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.
从 DNA 的结构一路讲到一个细胞如何变成两个完全相同的细胞。

PREPARED FOR

Phoebe Fan

Year 11 Biology · "Direction & Replication"

for Phoebe — from Dad

FOUR-DAY PLAN · 四天学习计划

1. **The Structure of DNA**
   DNA 的结构 · about 60 min
2. **The Cell Cycle and Interphase**
   细胞周期与间期 · about 65 min
3. **DNA Replication: Making an Exact Copy**
   DNA 复制：制作一份精确的副本 · about 70 min
4. **Mitosis and Why It Matters**
   有丝分裂及其意义 · about 70 min

How to Use This Guide

使用说明 · 3–4 天内学完这一整块知识

1 English first, Chinese second · 先读英文，再读中文

每一段都是**先英文、后中文**。英文是你上课、考试真正要用的语言，请先读英文并试着读懂；再读下面带绿色竖线的中文，确认自己理解得对不对。中文里保留了英文术语，方便你把概念和考试用词对上号。

2 One day at a time · 一天一章，别赶进度

每天 45–75 分钟：读完当天内容 → 看懂图 → 做「Check Yourself 自我检测」→ 最后再对答案。四天的顺序是有依赖关系的，Day 3 建立在 Day 2 上，别跳着看。

3 Cover the answers · 先做题再看答案

检测题的答案就在同一页下方的虚线框里。**请用手或纸盖住**，写完再对。看过答案的题不算练过——这是最容易骗自己的地方。

4 Say it out loud in English · 用英文说一遍

每天最后合上手册，用**英文**把当天的核心观念（The Big Idea）讲一遍。能讲出来才算真会；讲不出来说明还得回去看。考试考的是你能不能用准确的英文术语解释，不是能不能认出选项。

5 Finish with the final test · 第 4 天后做总测验

全部学完后做书末的 Final Assessment（15 道选择 + 6 道简答 + 12 个术语默写）。简答题附有**逐条得分点**，照着数自己拿了几分，比只看对错有用得多。最后的中英术语对照表可以随时翻。

BOXES YOU WILL SEE · 手册中的四种提示框

- ✦ TIP — **记忆技巧**——帮你把知识点记牢的口诀、类比和小窍门。
- ⚠ COMMON MISTAKE — **常见错误**——大多数学生在这里丢分。看到这个框请慢下来读两遍。
- ⬡ EXTENSION — **拓展内容**——超出基础要求的加深部分。基础没稳可以先跳过，回头再补。
- ⚑ IN THE EXAM — **考试怎么考**——这个知识点在考卷上长什么样、答题要写到哪几点。

DAY 1

about 60 min · 约 60 分钟

The Structure of DNA

DNA 的结构

THE BIG IDEA · 核心观念

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.

DNA（脱氧核糖核酸）是由仅仅四种核苷酸 (nucleotide) 反复串起来的长链；因为腺嘌呤总是与胸腺嘧啶配对、胞嘧啶总是与鸟嘌呤配对，而且靠的是较弱的氢键 (hydrogen bond)，所以整条分子既能保持粗细一致的双螺旋 (double helix) 形状、用碱基的“顺序”储存信息，又能从中间被拉开——这就是它可以被精确复制的结构基础。

