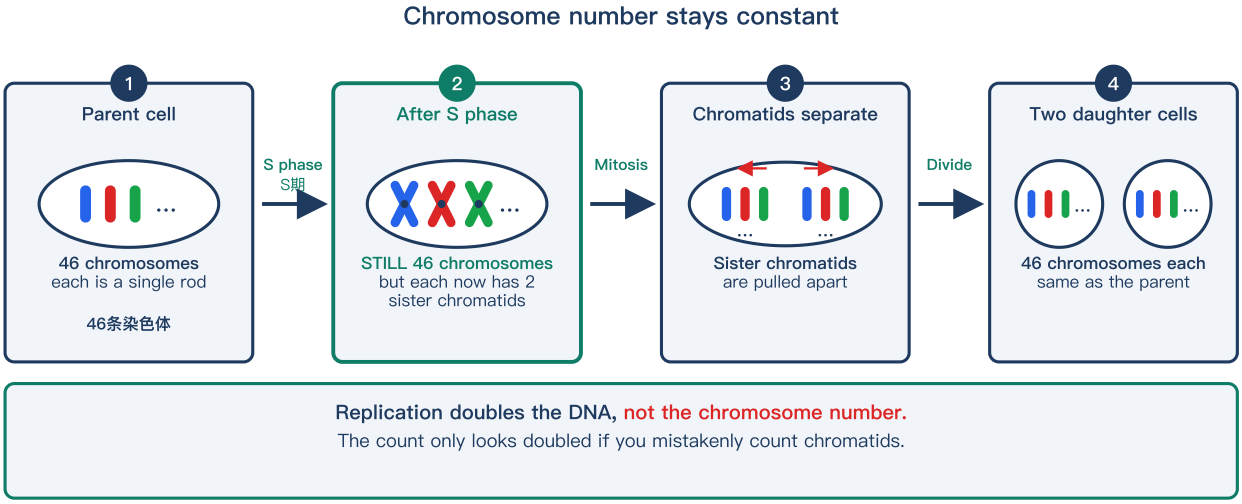
Markers penalise this answer because it leaves out the copying step. Sharing 46 chromosomes evenly between two cells would give 23 each. The cells are identical because the DNA was replicated FIRST in S phase, and only then shared out.

⚑ IN THE EXAM **Compare vs Distinguish**

'Compare sister chromatids and homologous chromosomes' needs similarities AND differences, ideally in the same sentence (both are chromosome-level structures carrying the same genes, BUT sister chromatids are identical and joined at a centromere while homologues are non-identical and separate). 'Distinguish between' needs only the explicit point of difference.

◈ EXAMPLE **Think of a song and its cover version**

You have a song saved on your phone. Copy the file so there are two of it, and the two match note for note. That is what sister chromatids are: two identical copies of one chromosome, made during S phase and physically held together at the centromere. Now think of a cover version of the same song by a different band. Same song, same verses in the same order, but not the same recording. That is a homologous pair — two separate chromosomes, one inherited from each parent, carrying the same genes in the same order but not necessarily the same version of each gene. And the cover sits in its own file: homologous chromosomes are never joined at a centromere. Where it breaks down, in two places. First, a cover can add or cut a verse, while homologous chromosomes carry the same genes at the same positions and differ only in the version of each one — and often not even that, because for many genes the two homologues carry identical versions. 'Not necessarily identical' does not mean 'always different'. Second, copying a file leaves you with an untouched original plus a new copy; replication does not work that way. Each of the two sister chromatids contains one old strand and one new strand, so neither of them is 'the original' — that is the semi-conservative rule from section 2.



Replication doubles the DNA but not the chromosome number: a 46-chromosome cell still has 46 chromosomes after S phase, each now made of two sister chromatids, and each daughter cell ends up with 46 again.

DAY 3 RECAP

- DNA replication happens in S phase of interphase — it is complete before mitosis begins, and mitosis contains no copying step at all. Interphase is the busiest part of the cycle, not a rest.
- Replication is semi-conservative: each new molecule keeps one whole original strand and gains one whole new strand. Each strand is entirely old or entirely new; each molecule is half and half.
- Helicase breaks the weak hydrogen bonds between paired bases; the strong covalent sugar-phosphate backbone is never broken. That contrast is why DNA can unzip safely and re-close.
- Free nucleotides — each a phosphate, a deoxyribose sugar and one base — are already present in the nucleus and are selected by complementary base pairing (A-T, C-G); DNA polymerase then joins them into a continuous new strand along each template.
- After replication each chromosome consists of two identical sister chromatids joined at one centromere — the X shape. That X is still ONE chromosome: count centromeres, not rods.
- A chromosome is only visible as an X once it condenses in prophase, and it stops being an X when the centromeres divide at anaphase. Between the end of S phase and prophase it is already replicated but still an uncondensed chromatin thread — replicated does not mean visibly X-shaped.
- The examinable causal chain: replicated in S phase so two identical chromatids form; centromeres divide at anaphase so one chromatid goes to each pole; therefore both daughter cells receive a complete identical set, stay diploid (46 chromosomes, 23 homologous pairs) and are genetically identical clones.

Check Yourself — Day 3

1 **During which stage of the cell cycle is DNA replicated? (1 mark)**

a) Prophase of mitosis

b) S phase of interphase

c) G2 phase of interphase

d) Anaphase of mitosis

2 **Which bonds are broken when the DNA double helix unzips at the start of replication? (1 mark)**

a) The covalent bonds of the sugar-phosphate backbone

b) The hydrogen bonds between complementary bases

c) The covalent bonds between complementary bases

d) The covalent bonds joining each phosphate group to the deoxyribose sugar

3 **A DNA molecule replicates once. Which statement correctly describes the two molecules produced? (1 mark)**

a) One molecule contains both original strands; the other contains two new strands

b) Each molecule contains one original strand and one new strand

c) Each strand in each molecule is half original and half new

d) Each molecule contains two strands that are each a random mixture of original and new sections

4 **Describe the events of DNA replication in S phase, in the order in which they occur. (4 marks)**

5 **A template strand has the sequence 5'-TACGGATC-3'. Construct the complementary strand, and state how many hydrogen bonds hold this double-stranded segment together. (3 marks)**

6 **A template strand reads 3'-GGCATTAC-5'. Construct the complementary strand. (1 mark)**

7 **A human somatic cell has just completed S phase. How many chromosomes and how many chromatids does it contain? (1 mark)**

a) 92 chromosomes and 92 chromatids

b) 46 chromosomes and 92 chromatids

c) 92 chromosomes and 46 chromatids

d) 23 chromosomes and 46 chromatids

8 **Distinguish between sister chromatids and homologous chromosomes. (3 marks)**

9 **Justify why DNA replication must be completed before mitosis begins. Refer to what happens to chromosome number in the daughter cells. (5 marks)**

ANSWERS

Write your answer out first. A question you have read the answer to is not practice.

1. **b) S phase of interphase**

2. **b) The hydrogen bonds between complementary bases**

3. **b) Each molecule contains one original strand and one new strand**

4. 1. Helicase breaks the weak hydrogen bonds between paired bases, so the double helix unwinds and the two strands separate; the strong covalent sugar-phosphate backbone is not broken. 2. Each separated strand acts as a template, exposing its bases. 3. Free nucleotides already present in the nucleus pair with the exposed bases by complementary base pairing: A with T, C with G. 4. DNA polymerase joins the new nucleotides into a continuous new strand along each template. 5. Each template and its new partner strand rewind into a double helix, producing two identical DNA molecules, each containing one original strand and one new strand (semi-conservative).

5. Complementary strand: 3'-ATGCCTAG-5'. There are four A-T pairs (2 hydrogen bonds each) and four C-G pairs (3 hydrogen bonds each), giving (4 x 2) + (4 x 3) = 20 hydrogen bonds.

6. 5'-CCGTAATG-3'. Working base by base: G-C, G-C, C-G, A-T, T-A, T-A, A-T, C-G. The 5' and 3' labels are flipped because the two strands are antiparallel — they run in opposite directions. At Year 11 you only need to know the labels flip; you are not expected to explain the 3' and 5' carbons.

7. **b) 46 chromosomes and 92 chromatids**

8. Sister chromatids are two genetically identical copies of a single chromosome, produced by DNA replication in S phase and joined together at a centromere. Homologous chromosomes are a matching pair of separate chromosomes, one inherited from each parent, which carry the same genes in the same order but not necessarily identical versions of those genes, and which are never joined at a centromere.

9. Mitosis does not copy DNA; it only separates sister chromatids that already exist. DNA is replicated semi-conservatively in S phase, so each chromosome becomes two identical sister chromatids joined at a centromere. At anaphase the centromeres divide and one chromatid of each pair moves to each pole, so each daughter nucleus receives one complete copy of every chromosome and the diploid number of 46 — two copies of every chromosome, arranged as 23 homologous pairs — is maintained. If replication had not occurred first, mitosis would simply share the existing 46 chromosomes between the two cells, giving 23 each; the chromosome number would halve at every division and the daughter cells would carry an incomplete and non-identical set of genetic information. Therefore replication must precede mitosis in order for genetically

identical daughter cells to be produced. Justify answers must be linked with 'so that', 'because' and 'therefore', and must end with a clear stated conclusion.

DAY 4

about 70 min

Mitosis and Why It Matters

THE BIG IDEA

Mitosis is division of the nucleus: it takes the two identical sister chromatids that S phase built into every chromosome and separates them precisely, one to each pole, and once cytokinesis has divided the cytoplasm the parent cell has become two genetically identical daughter cells, each with the same chromosome number as the parent cell (in a human somatic cell, 46 chromosomes — diploid) — which is exactly what an organism needs in order to grow, to repair and replace worn-out tissue, and in some species to reproduce asexually.