BY THE END OF TODAY YOU WILL BE ABLE TO · 今天学完你将能够

1. State the function of DNA — it stores the genetic instructions for making proteins — and identify where DNA is found in a eukaryotic cell.
   说出 (State) DNA 的功能——储存制造蛋白质的遗传指令——并指出 (Identify) 真核细胞中 DNA 存放的位置。
2. Identify the three parts of a DNA nucleotide and name the four nitrogenous bases.
   识别 (Identify) 一个 DNA 核苷酸 (nucleotide) 的三个组成部分，并说出四种含氮碱基 (nitrogenous base) 的名称。
3. Describe how nucleotides join end to end to form a strand with a sugar-phosphate backbone.
   描述 (Describe) 核苷酸如何首尾相连形成一条链，并在外侧形成磷酸—脱氧核糖骨架 (sugar–phosphate backbone)。
4. State the complementary base pairing rules and the number of hydrogen bonds holding each pair together.
   说出 (State) 碱基互补配对原则 (complementary base pairing)，以及每一对碱基之间氢键的数目（A—T 两个，C—G 三个）。
5. Explain why weak hydrogen bonds between the bases and strong covalent bonds along the backbone allow DNA to unzip without either strand breaking.
   解释 (Explain) 为什么碱基之间是弱氢键、骨架上是强共价键，这种搭配让 DNA 能从中间“拉开”而两条链本身不会断。
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.
   按顺序排列 (Sequence) 碱基对 → 基因 (gene) → DNA 分子 → 染色质 (chromatin) → 染色体 (chromosome，高度螺旋化、缩短变粗后) → 基因组 (genome)，并说明每一层与上一层的关系。
7. Apply the base-pairing rule to write the complementary strand for a given DNA base sequence.
   运用 (Apply) 碱基互补配对原则，根据给定的一条链的碱基顺序写出互补链。

What DNA is and what its job is

DNA 是什么，它的工作是什么

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.

> 先讲“用途”，因为只有知道这个分子要干什么，它的结构才讲得通。DNA（脱氧核糖核酸 deoxyribonucleic acid）是储存“造蛋白质的说明书”的化学物质。为什么这很重要？因为在生物体内几乎所有实际干活的都是蛋白质：加速化学反应的酶、头发和指甲里的角蛋白、运氧的血红蛋白、细胞膜上的受体等等。既然 DNA 掌握着造蛋白质的说明书，它实际上就决定了一个细胞能造什么、长什么样、能做什么。今年你不需要知道说明书具体是怎么被“读取”的（那是后面的课题），但必须能用一句话说清它的工作：DNA 储存制造蛋白质的遗传指令，并在细胞分裂时把这套指令传下去。

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.

> 它在哪里？在真核细胞（eukaryotic cell，即植物、动物、真菌细胞）里，绝大部分 DNA 都在细胞核（nucleus）里——这正是我们把细胞核叫做“细胞控制中心”的原因。（线粒体里也有少量 DNA，植物的叶绿体里也有。）原核生物（如细菌）根本没有细胞核：它们的 DNA 是一条环状染色体，直接漂在细胞质里。对你来说关键的一点是：地球上所有生物体内的 DNA 都是同一种分子、同一套构造。这套结构只要学一次，细菌、草莓、你自己身上都通用。这种“普遍性”本身就是一条生物学证据，也是为什么课本上的 DNA 结构图从来不标“人的 DNA”或“植物的 DNA”——它就叫 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.

> 想读懂结构，可以先问：这个分子必须擅长什么？第一，它要装下海量信息——人的一个体细胞里的 DNA 拉直大约有两米长，却要塞进直径只有几微米的细胞核里。第二，它必须能被复制，而且每次细胞分裂都要一模一样地复制，不能走样。今天这节课讲的全部结构，其实都是对这两个要求的“结构性回答”。今天最核心的一句话是：DNA 是一种多聚体（polymer）。多聚体就是把许多相同的小单位（单体 monomer）像纸链圈一样一个接一个连起来形成的长分子。DNA 的单体叫核苷酸（nucleotide），我们就从它讲起。

KEY TERMS · 关键术语

DNA DNA（脱氧核糖核酸）

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

脱氧核糖核酸：储存制造蛋白质的遗传指令、并在细胞分裂时传递给子细胞的分子。

nucleus 细胞核

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

真核细胞中由膜包被的细胞器，细胞内几乎全部 DNA 都存放在里面。

polymer 多聚体（聚合物）

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

由许多重复的小单位（单体 monomer）连成长链而形成的大分子；DNA 就是核苷酸的多聚体。

⚠ COMMON MISTAKE

DNA, gene and chromosome are not three different substances

DNA、基因、染色体不是三种不同的东西

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.

> 很多同学写答案时，好像 DNA、基因 (gene)、染色体 (chromosome) 是三种不同的物质、放在不同地方。其实它们是同一种物质在不同尺度上的叫法，就像字母、句子、整本书都是纸上的墨。本课后面会把它们从小到大排好序；现在先记住：既不能把它们当同义词乱换，也不能当成三样东西。

⚑ IN THE EXAM

One-sentence answers are worth real marks 一句话的定义题也是实打实的分

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.