BY THE END OF TODAY YOU WILL BE ABLE TO

1. Describe the events of prophase, metaphase, anaphase and telophase, stating what happens to the chromosomes, the nuclear envelope and the spindle fibres in each stage.
2. Identify the stage of mitosis shown in a diagram or micrograph, and justify your answer by naming the one observable feature that gives it away.
3. Distinguish mitosis from cytokinesis, and distinguish cytokinesis in an animal cell from cytokinesis in a plant cell.
4. Explain how two genetically identical daughter cells, each with the same chromosome number as the parent cell, are produced, linking semi-conservative replication in S phase to the separation of sister chromatids at anaphase.
5. Compare mitosis and meiosis using number of divisions, number of daughter cells, chromosome number, genetic outcome and function.
6. Assess the importance of mitosis to living organisms, supporting your judgement with named examples of growth, tissue repair and replacement, and asexual reproduction.

Mitosis is nuclear division — "cell division" means mitosis plus cytokinesis

Picture a human body cell as it finishes G2 and steps into M phase. Every one of its 46 chromosomes is now made of two identical sister chromatids joined at a centromere, because S phase copied every DNA molecule in the nucleus. The cell's problem from here on is a sorting problem, not a copying problem: it is holding two complete sets of genetic information inside one nucleus, and it must get exactly one complete

set into each of the two cells it is about to become. Mitosis is the process that solves that problem. Notice the strict meaning of the word: mitosis is the division of the nucleus. The chromosomes are separated and two new nuclei are formed. Mitosis does not divide the cell.

Splitting the cell itself is a separate event called cytokinesis, in which the cytoplasm is divided so that two physically separate daughter cells exist. Put them together and you get the equation your markers are looking for: mitosis + cytokinesis = M phase = cell division. This is not fussiness about words. If you use "mitosis" to mean the whole of cell division, you will have no vocabulary left when a question asks you to compare how plant and animal cells divide their cytoplasm, and you would not be able to explain a real biological observation (beyond the syllabus, but it settles the point): in some human tissues, notably the liver, mitosis occasionally occurs without cytokinesis, leaving one cell with two nuclei. That would be impossible if the two processes were the same thing.

Here is the outcome statement, worth learning almost word for word: mitosis followed by cytokinesis produces two genetically identical daughter cells, each with the same chromosome number as the parent cell. In a human somatic cell that means each daughter cell has 46 chromosomes, arranged as 23 pairs — diploid, just like the cell it came from. Mitosis happens in somatic cells — ordinary body cells such as skin, liver, root-tip and gut-lining cells — and also in the germ-line cells that multiply before meiosis begins. In animals it is not the division that produces eggs and sperm; that is meiosis, and we will contrast the two at the end of today. One last thing to keep in proportion: mitosis takes up most of the lesson, but only a small slice of the actual cell cycle. Interphase is far longer.

KEY TERMS

mitosis

The division of the nucleus, in which sister chromatids are separated to produce two genetically identical daughter nuclei.

cytokinesis

The division of the cytoplasm after nuclear division, producing two physically separate daughter cells.

M phase

The part of the cell cycle made up of mitosis and cytokinesis together; the shortest part of the cycle.

somatic cell

Any ordinary body cell, as opposed to a gamete; in humans somatic cells are diploid, with 46 chromosomes.

daughter cell

Either of the two cells produced when a parent cell completes mitosis and cytokinesis.

⚠ COMMON MISTAKE **"Mitosis" is not a synonym for "cell division"**

Mitosis is one half of the job — the nucleus half. Cell division is mitosis plus cytokinesis. At the end of telophase you have two nuclei inside one cell; only cytokinesis makes them two cells. Whenever you write an answer, ask yourself whether the sentence is about chromosomes and nuclei (mitosis) or about the cytoplasm and membrane (cytokinesis), and use the matching word.

✦ TIP **Two jobs, two words**

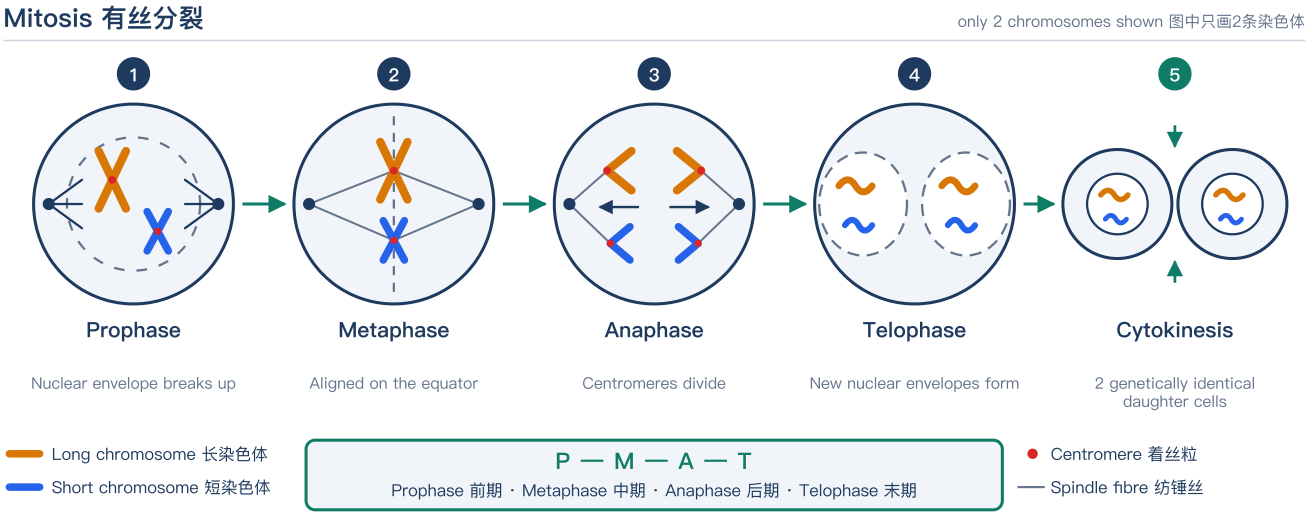
Think of moving a shared library into two rooms. First you sort the books into two complete, identical piles — that is mitosis. Then you build a wall down the middle of the room — that is cytokinesis. The analogy breaks down in one important way: in a real cell the books were photocopied first, back in S phase, which is why both piles can be complete. Nothing is torn in half.

⚑ IN THE EXAM **Outline, Describe and Explain are three different tasks**

Outline the events of the cell cycle asks for a short sequence of main features — a few lines, no mechanism. Describe what occurs during anaphase asks for a detailed account of what happens, with no cause required; naming the stage without saying what happens in it scores nothing. Explain how genetically identical daughter cells are produced demands a causal chain, with every sentence linked to the next by because, so that or therefore. Read the verb before you start writing.

PMAT: what happens in each stage, and how to recognise it

Mitosis is one continuous process, but biologists cut it into four named stages: prophase, metaphase, anaphase and telophase — PMAT. The stages are named for what you can see down a microscope, and a real cell slides smoothly from one into the next, so the boundaries are a convenience for describing and for examining. (Some textbooks slip prometaphase in between prophase and metaphase. Australian senior-biology courses examine the four PMAT stages, so learn those four; prometaphase is background only.)



The five stages of mitosis — prophase, metaphase, anaphase, telophase and cytokinesis — followed with just two chromosomes (one long, one short) to show how each daughter cell ends up genetically identical.

Prophase. The chromatin — the long, thin, tangled form the DNA has been in all through interphase — coils up and condenses until each chromosome is short, thick and visible with a stain. Because S phase has already been and gone, each chromosome appears as two sister chromatids joined at a centromere: the familiar X shape. Do not let that picture become your definition of a chromosome, though. A chromosome only looks like an X between S phase and anaphase. For most of a cell's life — including in both daughter cells immediately after division — each chromosome is a single, unreplicated thread of chromatin, too thin to see. The nucleolus disappears, the nuclear envelope breaks down so the chromosomes are no longer fenced off from the cytoplasm, and spindle fibres — protein threads — form and extend from opposite poles of the cell. In animal cells a pair of centrioles moves to each pole; plant cells build a perfectly good spindle without centrioles.

Metaphase. The spindle fibres attach to each chromosome at the kinetochore, a protein structure built on the centromere — not at the ends of the chromosome, which is one of the most common diagram-drawing errors — and manoeuvre the chromosomes until they are all lined up in a single plane across the middle of the cell. That plane is the equator, also called the metaphase plate. Metaphase is the easiest stage of all to recognise: a tidy line of chromosomes across the centre of the cell and nothing at the poles. Think of it as the cell checking its work — every chromosome is gripped from both sides before anything is pulled apart.

Anaphase. The centromere of each chromosome divides, and the two sister chromatids are finally separated. The spindle fibres shorten and drag one chromatid of every pair towards one pole and the other towards the opposite pole. The instant the centromere splits, each chromatid stops being a chromatid and becomes a chromosome in its own right. Under the microscope, anaphase looks like two clusters of V-shaped or J-shaped chromosomes moving apart with a widening gap between them — V-shaped because each one is being dragged centromere-first, with its arms trailing behind.

Telophase. The chromosomes reach the poles and mitosis reverses its opening moves: the chromosomes uncoil and decondense back into chromatin, a nuclear envelope forms around each of the two groups, the nucleolus reappears and the spindle breaks down. At the end of telophase there are two complete, identical nuclei — inside what is still, for the moment, a single cell. Mitosis is over. Cytokinesis is what happens next.

KEY TERMS

prophase

The first stage of mitosis: chromatin condenses into visible chromosomes, the nuclear envelope breaks down and spindle fibres form.

metaphase

The second stage of mitosis: chromosomes line up along the equator with spindle fibres attached at their centromeres.

anaphase

The third stage of mitosis: centromeres divide and sister chromatids are pulled to opposite poles of the cell.

telophase

The final stage of mitosis: chromosomes reach the poles and decondense, and two new nuclear envelopes form.

spindle fibre

A protein thread (microtubule) extending from a pole of a dividing cell; those that attach to a kinetochore at a chromosome's centromere move the chromosomes, while others simply push the poles apart.

⚑ IN THE EXAM **Identify the stage shown — one giveaway feature each**

Identify earns its mark for the name alone, but if the question adds justify, name the single feature you can actually see. Interphase: no distinct chromosomes, nucleus intact. Prophase: chromosomes visible but scattered, no nuclear membrane, no line. Metaphase: a single row across the equator. Anaphase: two separating groups of V-shaped chromosomes with a gap between them. Telophase: two groups at the poles, decondensing, with nuclear envelopes reforming. For a Sequence question, order them by that logic rather than by memory of the diagram.

⚠ COMMON MISTAKE **Chromosome number does not double at prophase or halve at anaphase**

Count carefully. A human cell entering mitosis has 46 chromosomes, each made of 2 sister chromatids — that is 92 chromatids but still 46 chromosomes, at prophase and at metaphase. The moment the centromeres divide in anaphase, each chromatid becomes a chromosome, so there are momentarily 92 chromosomes in the one cell, 46 travelling to each pole. Each daughter nucleus therefore ends up with 46. The cell is diploid at the start and both daughter cells are diploid at the end: ploidy never changes in mitosis.

⚠ COMMON MISTAKE **DNA is not replicated during prophase**

Chromosomes only become visible at prophase, so students routinely conclude that this must be when the DNA is copied. Nothing is copied during mitosis. Replication was completed back in S phase, hours earlier — which is exactly why each chromosome already consists of two sister chromatids the moment it condenses. Seeing two chromatids at prophase is evidence that replication has already happened, not that it is happening now.

⬡ EXTENSION **Extension: the mitotic index**

Extension — a classic Australian practical and data question. On a stained onion root tip or whitefish blastula slide, count the cells in each stage. The mitotic index is the number of cells in mitosis divided by the total number of cells counted, times 100. Because the slide is a frozen snapshot of a population, the proportion of cells caught in a stage is proportional to how long that stage lasts, so you can estimate a stage's duration as (proportion in that stage) x (length of the whole cell cycle). This is also why most cells on any slide are in interphase — not because interphase is boring, but because it is long.

◈ EXAMPLE **Think of two keys on one keyring**

Picture a keyring holding two identical cut copies of your front door key. You would still call that one keyring, even though it carries two keys. A cell counts the same way, and the centromere is the ring. At prophase and metaphase a human cell has 46 rings, so 46 chromosomes, even though it is carrying 92 keys — the sister chromatids. Nothing has doubled; the count of rings has not moved. At anaphase the centromere divides: the ring itself splits in two, and each key leaves on a ring of its own. That is exactly why we say each chromatid becomes a chromosome in its own right, and why the one cell momentarily holds 92 chromosomes, 46 travelling to each pole. Where it breaks down: the ring is not a clip attached onto the chromosome from outside. The centromere is a region of the chromosome's own DNA, and each new chromosome still has one after the split — which matters, because that is where the spindle fibre grips as it drags the chromosome centromere-first, and that is what gives anaphase its V shapes.

Cytokinesis: dividing the cytoplasm, and why plants do it differently

Cytokinesis usually begins in late anaphase, is well under way through telophase, and finishes just after mitosis ends. In an animal cell, a ring of protein filaments lying just beneath the cell membrane around the equator contracts, like a drawstring being pulled tight. The membrane is drawn inwards, forming a groove called a cleavage furrow, and the furrow deepens until the two halves are pinched right apart into two separate cells. The drawstring analogy is a good one, with a caution: the "string" is inside the cell, made of protein filaments, and nothing has to be tied off — the membrane simply meets in the middle and fuses.

A plant cell cannot be pinched. It is surrounded by a rigid cellulose cell wall that will not deform like that, so plant cells build a partition instead. Small membrane-bound vesicles carrying wall material gather along the equator and fuse with one another to form a structure called the cell plate. The cell plate grows

outwards from the centre of the cell until it reaches and joins the existing cell wall, and the material inside it becomes a new cell wall with a new membrane on either side. The direction is the giveaway you should quote in an exam: animal cytokinesis works from the outside inwards, plant cytokinesis from the inside outwards.

One more accurate detail worth having. The cytoplasm and its organelles are shared out roughly, not precisely — one daughter cell may end up with a few more mitochondria than the other, and that does not matter. The genetic identity of the daughter cells comes from the nucleus, and specifically from replication in S phase followed by the precise separation of chromatids at anaphase. Cytokinesis in plant and animal cells is named content in VCE Unit 1, and it is a favourite comparison question, so learn both mechanisms with their proper terms.

KEY TERMS

cleavage furrow

The inward-deepening groove formed at the equator of a dividing animal cell as a ring of protein filaments contracts, pinching the cell in two.

cell plate

The structure formed at the equator of a dividing plant cell by fusing vesicles, which grows outwards and becomes the new cell wall between the daughter cells.

cell wall

The rigid cellulose layer outside the membrane of a plant cell, which is why plant cells cannot divide by pinching inwards.

⚠ COMMON MISTAKE **Plant cells do not pinch, and the cell plate does not close inwards**

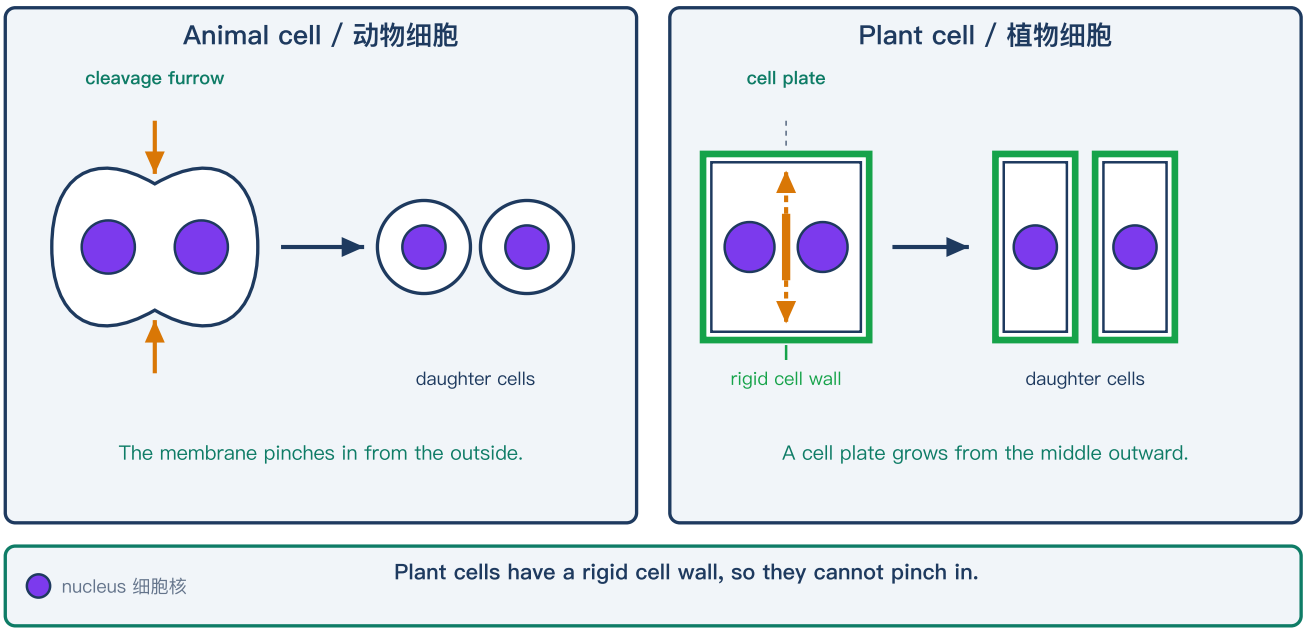
Two errors travel together here. First, plant cells cannot form a cleavage furrow, because the rigid cell wall will not be pulled in. Second, the cell plate does not close in from the edges like a camera shutter — it starts at the centre and extends outwards until it fuses with the existing wall. If you can state the reason (the cell wall) as well as the mechanism, you have the Explain mark as well as the Describe mark.

⚑ IN THE EXAM **"Distinguish" wants one explicit point of difference**

Distinguish between cytokinesis in plant and animal cells is answered in a single sentence that names the criterion and applies it to both: "In an animal cell the membrane is pinched inwards by a cleavage furrow, whereas in a plant cell a cell plate forms at the equator and grows outwards to become a new cell wall." Two separate descriptions sitting side by side often lose the mark; the word whereas is doing real work.

TIP Animals pinch in, plants build out

Five words to hold under exam pressure: animals pinch in, plants build out. Then unpack it with the proper terms — cleavage furrow for the pinching, cell plate and new cell wall for the building — and add the reason: the plant cell wall is rigid.



Cytokinesis compared: an animal cell splits by a cleavage furrow pinching inward from the membrane, while a plant cell builds a cell plate outward from the middle because its rigid cell wall cannot pinch in.