> 考题里如果是 Identify（识别）或 State（说出）——例如 Identify the molecule that stores genetic information、State the function of DNA——那是记忆分：直接答出来就停。别顺手写一大段双螺旋，Identify / State 不会因为写多而加分，反而会浪费后面 Explain 大题的时间。

◈ EXAMPLE **Think of a flat-pack instruction booklet** 把它想成平板家具的说明书

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.

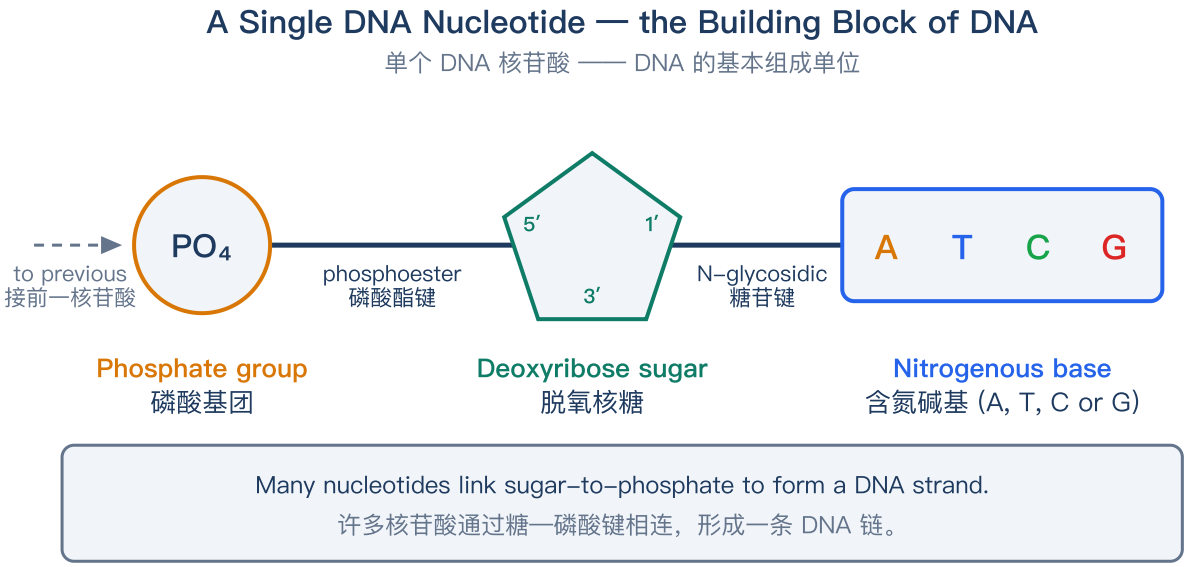
> 用平板家具（宜家那种）的说明书打比方：说明书告诉你哪块板配哪个螺丝，但它自己一块板也搬不动，真正干活的是人、螺丝和内六角扳手。DNA 就是这样——它只储存造蛋白质的指令，真正干活的是蛋白质：酶加速反应、角蛋白构成头发、血红蛋白运氧。所以考题问 DNA 的功能时，答案是「储存制造蛋白质的遗传指令」，而不是「运氧」或「加速反应」——那是某些具体蛋白质的工作。比喻在两处失效：第一，说明书教你组装的是本来就存在的零件，而 DNA 的指令是用来「造出干活的人」本身的——你体内每一种在干活的蛋白质，都是照着一段 DNA 造出来的；第二，家具装好后说明书就扔了，而 DNA 要永久保存，并在每次细胞分裂时被完整复制传下去。

The nucleotide: the repeating building block

核苷酸：反复出现的基本单位

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.

> 每个核苷酸 (nucleotide) 恰好有三个部分，你要能不假思索地说出来：磷酸基团 (phosphate group)、脱氧核糖 (deoxyribose sugar)、一个含氮碱基 (nitrogenous base)。看着图用手指顺一遍。注意它们的排列方式——脱氧核糖在中间，起“连接件”的作用：磷酸基团接在糖的一边，碱基接在糖的另一边。这个排列不是装饰，正因为糖在中间，分子才能在外侧连成骨架、把碱基留在内侧。考试常给一张没有标注的核苷酸结构图，让你标出三个组成部分的名称，所以要把它当“图”记，而不只是当“三个词”背。图上分不清谁是谁时记住：中间那个、两边都有邻居的，就是糖。



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.