How two genetically identical daughter cells are actually produced

This is the big question of the whole four-day chain, and the answer is a chain of causes. One: in S phase every DNA molecule is replicated semi-conservatively — the helix unzips as the hydrogen bonds between the bases break, each old strand acts as a template, and free nucleotides already present in the nucleus pair complementarily, A with T and C with G. Two: because the pairing rules are fixed, the sequence of each new strand is dictated by the old one, so the two DNA molecules produced are identical. Three: those two identical molecules stay attached to each other as sister chromatids, joined at a centromere.

So much for making the copies; the next three steps are about delivering them. Four: at metaphase every chromosome is held at its centromere by spindle fibres from both poles. Five: at anaphase every centromere divides, so one chromatid of each pair goes to each pole — each pole receives one copy of every chromosome, never a random half. Six: telophase and cytokinesis wrap each set in its own nuclear envelope and cytoplasm.

Notice which step does the real work. Students very often write that the daughter cells are identical "because the DNA is divided evenly between them". Markers do not accept that, and they are right not to: dividing something evenly gives each side half of it, not a complete copy of it. The identity comes from copying first, in S phase, and separating precisely afterwards, at anaphase. If you remember one sentence for the exam, make it this one: replication makes the copies, anaphase distributes them. This is also why

replication has to be finished in S phase before mitosis begins. Mitosis only separates chromatids that already exist; it never makes new DNA. If a human cell entered mitosis without copying its DNA first, its 46 single-chromatid chromosomes would simply be split between the two poles, each daughter cell would receive about 23 chromosomes and an incomplete set of genes, and the chromosome number would halve again at every division.

Finally, be careful about what "genetically identical" does and does not claim. It means the daughter cells carry the same DNA sequence — the same genes — as each other and as the parent cell. It does not mean they will always look alike or do the same job. As a multicellular organism develops, cells differentiate: a muscle cell and a nerve cell in your body contain identical DNA but switch on different genes, so they end up with completely different shapes and functions. Same instruction book, different pages open.

KEY TERMS

genetically identical

Having exactly the same DNA sequence, and therefore the same genes, as another cell or organism.

clone

A cell or organism that is genetically identical to the one it came from, because it was produced by mitosis rather than sexual reproduction.

differentiation

The process by which a cell becomes specialised for a particular function by switching on some of its genes and not others, even though its DNA is unchanged.

diploid

Having two complete sets of chromosomes, one from each parent; human somatic cells are diploid with 46 chromosomes in 23 pairs.

⚠ COMMON MISTAKE **"The DNA is shared out evenly" is not an explanation**

This is the single most heavily penalised sentence in this topic, because the copying step is missing. Sharing a set of instructions between two cells leaves both incomplete. What actually happens is that each chromosome was duplicated into two identical sister chromatids during S phase, and anaphase then delivers one of each pair to each pole. Any answer that does not mention replication cannot score full marks, however fluently it describes PMAT.

IN THE EXAM **A model 4–mark "Explain" answer**

"During S phase of interphase, each DNA molecule is replicated semi-conservatively, so each chromosome now consists of two identical sister chromatids joined at a centromere. At metaphase the chromosomes align on the equator with spindle fibres attached at their centromeres. At anaphase the centromeres divide and one chromatid from each pair is pulled to each pole, so that each pole receives one complete copy of every chromosome. Therefore the two nuclei formed at telophase, and the two daughter cells formed after cytokinesis, are genetically identical to each other and to the parent cell." Four sentences, four linking words, four marks.

EXTENSION **Extension: cell cycle checkpoints**

Extension — required background for the VCE Unit 1 dot point on disruption to cell cycle regulation, and useful stretch elsewhere. The cell cycle is policed at checkpoints. The G1 checkpoint, before S phase, asks whether the cell is large enough, has enough nutrients and growth signals, and whether its DNA is undamaged — essentially, is it worth starting? The G2 checkpoint, before mitosis, checks that DNA replication has been completed correctly. The M or spindle checkpoint, during metaphase, checks that every chromosome is properly attached to spindle fibres from both poles before anaphase is allowed to begin. If a check fails, the cycle is paused for repair, or the cell is destroyed.

EXAMPLE **Think of splitting a fifty at dinner**

You and a friend split a fifty at the end of a meal. You each walk out with twenty-five — half the money, not fifty each. There is no way to share your way to two full amounts. The only way you both hold fifty is if the money was duplicated beforehand. That is exactly why "the DNA is shared out evenly" is the penalised answer here. Divide one set of chromosomes between two cells and each gets about 23 and an incomplete set of genes, which is precisely what the section says would happen if a cell entered mitosis without copying first. Both daughter cells end up with a complete 46 because S phase replicated every DNA molecule semi-conservatively; anaphase then only has to hand out copies that already exist. Replication makes the copies, anaphase distributes them. Where it breaks down: unlike money, copying DNA does cost something real — free nucleotides, enzymes, hours of S phase. And the parent cell does not keep its own set and hand out spares: it becomes the two daughter cells, and because replication is semi-conservative, each daughter chromosome carries one of the parent's original strands alongside a newly built one.

Why it matters: growth, repair and replacement, and asexual reproduction

Growth. You began as a single cell, a fertilised egg, and every one of the tens of trillions of cells in your body descends from it by mitosis. Growth in a multicellular organism is mostly an increase in the number of cells (cells also enlarge and differentiate), and because mitosis copies faithfully, every one of those cells inherits the same complete set of instructions. In plants, growth is concentrated in regions called meristems, which is exactly why a root tip is the standard slide for seeing mitosis: it is one of the few places where a large proportion of cells are dividing at any given moment.

Repair and replacement. Mitosis does not stop when you stop growing, and this is the point students most often miss. Your skin is shed and replaced continuously. The lining of your gut is replaced every few days because it takes such a battering from digestive enzymes. Your bone marrow makes new red and white blood cells constantly, partly because a mature red blood cell has no nucleus and cannot divide, and survives only about four months. And when you cut yourself, mitosis is what closes the wound: cells at the edges of the cut divide to fill the gap, and normally stop dividing again once they meet neighbouring cells.

Asexual reproduction. Some organisms use mitosis to produce whole new individuals. Yeast and Hydra reproduce by budding: a small outgrowth produced by mitosis eventually detaches and lives independently. A strawberry plant sends out runners that root and become new plants, and a gardener taking a cutting is using the same ability — both are vegetative propagation. A planarian flatworm cut in two can regenerate the missing half, and some starfish can regenerate from a fragment. In every case the offspring are produced by mitosis, so they are genetically identical to the parent: clones.

Binary fission. Bacteria also reproduce asexually, but they do not use mitosis — they use binary fission, and that contrast is named content in VCE Unit 1. A bacterium has no nucleus and no spindle, and its genetic material is a single circular chromosome. In binary fission that chromosome is copied, the two copies move apart as the cell elongates, and then the membrane and wall grow inwards to divide the cell into two. It is far simpler and much faster than the eukaryotic cell cycle: under ideal laboratory conditions E. coli can divide roughly every 20 minutes. If a question asks how bacteria reproduce, the word mitosis is wrong.

KEY TERMS

asexual reproduction

Reproduction involving one parent and no gametes, producing offspring that are genetically identical to the parent.

binary fission

The division of a prokaryotic cell into two, in which a single circular chromosome is copied and the cell splits; it involves no nucleus and no spindle.

tissue repair

The replacement of damaged or worn-out cells by mitosis, for example in wound healing or the continuous renewal of skin and gut lining.

vegetative propagation

Asexual reproduction in plants from a non-reproductive part such as a runner, tuber or cutting, producing genetically identical offspring.

⚠ COMMON MISTAKE **Mitosis is not only for children**

Many students associate mitosis exclusively with growth and assume adults have finished with it. In fact an adult body carries out an enormous amount of mitosis every day, simply to replace skin, gut lining and blood cells and to heal injuries. A question asking you to assess the importance of mitosis expects replacement and repair to appear alongside growth, with named examples.

⚠ COMMON MISTAKE **Clones are not identical in every respect**

Offspring produced asexually are genetically identical to the parent at the moment they are produced, but two qualifications matter. Mutations can arise, since no copying process is perfect, so genetic differences can appear over time. And phenotype is shaped by the environment as well as by genes: two genetically identical strawberry plants growing in different soil and light will not end up the same size. Write "genetically identical", not "exactly the same".

⬡ EXTENSION **Extension: advantages and disadvantages of asexual reproduction**

Extension — beyond what this chain requires, but a common follow-up question. The advantages of asexual reproduction are speed, no need to find a mate, and the exact preservation of a genotype that is already well adapted to its environment. The disadvantage is the lack of genetic variation: every individual carries the same weaknesses, so a single new disease or environmental change can wipe out a whole population.

⬡ EXTENSION **Extension: stem cells and potency**

Extension — required content in VCE Unit 1 and QCAA Unit 1, useful enrichment elsewhere. A stem cell is an unspecialised cell that can divide by mitosis to make more of itself and can also differentiate into specialised cells. Potency describes how many types it can become: totipotent cells (the zygote and the cells of the very early embryo) can form every cell type including the extra-embryonic tissue that becomes the placenta; pluripotent cells (embryonic stem cells) can form any cell type of the body but not those extra-embryonic tissues; multipotent cells (such as the blood-forming stem cells of bone marrow) form a limited related range; unipotent cells make only one type but can still renew themselves. Mitosis plus differentiation is how one fertilised egg becomes more than 200 different cell types.

⬡ EXTENSION **Extension: G0, the cells that stop dividing**

Extension. Many specialised cells leave the cell cycle altogether into a non-dividing state called G0. Mature neurons and cardiac muscle cells stay there permanently, which is part of why heart and nerve damage tends to leave scar tissue rather than regenerating fully, while skin and gut lining repair themselves completely.