单个 DNA 核苷酸：磷酸基团经 5′ 碳与脱氧核糖相连，含氮碱基（A、T、C 或 G）经 1′ 碳与糖相连。

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.

> DNA 中只有四种碱基：腺嘌呤 (adenine, A)、胸腺嘧啶 (thymine, T)、胞嘧啶 (cytosine, C)、鸟嘌呤 (guanine, G)。关键来了：每个核苷酸里的磷酸基团都一模一样，脱氧核糖也一模一样，唯一不同的就是接上去的是四种碱基中的哪一种。所以整条 DNA 里其实只有四种核苷酸，一条 DNA 链就是用四个字母写成的信息。

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.

> 核苷酸是这样连成链的：前一个核苷酸的糖与后一个核苷酸的磷酸基团相连，如此重复几百万次。于是在分子外侧形成一条“糖—磷酸—糖—磷酸”交替的连续长链，叫做磷酸—脱氧核糖骨架 (sugar–phosphate backbone)。有两点必须记牢。第一，骨架上的这些连接是强共价键 (covalent bond)——一定记住，明天讲到它与另一种弱得多的键的对比时，这就是全部重点。第二，碱基不属于骨架，它们挂在骨架侧面、朝内伸出。你可以把一条单链想成一把梯子从中间锯开后的一半：骨架是竖着的边框，碱基是横着伸出来的“半截横档”，每一根都在等一个搭档。

KEY TERMS · 关键术语

nucleotide 核苷酸

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

DNA 的重复单体，由一个磷酸基团、一个脱氧核糖和一个含氮碱基组成。

phosphate group 磷酸基团

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.

核苷酸中接在糖上、并与相邻核苷酸的糖相连的部分，使骨架上糖与磷酸交替排列。

deoxyribose sugar 脱氧核糖

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

位于核苷酸中间的五碳糖，一边接磷酸基团，另一边接碱基。

nitrogenous base 含氮碱基

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

核苷酸中会变化的那一部分：腺嘌呤、胸腺嘧啶、胞嘧啶或鸟嘌呤。它们沿链排列的顺序承载信息。

sugar–phosphate backbone 磷酸—脱氧核糖骨架

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

由糖和磷酸基团交替相连、以强共价键结合、沿每条链外侧延伸的连续长链。

✦ TIP **Memory aid: P–S–B, sugar in the middle** 记忆口诀：磷—糖—碱，糖在中间

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.

> 按顺序三拍念：磷酸 (Phosphate) — 糖 (Sugar) — 碱基 (Base)。糖永远在中间那一拍，因为它是把另外两个连起来的零件。只要能念出“磷—糖—碱”并在图上指出来，填图题就稳了。

⚠ COMMON MISTAKE **A base is not a nucleotide** 碱基不等于核苷酸

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.

> 很常见的失误是写成“DNA 由 A、T、C、G 组成”。严格说，DNA 由核苷酸 (nucleotide) 组成，碱基只是每个核苷酸三个部分中的一个。阅卷老师看得出这个差别。要写成：DNA 是核苷酸的多聚体，每个核苷酸含四种碱基中的一种。

⬡ EXTENSION

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

拓展：碱基顺序就是信息，四个字母为什么够用

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.