◈ EXAMPLE **Think of two dots on a balloon**

Draw two dots close together on a deflated balloon, then blow it up. The dots end up at opposite ends without anyone touching them — the surface between them simply grew. That is close to how binary fission separates genetic material. A bacterium copies its single circular chromosome, the two copies move apart as the cell elongates, and then the membrane and wall grow inwards and the cell divides in two. No nucleus, no spindle, no fibres gripping the DNA and hauling it anywhere. Set that against mitosis, where 46 separate chromosomes have to be gripped at their centromeres and dragged by spindle fibres so that each pole receives one of every chromosome. Where it breaks down: a balloon is inflated from outside and its rubber only stretches thinner, whereas a bacterium is not being blown up — it builds new membrane and wall material as it elongates. And a balloon never divides; the dots sit on the outside, while the bacterial chromosome is inside the cell.

Mitosis is not meiosis: the contrast you must be able to write

A safe rule is that Compare should cover both similarities and differences, so start with the similarities, which are real and often forgotten. Both mitosis and meiosis are forms of nuclear division. Both are preceded by one round of DNA replication in S phase. Both use spindle fibres to move chromosomes. Both involve chromosomes or chromatids being pulled to opposite poles. Both are followed by cytokinesis. If a question says Contrast, give differences only — the two command words are not interchangeable.

Now the differences, criterion by criterion — and always apply each criterion to both processes in the same sentence. Number of divisions: mitosis is one nuclear division, whereas meiosis is two in succession. Number of daughter cells: mitosis gives two, whereas meiosis gives four. Chromosome number: mitosis keeps it the same, so a diploid human cell with 46 chromosomes gives two diploid cells with 46, whereas meiosis halves it, giving haploid cells with 23. Genetic outcome: mitosis produces daughter cells genetically identical to the parent, whereas meiosis produces cells that are genetically different from one another and from the parent. Function: mitosis occurs in body cells for growth, repair and asexual reproduction, and also in the germ-line cells that multiply before meiosis, whereas meiosis occurs in reproductive tissue and, in animals, produces the gametes used in sexual reproduction.

You do not need the internal machinery of meiosis for this topic — the two divisions, crossing over and how variation arises come later. In some Australian courses meiosis and crossing over come later in the Year 11 sequence; in others they are met in Year 12, so check where your own course places them. For now, the job is simply to keep the two processes apart in your writing, because the classic way to lose marks here is to describe mitosis using facts that only apply to meiosis.

KEY TERMS

meiosis

A form of nuclear division involving two successive divisions that produces four genetically different haploid cells, used to make gametes in animals.

gamete

A sex cell such as an egg or sperm, containing half the chromosome number of a body cell; in animals gametes are produced by meiosis.

haploid

Having one complete set of chromosomes; a human gamete is haploid, with 23 chromosomes.

⚠ COMMON MISTAKE **Do not import meiosis logic into mitosis**

Three claims turn up constantly in mitosis answers and all three are wrong: that mitosis halves the chromosome number, that it produces four daughter cells, and that the daughter cells are genetically different. Mitosis produces two daughter cells with the same chromosome number as the parent and genetically identical to it. If the words halved, four or variation appear in your mitosis answer, something has gone wrong.

⬡ EXTENSION **Extension: when the cell cycle loses control — tumours and cancer**

Extension — required content in VCE Unit 1, strong enrichment elsewhere. Mitosis is normally tightly controlled: cells divide when the organism needs them to and stop when they should. If the checkpoints fail, a cell may divide when it should not, and repeated uncontrolled division produces a mass of cells called a tumour. A benign tumour stays in one place; a malignant tumour invades surrounding tissue, and cells from it may spread to other parts of the body, which is what makes cancer dangerous. Cancer cells typically divide rapidly, ignore the signals that normally stop division when cells are crowded, and often fail to differentiate properly. Note what a good answer says: cancer is a failure of cell cycle regulation, not vaguely "cells growing wrongly".

⬡ EXTENSION **Extension: apoptosis, the cell death that is supposed to happen**

Extension — required content in VCE Unit 1. Apoptosis is programmed cell death: a controlled, tidy self-destruction in which the cell shrinks, its contents are packaged into membrane-bound fragments, and neighbouring cells clear those fragments away without causing inflammation. Contrast this with necrosis, the uncontrolled death that follows injury or lack of oxygen, in which the cell swells and bursts, spilling its contents and triggering inflammation. Why would an organism deliberately kill its own cells? To sculpt structures during development — the webbing between an embryo's fingers is removed by apoptosis — and to eliminate cells that are damaged, infected or no longer needed, before they can cause harm.

Feature	MITOSIS	MEIOSIS
Number of divisions	1	2
Number of daughter cells	2	4
Genetically	identical to parent	genetically different
Chromosome number	stays the same, diploid	halved, haploid
Where it happens	body cells	gamete–forming cells
Purpose	growth, repair, asexual reproduction	sexual reproduction, genetic variation

This guide is about MITOSIS. Meiosis is here only so you do not mix them up.

A side–by–side table comparing mitosis and meiosis across six key features: number of divisions, number of daughter cells, genetic outcome, chromosome number, location, and purpose.

DAY 4 RECAP

- DNA is a polymer of nucleotides, each made of a phosphate group, a deoxyribose sugar and one nitrogenous base. Strong covalent bonds hold each sugar-phosphate backbone together, while weak hydrogen bonds hold the complementary base pairs A-T and C-G between the two strands of the double helix, which run in opposite directions (antiparallel) — which is exactly why the helix can unzip without the strands breaking.
- The same molecule appears at every scale, and you should be able to rank them: base pair, gene, DNA molecule, chromatin, condensed chromosome, genome. A human somatic cell is diploid: 46 chromosomes in 23 homologous pairs, with sister chromatids (identical copies of one chromosome) never to be confused with homologous chromosomes (a maternal and a paternal version of the same chromosome).
- The cell cycle is interphase (G1, S, G2) followed by M phase (mitosis plus cytokinesis). Interphase is the longest and busiest part of the cycle, never a rest: in G1 the cell grows and makes organelles, in S it replicates its DNA, and in G2 it grows further and makes the proteins and spindle components it will need to divide.
- In S phase every DNA molecule is replicated semi-conservatively: the hydrogen bonds break and the strands separate, each old strand acts as a template, free nucleotides already present in the nucleus pair complementarily, and every new molecule ends up with one original strand and one new strand. Each chromosome is now two identical sister chromatids joined at a centromere — and the chromosome number has not changed.
- Mitosis then sorts those copies: chromosomes condense and become visible while the nuclear envelope breaks down and the spindle forms (prophase); chromosomes line up on the equator with spindle fibres attached at their centromeres (metaphase); centromeres divide and sister chromatids are pulled to opposite poles (anaphase); chromosomes decondense and two nuclear envelopes reform (telophase). Replication is finished long before any of this begins.
- Cytokinesis then divides the cytoplasm — a cleavage furrow pinching inwards in an animal cell, a cell plate growing outwards into a new cell wall in a plant cell — completing cell division and giving two genetically identical daughter cells with the same chromosome number as the parent (in a human somatic cell, 46 chromosomes, diploid, exactly as the parent was). Mitosis is nuclear division; cell division is mitosis plus cytokinesis.
- And that genetic identity is the whole point: it lets an organism grow from one fertilised egg, repair wounds and continuously replace skin, gut lining and blood cells, and in many species reproduce asexually by budding, runners or regeneration (while bacteria do the same job by binary fission, not mitosis). When the control of this cycle fails, the very same process running unchecked produces a tumour — which is why it is worth being able to trace the chain precisely, from a single base pair all the way to two identical daughter cells.

Check Yourself — Day 4

1 **A cell is viewed under a microscope. Its chromosomes are lined up in a single row across the middle of the cell, with spindle fibres attached at their centromeres. Which stage of mitosis is shown? (1 mark)**

a) Prophase

b) Metaphase

c) Anaphase

d) Telophase

2 **A human somatic cell is at metaphase of mitosis. How many chromosomes and how many chromatids are present in that cell? (1 mark)**

a) 46 chromosomes, each made of two sister chromatids

b) 92 chromosomes, each made of a single chromatid

c) 23 chromosomes, each made of two sister chromatids

d) 46 chromatids, arranged as 23 homologous pairs

3 **Which statement best explains why the two daughter cells produced by mitosis are genetically identical? (1 mark)**

a) The DNA of the parent cell is shared out equally between the two daughter cells.

b) Each chromosome was replicated in S phase into two identical sister chromatids, and one chromatid of each pair was delivered to each pole at anaphase.

c) The chromosome number is halved at anaphase and then restored during cytokinesis.

d) Free nucleotides are added to the chromosomes during prophase, so both sets end up complete.

4 **Which statement correctly distinguishes cytokinesis in a plant cell from cytokinesis in an animal cell? (1 mark)**

a) In a plant cell a cleavage furrow pinches the cell inwards, whereas in an animal cell a cell plate forms at the equator.

b) In a plant cell a cell plate forms at the equator and grows outwards to join the existing cell wall, whereas in an animal cell the membrane is pinched inwards by a cleavage furrow.

c) Plant cells complete cytokinesis during metaphase, whereas animal cells complete it during telophase.

d) Plant cells divide their cytoplasm during mitosis, whereas animal cells divide it only after mitosis is complete.

5 **Which of the following is true of mitosis but NOT of meiosis? (1 mark)**

a) It is preceded by one round of DNA replication in S phase.

b) It produces daughter cells with the same chromosome number as the parent cell.

c) Spindle fibres attach to chromosomes and move them.

d) It is followed by cytokinesis.

6 **Explain how mitosis produces two genetically identical daughter cells. (4 marks)**

7 **Outline three roles of mitosis in living organisms, giving a named biological example of each. (3 marks)**

8 **Compare mitosis and meiosis using number of divisions, number of daughter cells, chromosome number and genetic outcome. (4 marks)**

9 **Assess the importance of mitosis to a multicellular organism. (5 marks)**

10 **Extension: In a stained onion root tip a student counts 150 cells and records 120 in interphase, 18 in prophase, 6 in metaphase, 3 in anaphase and 3 in telophase. (a) Calculate the mitotic index as a percentage. (b) If the complete cell cycle in these cells takes 20 hours, estimate how long a cell spends in mitosis and how long it spends in anaphase. Show your working and state the assumption you are making. (4 marks)**

ANSWERS

Write your answer out first. A question you have read the answer to is not practice.

1. **b) Metaphase**

2. **a) 46 chromosomes, each made of two sister chromatids**

3. **b) Each chromosome was replicated in S phase into two identical sister chromatids, and one chromatid of each pair was delivered to each pole at anaphase.**

4. **b) In a plant cell a cell plate forms at the equator and grows outwards to join the existing cell wall, whereas in an animal cell the membrane is pinched inwards by a cleavage furrow.**

5. **b) It produces daughter cells with the same chromosome number as the parent cell.**

6. During S phase of interphase, each DNA molecule is replicated semi-conservatively: the strands separate at the hydrogen bonds, each acts as a template, and free nucleotides pair complementarily (A-T, C-G), so the two molecules produced are identical in sequence. Each chromosome therefore consists of two identical sister chromatids joined at a centromere. At metaphase the chromosomes align on the equator with spindle fibres attached at their centromeres. At anaphase the centromeres divide and one chromatid of each pair is pulled to each pole, so each pole receives one complete copy of every chromosome. Therefore the two nuclei formed at telophase, and the two cells formed after cytokinesis, contain identical DNA and are genetically identical to each other and to the parent cell, with the same chromosome number as the parent.

7. 1. Growth: a multicellular organism increases its number of cells by mitosis — for example, a fertilised egg develops into an embryo, and a plant root grows from dividing cells at the root tip. 2. Repair and replacement: damaged or worn-out cells are replaced by mitosis — for example, skin cells dividing to heal a wound, the lining of the gut being replaced every few days, or bone marrow producing replacement red blood cells. 3. Asexual reproduction: some organisms produce genetically identical offspring by mitosis — for example, budding in yeast or Hydra, or vegetative propagation such as a strawberry plant growing new plants from runners. (Bacteria also reproduce asexually, but by binary fission, not mitosis.)

8. Both are forms of nuclear division preceded by one round of DNA replication in S phase, both use spindle fibres and both are followed by cytokinesis. However, mitosis involves one nuclear division whereas meiosis involves two in succession; mitosis produces two daughter cells whereas meiosis produces four; mitosis maintains the chromosome number (a human diploid cell with 46 gives two cells with 46) whereas meiosis halves it (giving haploid cells with 23); and mitosis produces cells genetically identical to the parent whereas meiosis produces cells genetically different from the parent and from one another.

9. Judgement first: mitosis is essential to a multicellular organism, because without it the organism could neither reach its adult size nor maintain itself. Evidence: growth — every one of the tens of trillions of cells in a human body descends by mitosis from one fertilised egg, and plant root tips grow by mitosis at the meristem; repair and replacement — mitosis heals wounds and continuously replaces skin, the gut lining every few days and red blood cells, which cannot divide themselves; reproduction — in some species mitosis produces whole new individuals (budding in yeast and Hydra, strawberry runners). Its importance is also shown by what happens when it fails: uncontrolled division produces a tumour. Conclusion: mitosis matters not only during childhood growth but every day of adult life.

10. (a) Cells in mitosis = 18 + 6 + 3 + 3 = 30. Mitotic index = 30 / 150 x 100 = 20%. (b) Time in mitosis = 0.20 x 20 hours = 4 hours. Cells in anaphase = 3 / 150 = 0.02, so time in anaphase = 0.02 x 20 hours = 0.4 hours = 24 minutes. Assumption: the slide is a random snapshot of a population of dividing cells, so the proportion of cells found in a stage is proportional to the length of time a cell spends in that stage. Note that 120 of the 150 cells (80%) are in interphase, which is consistent with interphase being by far the longest part of the cell cycle.

Final Assessment

Part A · Multiple Choice 15 questions

1 **A DNA molecule is a polymer built from many repeating units called nucleotides. Which three components make up ONE nucleotide?**

- **a)** A phosphate group, a deoxyribose sugar and one nitrogenous base
- **b)** A phosphate group, a ribose sugar and one nitrogenous base
- **c)** Two nitrogenous bases joined to one deoxyribose sugar
- **d)** A deoxyribose sugar, a hydrogen bond and a base pair

2 **Which statement about interphase is correct?**

- **a)** It is the longest part of the cell cycle and the cell is metabolically very active
- **b)** It is a resting phase in which very little happens inside the cell
- **c)** It is the first phase of mitosis, occurring immediately before prophase
- **d)** Chromatin condenses into visible chromosomes during interphase

3 **State the outcome of mitosis followed by cytokinesis in a human somatic cell.**

- **a)** Two genetically identical diploid daughter cells with the same chromosome number as the parent cell
- **b)** Four genetically different haploid daughter cells
- **c)** Two daughter cells each with half the chromosome number of the parent cell
- **d)** Two diploid daughter cells that are genetically different from each other

4 **Which statement about complementary base pairing in DNA is correct?**

- **a)** Adenine pairs with thymine and cytosine pairs with guanine, joined by hydrogen bonds
- **b)** Adenine pairs with guanine and cytosine pairs with thymine, joined by hydrogen bonds
- **c)** Adenine pairs with thymine and cytosine pairs with guanine, joined by covalent bonds
- **d)** Any base can pair with any other base as long as the two fit together in the helix

5 **DNA replication is described as semi-conservative. What does this mean?**

- **a)** Each new DNA molecule contains one original (template) strand and one newly made strand
- **b)** Each new strand is half made of original nucleotides and half of new nucleotides
- **c)** One new molecule is made entirely of original strands and the other entirely of new strands
- **d)** Both new DNA molecules are built entirely from free nucleotides, and the original is broken down

6 **Which statement best describes what happens during S phase of the cell cycle?**

a) DNA is replicated, so that each chromosome comes to consist of two identical sister chromatids joined at a centromere

b) Chromosomes condense, the nuclear envelope breaks down and spindle fibres form

c) The cell grows and synthesises organelles immediately after the previous division

d) Sister chromatids are pulled apart to opposite poles of the cell

7 **Which statement correctly contrasts cell division in bacteria with mitosis in a human cell?**

a) Bacteria divide by binary fission, which involves no nuclear envelope breakdown and no spindle, because a bacterium has a single circular chromosome and no nucleus

b) Bacteria undergo mitosis, but it is faster because bacterial cells are much smaller

c) Binary fission produces four genetically different daughter cells, whereas mitosis produces two identical ones

d) In binary fission the bacterial chromosome is not copied before the cell divides

8 **One strand of a short section of DNA has the base sequence: T - A - C - G - G - C - A - T. What is the base sequence of the complementary strand?**

a) A - T - G - C - C - G - T - A

b) T - A - C - G - G - C - A - T

c) A - T - C - G - G - C - T - A

d) A - T - G - C - C - G - A - T

9 **During DNA replication the double helix 'unzips'. Which bonds are broken when this happens?**

a) The hydrogen bonds between complementary bases on the two strands

b) The covalent bonds of the sugar-phosphate backbone

c) The covalent bonds joining each base to its deoxyribose sugar

d) The bonds holding two sister chromatids together at the centromere

10 **A micrograph of an onion root-tip cell shows the following: no nuclear envelope is visible; each chromosome is clearly made of two chromatids; all the chromosomes lie in a single line across the middle of the cell; spindle fibres run from each pole and attach to the chromosomes at their centromeres. Identify the stage of mitosis shown.**

a) Metaphase

b) Prophase

c) Anaphase

d) Telophase

11 **Which option places these structures in order from SMALLEST to LARGEST?**

a) Base pair → gene → chromosome → genome

b) Gene → base pair → chromosome → genome

c) Base pair → chromosome → gene → genome

d) Gene → chromosome → base pair → genome

12 **A student examines a stained garlic root-tip squash under the microscope. Of the 250 cells counted, 40 show condensed chromosomes and spindle fibres, indicating they are undergoing mitosis. Calculate the mitotic index of this tissue.**

a) 16%

b) 6.25%

c) 40%

d) 84%

13 **A human somatic cell has just completed S phase and is now in G2. How many chromosomes and how many chromatids does this cell contain?**

a) 46 chromosomes and 92 chromatids

b) 92 chromosomes and 92 chromatids

c) 92 chromosomes and 46 chromatids

d) 23 chromosomes and 46 chromatids

14 **Which statement BEST explains why the two daughter cells produced by mitosis are genetically identical to each other?**

a) DNA was replicated semi-conservatively in S phase to form two identical sister chromatids on each chromosome, and at anaphase one chromatid of each pair moves to each pole

b) The DNA of the parent cell is shared out evenly between the two daughter cells

c) Homologous chromosomes pair up and are then separated equally into the two daughter cells

d) Mitosis halves the chromosome number, so each daughter cell receives an equal share

15 **A drug completely blocks DNA replication, but a cell nevertheless enters mitosis. Predict the most likely consequence for the two daughter cells.**

a) Each chromosome would consist of only one chromatid, so the two daughter cells could not each receive a complete set of chromosomes

b) Each daughter cell would receive twice the normal amount of DNA

c) The cell would produce four haploid daughter cells instead of two diploid ones

d) The daughter cells would still be genetically identical, but each would be half the normal size

Part B · Short & Extended Response 22 marks total

1 **Describe the structure of a DNA molecule. (3 marks)** (3 marks)

2 **Explain why it is important that the sugar-phosphate backbone is held together by strong covalent bonds while the two strands are held together by weak hydrogen bonds. (3 marks)** (3 marks)

3 **Outline the events that occur in a eukaryotic cell from the beginning of G1 phase through to the completion of cytokinesis. (4 marks)** (4 marks)

4 **Justify the statement that DNA replication must be completed before mitosis begins. (4 marks)** (4 marks)

5 **Compare cytokinesis in a plant cell with cytokinesis in an animal cell. (3 marks)** (3 marks)

6 **Explain how mitosis produces two genetically identical daughter cells. Use correct biological terminology in your answer. (5 marks)** (5 marks)

Part C · Name the Term Read the definition and write the term it describes.