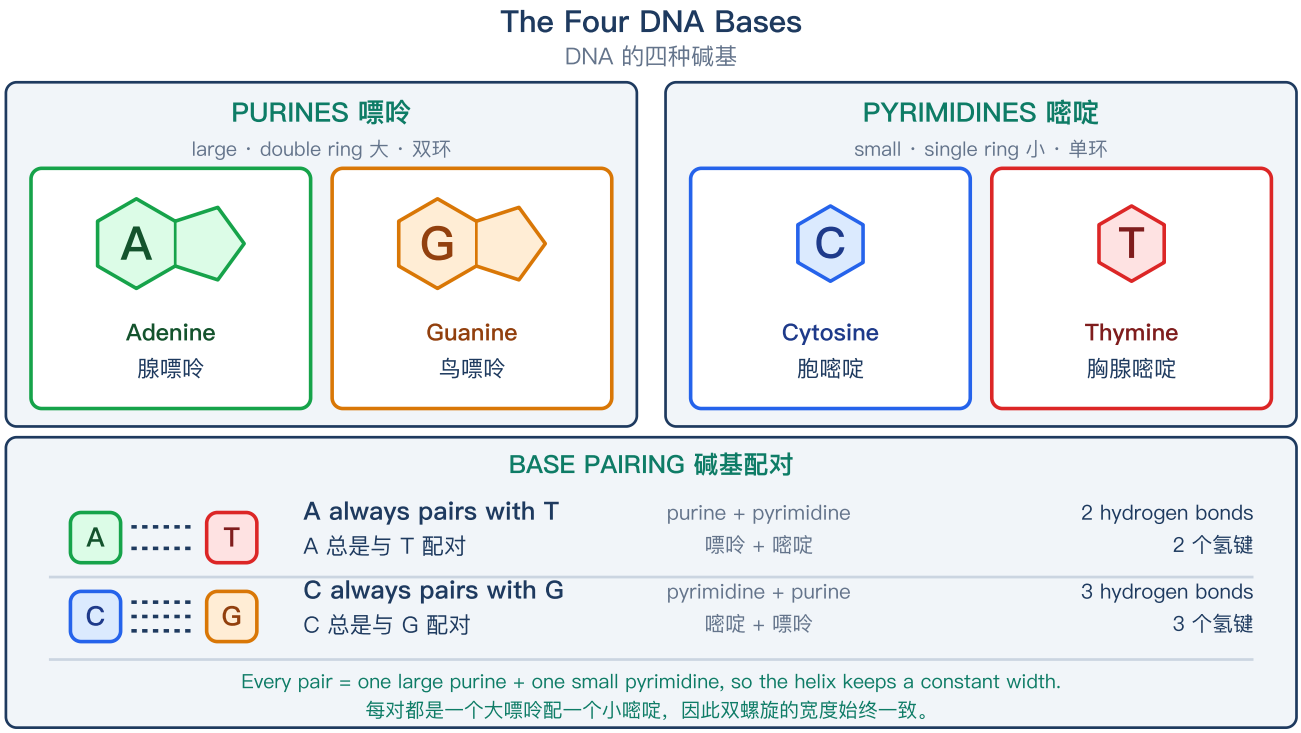
> 信息本身并不在这些化学物质里（所有生物用的都是同样四种碱基），而在于碱基沿着链排列的“顺序”——就像 star 和 rats 用的是同样的字母，意思却完全不同。“只有四个字母”听起来很少，但算一下组合数就明白了：仅仅 10 个碱基的排列方式就有 4 的 10 次方 = 1,048,576 种。一个基因动辄几百上千个碱基，储存容量实际上根本用不完。别的课本里可能给骨架上那些强共价键起了一个更长的化学名称，不用管它——在澳洲考试里写“磷酸—脱氧核糖骨架上的强共价键”就完全够了。

◈ EXAMPLE

Think of a row of people linking arms 想象一排人互相挽着手臂

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.

> 想象一排人并肩站着：每个人用左臂挽住左边那个人，右手空着，举着一张写有字母的卡片朝前伸。每个人就是一个核苷酸：中间的身体＝脱氧核糖，那条唯一用来挽人的手臂＝磷酸基团（每人只有一个，把自己的身体连到隔壁那个人身上），手里的卡片＝含氮碱基。由此得出两点：①这条「链」是由人本身连成的，不是他们共同抓着一根绳子——这正对应课文里那句「前一个核苷酸的糖与后一个核苷酸的磷酸相连」，于是形成一条「糖—磷酸—糖—磷酸」交替的连续骨架；②卡片始终朝前伸出，说明碱基是挂在骨架侧面的，不属于骨架本身。比喻失效之处：手一松手臂就散开，而骨架上的糖—磷酸连接是强共价键，即使两条链被拉开也不会断。



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).