1	**DNA is the molecule found inside the nucleus of a cell that stores the genetic instructions for building and running an organism.**	
2	**Deoxyribonucleic acid is the full chemical name for DNA: a nucleic acid built from many repeating nucleotide units, each containing a deoxyribose sugar.**	
3	**A nucleotide is the repeating building block (monomer) of DNA, made of a phosphate group, a deoxyribose sugar and one nitrogenous base.**	
4	**The cell cycle is the ordered sequence of events in which a cell grows, copies its DNA and then divides to produce two new cells.**	
5	**Interphase is the longest part of the cell cycle, made up of G1, S and G2, during which the cell grows, carries out its normal functions and replicates its DNA — it is not a resting phase.**	
6	**G1, the first gap phase, is the part of interphase after division in which the cell grows, makes proteins and new organelles, and prepares for DNA replication.**	
7	**DNA replication is the process in which a DNA molecule is copied to produce two identical molecules; it happens during S phase of interphase, before mitosis begins.**	

8	**Semi-conservative replication means each new DNA molecule keeps one original (parent) strand and one newly built strand.**	
9	**A template strand is an original strand of DNA whose base sequence is read to determine the sequence of the new complementary strand.**	
10	**Prophase is the first stage of mitosis, in which chromatin condenses into visible chromosomes (each already made of two sister chromatids), the spindle begins to form and the nuclear envelope breaks down.**	
11	**Metaphase is the stage in which the chromosomes are lined up along the equator of the cell, attached to spindle fibres at their centromeres.**	
12	**Anaphase is the stage in which the centromeres split and the spindle fibres pull the sister chromatids to opposite poles, so each pole receives an identical set.**	

Final Assessment — Answer Key

PART A

Anything you got wrong — go back to that day and read it again.

1. **a) A phosphate group, a deoxyribose sugar and one nitrogenous base**

2. **a) It is the longest part of the cell cycle and the cell is metabolically very active**

3. **a) Two genetically identical diploid daughter cells with the same chromosome number as the parent cell**

4. **a) Adenine pairs with thymine and cytosine pairs with guanine, joined by hydrogen bonds**

5. **a) Each new DNA molecule contains one original (template) strand and one newly made strand**

6. **a) DNA is replicated, so that each chromosome comes to consist of two identical sister chromatids joined at a centromere**

7. **a) Bacteria divide by binary fission, which involves no nuclear envelope breakdown and no spindle, because a bacterium has a single circular chromosome and no nucleus**

8. **a) A - T - G - C - C - G - T - A**

9. **a) The hydrogen bonds between complementary bases on the two strands**

10. **a) Metaphase**

11. **a) Base pair → gene → chromosome → genome**

12. **a) 16%**

13. **a) 46 chromosomes and 92 chromatids**

14. **a) DNA was replicated semi-conservatively in S phase to form two identical sister chromatids on each chromosome, and at anaphase one chromatid of each pair moves to each pole**

15. **a) Each chromosome would consist of only one chromatid, so the two daughter cells could not each receive a complete set of chromosomes**

PART B

Compare with the model answer and count how many marking points you actually hit.

1. (3 marks)

DNA is a polymer made of many nucleotides, and each nucleotide consists of a phosphate group, a deoxyribose sugar and one nitrogenous base (adenine, thymine, cytosine or guanine). The nucleotides of one strand are joined through their sugars and phosphates by strong covalent bonds, forming a sugar-phosphate backbone. Two such strands run in opposite directions (antiparallel) and are wound into a double helix, held

together by weak hydrogen bonds between complementary bases: adenine always pairs with thymine (two hydrogen bonds) and cytosine always pairs with guanine (three hydrogen bonds).

2. (3 marks)

Hydrogen bonds between paired bases are individually weak, so they can be broken relatively easily and the two strands can separate, or 'unzip', when the DNA needs to be replicated. Because the sugar-phosphate backbone is held by strong covalent bonds, each separated strand stays intact and its base sequence is preserved, so it can act as a template for building a new complementary strand. At the same time, a DNA molecule contains an enormous number of hydrogen bonds, so collectively they are strong enough to hold the double helix together and keep the molecule stable when it is not replicating.

3. (4 marks)

During G1 the cell grows in size, carries out normal metabolism and synthesises organelles and proteins. In S phase the DNA is replicated, so that each chromosome comes to consist of two identical sister chromatids joined at a centromere. In G2 the cell grows further and makes the proteins needed for division, including the components of the spindle, and checks that the DNA has been correctly copied. The cell then enters M phase: mitosis divides the nucleus through prophase, metaphase, anaphase and telophase, and this is followed by cytokinesis, in which the cytoplasm divides to produce two separate daughter cells.

4. (4 marks)

DNA replication occurs during S phase of interphase, and it is the only stage at which the genetic material is copied. Mitosis itself does not copy DNA; it only separates chromatids that already exist, because at anaphase the centromeres divide and one chromatid of each pair is pulled to each pole. Therefore, if replication had not already produced two identical sister chromatids on every chromosome, there would be no identical copy to send to each pole, and the DNA content of the daughter cells would be halved at every division so that each daughter cell would receive an incomplete set of genetic instructions. Replication before mitosis is therefore essential for producing two complete, genetically identical daughter cells, and this is why the statement is valid.

5. (3 marks)

In both plant and animal cells, cytokinesis is a separate process that follows mitosis and divides the cytoplasm of the parent cell, producing two separate daughter cells. In an animal cell the plasma membrane is pulled inwards at the equator to form a cleavage furrow, which deepens until the cell is pinched into two. In a plant cell no furrow can form because of the rigid cell wall; instead, vesicles collect at the equator and fuse to form a cell plate, which develops into a new cell wall and membrane separating the two daughter cells.

6. (5 marks)

Before mitosis begins, the DNA is replicated semi-conservatively during S phase of interphase: the double helix unzips as the hydrogen bonds between complementary bases break, each original strand acts as a template, and free nucleotides pair complementarily with it, so that each new DNA molecule contains one original and one new strand and is an exact copy of the original. As a result, each chromosome now consists of two identical sister chromatids joined at a centromere. In prophase the chromosomes condense and become visible, the nuclear envelope breaks down and spindle fibres form; in metaphase the chromosomes line up on the equator with spindle fibres attached at their centromeres. At anaphase the centromeres divide and the spindle fibres pull one chromatid of each pair to each pole, so each pole receives one complete copy of every chromosome. In telophase the chromosomes decondense and a nuclear envelope reforms around each set,

and cytokinesis then divides the cytoplasm, producing two diploid daughter cells that are genetically identical to each other and to the parent cell.

PART C · TERMS

1. DNA · **2. deoxyribonucleic acid** · **3. nucleotide** · **4. cell cycle** · **5. interphase** · **6. G1 phase** · **7. DNA replication** · **8. semi-conservative replication** · **9. template strand** · **10. prophase** · **11. metaphase** · **12. anaphase**

Glossary

Day 1 · The Structure of DNA

ENGLISH TERM	DEFINITION	
DNA	DNA（脱氧核糖核酸）	DNA is the molecule found inside the nucleus of a cell that stores the genetic instructions for building and running an organism.
deoxyribonucleic acid *dee-OK-see-RYE-boh-new-KLAY-ik AS-id*	脱氧核糖核酸	Deoxyribonucleic acid is the full chemical name for DNA: a nucleic acid built from many repeating nucleotide units, each containing a deoxyribose sugar.
nucleotide *NEW-klee-oh-tide*	核苷酸	A nucleotide is the repeating building block (monomer) of DNA, made of a phosphate group, a deoxyribose sugar and one nitrogenous base.
phosphate group *FOS-fate*	磷酸基团	A phosphate group is the phosphorus-containing part of a nucleotide, which links to the sugar of the next nucleotide to form the backbone of the strand.
deoxyribose sugar *dee-OK-see-RYE-bose*	脱氧核糖	Deoxyribose is the five-carbon sugar in a DNA nucleotide; it joins to a phosphate group on one side and to a nitrogenous base on the other.
nitrogenous base *nye-TROJ-uh-nus base*	含氮碱基	A nitrogenous base is the nitrogen-containing part of a nucleotide — adenine, thymine, cytosine or guanine — and the order of these bases carries the genetic information.
adenine *AD-uh-neen*	腺嘌呤	Adenine (A) is a purine base that always pairs with thymine on the opposite strand, held there by two hydrogen bonds.
thymine *THIGH-meen*	胸腺嘧啶	Thymine (T) is a pyrimidine base that always pairs with adenine, held there by two hydrogen bonds.
cytosine *SIGH-toh-seen*	胞嘧啶	Cytosine (C) is a pyrimidine base that always pairs with guanine, held there by three hydrogen bonds.
guanine *GWAH-neen*	鸟嘌呤	Guanine (G) is a purine base that always pairs with cytosine, held there by three hydrogen bonds.
purine *PURE-een*	嘌呤	A purine is a nitrogenous base with a double-ring structure; adenine and guanine are the two purines found in DNA.