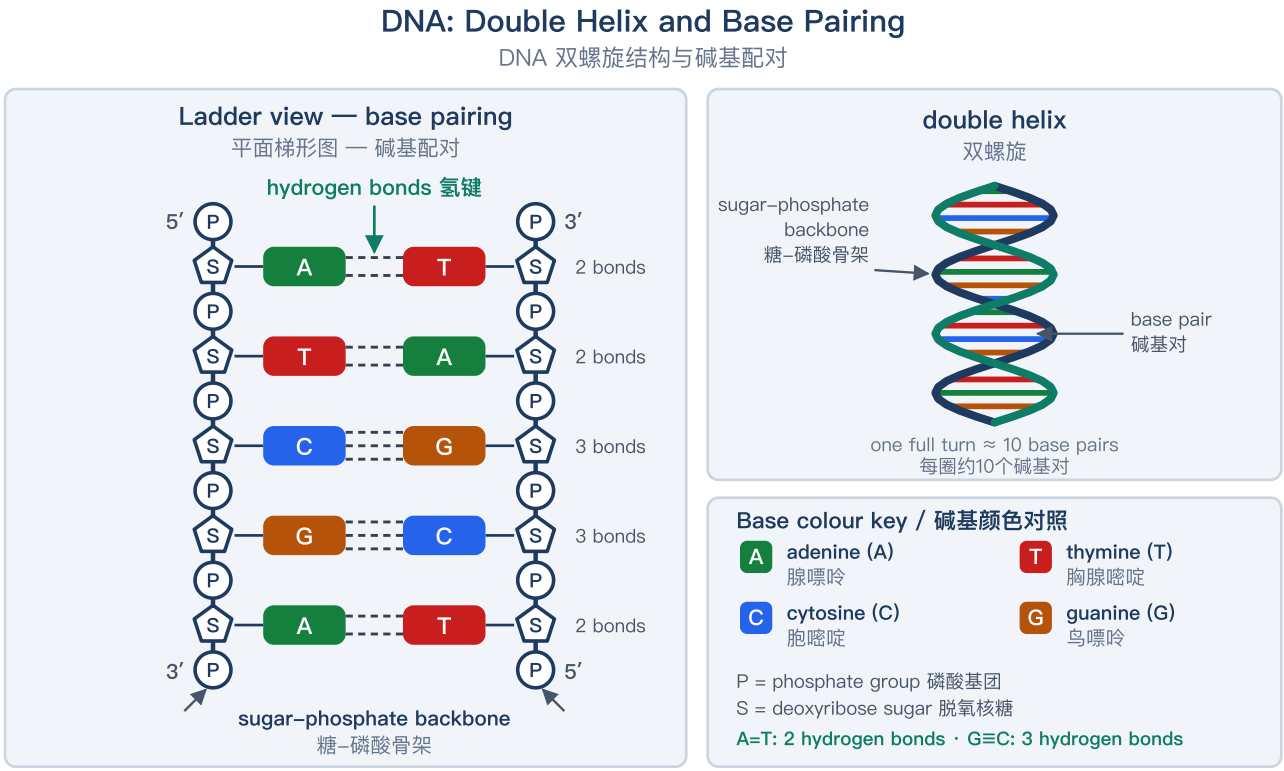
DNA 的四种碱基：嘌呤 A 和 G 是较大的双环分子，嘧啶 C 和 T 是较小的单环分子；A 总是与 T 配对（2 个氢键），C 总是与 G 配对（3 个氢键）。

Base pairing and the double helix

碱基配对与双螺旋

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.

> 真正的 DNA 分子是两条链，不是一条。两条链并排贴在一起，骨架在外侧，碱基朝内彼此相对。把两条链连在一起的正是碱基，而且遵循一条固定的原则——碱基互补配对原则 (complementary base pairing)：腺嘌呤总是与胸腺嘧啶配对（A—T），胞嘧啶总是与鸟嘌呤配对（C—G），绝无其他组合。这里要停一下，因为这是整个课题里最有用的一条：只要知道一条链的碱基顺序，就能准确推出另一条链。一条链是 A—T—G—C，对面必然是 T—A—C—G。注意，两条链不是“相同”，而是“互补 (complementary)”，彼此是对方的镜像记录——这正是精确复制得以可能的原因。



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.