pyrimidine *pie-RIM-uh-deen*	嘧啶	A pyrimidine is a nitrogenous base with a single-ring structure; thymine and cytosine are the two pyrimidines in DNA, and because a purine always pairs with a pyrimidine the helix stays a constant width.
complementary base pairing *kom-pluh-MEN-tree*	碱基互补配对	Complementary base pairing is the rule that adenine always pairs with thymine and cytosine always pairs with guanine, so the sequence of one strand determines the sequence of the other.
hydrogen bond	氢键	A hydrogen bond is a weak attraction that holds a base pair together; each one is weak, but there are so many along a DNA molecule that together they hold the two strands stable.
phosphodiester bond *FOS-foh-dye-ES-ter*	磷酸二酯键	A phosphodiester bond is the strong covalent bond joining the phosphate of one nucleotide to the sugar of the next, forming the sugar-phosphate backbone.
sugar-phosphate backbone *FOS-fate*	磷酸—脱氧核糖骨架	The sugar-phosphate backbone is the alternating chain of deoxyribose sugars and phosphate groups running along the outside of each DNA strand, holding the bases in order.
double helix *DUB-ul HEE-liks*	双螺旋	The double helix is the twisted-ladder shape of DNA, formed by two antiparallel strands coiled around the same axis with the base pairs on the inside.
antiparallel *AN-tee-PA-ruh-lel*	反向平行	Antiparallel means the two strands of DNA run in opposite directions, one from 5' to 3' and the other from 3' to 5'.
gene	基因	A gene is a section of DNA that codes for a particular protein and therefore for a particular characteristic.
genome *JEE-nohm*	基因组	The genome is the complete set of DNA, and therefore all the genes, contained in one cell of an organism.
chromosome *KROH-muh-sohm*	染色体	A chromosome is one long DNA molecule wound around histone proteins; it only becomes short and thick enough to see under a light microscope when the cell is dividing.
chromatin *KROH-muh-tin*	染色质	Chromatin is the loose, thread-like form of DNA and its associated proteins during interphase, when the DNA must be accessible for copying and for making proteins.
histone *HIS-tohn*	组蛋白	Histones are the proteins that DNA coils around, allowing a very long DNA molecule to be packaged neatly inside the nucleus.

nucleus *NEW-klee-us*	细胞核	The nucleus is the membrane-bound organelle that contains the cell's chromosomes and controls the cell's activities.

Day 2 · The Cell Cycle

ENGLISH TERM	DEFINITION	
cell cycle	细胞周期	The cell cycle is the ordered sequence of events in which a cell grows, copies its DNA and then divides to produce two new cells.
interphase *IN-ter-fayz*	（分裂）间期	Interphase is the longest part of the cell cycle, made up of G1, S and G2, during which the cell grows, carries out its normal functions and replicates its DNA — it is not a resting phase.
G1 phase	G1 期（第一间隙期）	G1, the first gap phase, is the part of interphase after division in which the cell grows, makes proteins and new organelles, and prepares for DNA replication.
S phase	S 期（合成期）	S phase (synthesis) is the part of interphase in which DNA replication occurs, so that afterwards every chromosome consists of two identical sister chromatids.
G2 phase	G2 期（第二间隙期）	G2, the second gap phase, follows DNA replication: the cell continues to grow, makes the proteins needed for division, and checks the copied DNA for errors.
M phase	M 期（分裂期）	M phase is the dividing part of the cell cycle, consisting of mitosis (division of the nucleus) followed by cytokinesis (division of the cytoplasm).
mitosis *my-TOH-sis*	有丝分裂	Mitosis is the division of one nucleus into two nuclei with identical sets of chromosomes, occurring in four stages: prophase, metaphase, anaphase and telophase.
cytokinesis *SY-toh-kih-NEE-sis*	胞质分裂	Cytokinesis is the division of the cytoplasm that follows mitosis, physically separating the cell into two daughter cells.
checkpoint	检查点	A checkpoint is a control point in the cell cycle where the cell checks that conditions are suitable and the DNA is correct before it is allowed to move on to the next stage.
growth	生长	Growth is the increase in cell number, and therefore in body size, of a multicellular organism, achieved by repeated cell cycles ending in mitosis.

differentiation *DIF-uh-ren-shee-AY-shun*	（细胞）分化	Differentiation is the process in which an unspecialised cell develops the particular structure and function of one cell type, such as a nerve cell or a muscle cell.
organelle *or-guh-NEL*	细胞器	An organelle is a specialised structure inside a cell that carries out a particular job, such as the nucleus or a mitochondrion.

Day 3 · DNA Replication

ENGLISH TERM	DEFINITION	
DNA replication *rep-lih-KAY-shun*	DNA 复制	DNA replication is the process in which a DNA molecule is copied to produce two identical molecules; it happens during S phase of interphase, before mitosis begins.
semi-conservative replication *SEM-ee kun-SER-vuh-tiv*	半保留复制	Semi-conservative replication means each new DNA molecule keeps one original (parent) strand and one newly built strand.
template strand *TEM-playt*	模板链	A template strand is an original strand of DNA whose base sequence is read to determine the sequence of the new complementary strand.
helicase *HEE-lih-kayz*	解旋酶	Helicase is the enzyme that unwinds the double helix and breaks the hydrogen bonds between the base pairs, separating the two strands.
DNA polymerase *puh-LIM-uh-rayz*	DNA 聚合酶	DNA polymerase is the enzyme that adds free nucleotides to the template strand according to the base-pairing rules and joins them together into a new strand.
replication fork	复制叉	The replication fork is the Y-shaped region where the double helix has been separated and the new strands are being built.
daughter strand	子链	A daughter strand is the newly made DNA strand that is complementary to the template strand it was built on.
sister chromatid *KROH-muh-tid*	姐妹染色单体	Sister chromatids are the two identical copies of a replicated chromosome, joined at the centromere; they are not counted as separate chromosomes until they separate in anaphase.
centromere *SEN-troh-meer*	着丝粒	The centromere is the region that holds sister chromatids together and to which the spindle fibres attach during mitosis.

ENGLISH TERM	DEFINITION	
prophase *PROH-fayz*	前期	Prophase is the first stage of mitosis, in which chromatin condenses into visible chromosomes (each already made of two sister chromatids), the spindle begins to form and the nuclear envelope breaks down.
metaphase *MET-uh-fayz*	中期	Metaphase is the stage in which the chromosomes are lined up along the equator of the cell, attached to spindle fibres at their centromeres.
anaphase *AN-uh-fayz*	后期	Anaphase is the stage in which the centromeres split and the spindle fibres pull the sister chromatids to opposite poles, so each pole receives an identical set.
telophase *TEL-oh-fayz*	末期	Telophase is the final stage of mitosis, in which the chromosomes reach the poles and uncoil, and a new nuclear envelope forms around each set.
spindle fibre *SPIN-dul FY-ber*	纺锤丝（纺锤体）	Spindle fibres are protein microtubules that attach to the centromeres and move the chromosomes during mitosis.
centriole *SEN-tree-ohl*	中心粒	Centrioles are small cylindrical structures in animal cells that move to opposite poles and help organise the spindle; plant cells form a spindle without them.
equator (metaphase plate) *ih-KWAY-ter*	赤道板	The equator, or metaphase plate, is the imaginary plane midway between the two poles of the cell where the chromosomes line up during metaphase.
nuclear envelope *NEW-klee-uh EN-vuh-lohp*	核膜	The nuclear envelope is the double membrane surrounding the nucleus; it breaks down during prophase and re-forms around each new set of chromosomes during telophase.
daughter cell	子细胞	Daughter cells are the two new cells produced at the end of the cell cycle; after mitosis and cytokinesis they are genetically identical to each other and to the parent cell.
genetically identical *juh-NET-ik-lee eye-DEN-tik-ul*	遗传物质完全相同	Genetically identical means having exactly the same DNA base sequence and the same number of chromosomes, which results from semi-conservative replication in S phase followed by the precise separation of sister chromatids in mitosis.

diploid *DIP-loyd*	二倍体	Diploid (2n) describes a cell that has two complete sets of chromosomes, one inherited from each parent; human body cells are diploid with 46 chromosomes.
haploid *HAP-loyd*	单倍体	Haploid (n) describes a cell with only one set of chromosomes, such as a gamete; haploid cells are produced by meiosis, not by mitosis.
asexual reproduction *ay-SEK-shoo-al*	无性生殖	Asexual reproduction is reproduction involving only one parent, using mitosis, so the offspring are genetically identical to that parent.
tissue repair *TISH-oo*	组织修复	Tissue repair is the replacement of damaged or worn-out cells by new, genetically identical cells produced by mitosis, for example when a cut in the skin heals.
stem cell	干细胞	A stem cell is an unspecialised cell that can keep dividing by mitosis and can differentiate into one or more specialised cell types.
cancer (tumour) *TYOO-mer*	癌症（肿瘤）	Cancer is a disease in which checkpoint control of the cell cycle fails and cells divide in an uncontrolled way; the mass of cells that builds up is called a tumour.
meiosis *my-OH-sis*	减数分裂	Meiosis is a different type of nuclear division that produces four genetically varied haploid gametes from one diploid cell, in contrast to mitosis, which produces two genetically identical diploid cells.

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