DNA 结构：左侧梯形图展示两条反向平行的糖–磷酸骨架，A–T 之间为两个氢键、C–G 之间为三个氢键；右侧为双螺旋形态。

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.

> 碱基对之间靠氢键 (hydrogen bond) 相连，而 NESA 风格的题目要的就是数字：A 与 T 之间是 2 个氢键，C 与 G 之间是 3 个氢键。单个氢键很弱，比每条骨架上的共价键弱得多；但一个 DNA 分子有几百万个碱基对，几百万个弱键加在一起，就把两条链牢牢地拉住了。这套“强弱搭配”是这个结构里最巧妙的地方，值得在笔记上写成一整句：两条链之间靠大量弱氢键相连，这些氢键可以一个一个地被打断；而每条链自身靠强共价键连接，这些键始终不会断。这正是 DNA 能从中间像拉链一样被拉开、而两条链本身不会散架的原因——这也是“拉链”比喻好用的地方。

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.

> 最后，整个分子是拧着的。两条链互相缠绕成螺旋形，叫双螺旋 (double helix)。这就是沃森 (Watson) 和克里克 (Crick) 在 1953 年发表的模型，其依据是 Rosalind Franklin 与 Maurice Wilkins 拍摄的 X 射线衍射图。两条链的走向彼此相反，这个术语叫反向平行 (antiparallel)——11 年级只要求你说出这个词，不要求解释原因。由于配对规则是固定的，螺旋从头到尾粗细一致，就像每级台阶长度都相同的旋转楼梯。“拧过的梯子”这个比喻可以一直用：两条磷酸—脱氧核糖骨架是梯子的两根边框，每一个碱基对是一根横档。但要清楚它在哪里失效：真梯子的横档是一整根实木，而 DNA 的每根“横档”其实是两根半截横档拼起来的，中间只靠两三个氢键连着（A—T 两个，C—G 三个）——正因为如此，这个分子才打得开。

KEY TERMS · 关键术语

complementary base pairing 碱基互补配对原则

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

固定原则：腺嘌呤只与胸腺嘧啶配对，胞嘧啶只与鸟嘌呤配对；因此一条链就决定了另一条链的顺序。

hydrogen bond 氢键

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.

把配对碱基连在一起的弱键：A—T 之间 2 个，C—G 之间 3 个。数量多才拉得住两条链，但每个都可以被单独打断。

double helix 双螺旋

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

DNA 的三维形状：两条链互相缠绕成粗细一致的螺旋。

antiparallel 反向平行

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

形容 DNA 的两条链走向彼此相反。

⚠ COMMON MISTAKE

Unzipping breaks hydrogen bonds, not the backbone

“拉开”断的是氢键，不是骨架

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.

> 有两个错误年年被扣分。第一，写成“两条链是通过打断磷酸—脱氧核糖骨架分开的”——不是；骨架是共价键、保持完整，断开的只是配对碱基之间的氢键。第二，把 A 与 G、C 与 T 配对——不存在这种配对。另外别说碱基对之间是共价键：核苷酸“内部”是共价键，配对碱基“之间”是氢键。

⬡ EXTENSION

Extension: purines, pyrimidines and constant width 拓展：嘌呤、嘧啶与恒定的宽度

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.

> 四种碱基分两种大小：腺嘌呤 (A) 和鸟嘌呤 (G) 是嘌呤 (purine)，是较大的双环分子；胞嘧啶 (C) 和胸腺嘧啶 (T) 是嘧啶 (pyrimidine)，是较小的单环分子。因为 A—T 和 C—G 都是“一个大嘌呤配一个小嘧啶”，每根横档的总长度都相同，所以双螺旋从头到尾宽度恒定（约 2 纳米）。若两个嘌呤配对，螺旋会鼓出来；若两个嘧啶配对，则会瘪进去。不过大小只解释了一半。腺嘌呤 (A) 和胞嘧啶 (C) 也是“一大一小”，却从不配对。碱基能否配对，取决于它们上面形成氢键的位点能否对上——只有 A 与 T、C 与 G 的氢键位点是完全对齐的。所以：大小解释了螺旋宽度为什么恒定，氢键解释了配对为什么只有这两种。

⬡ EXTENSION

Extension: what antiparallel actually means 拓展：反向平行到底是什么意思

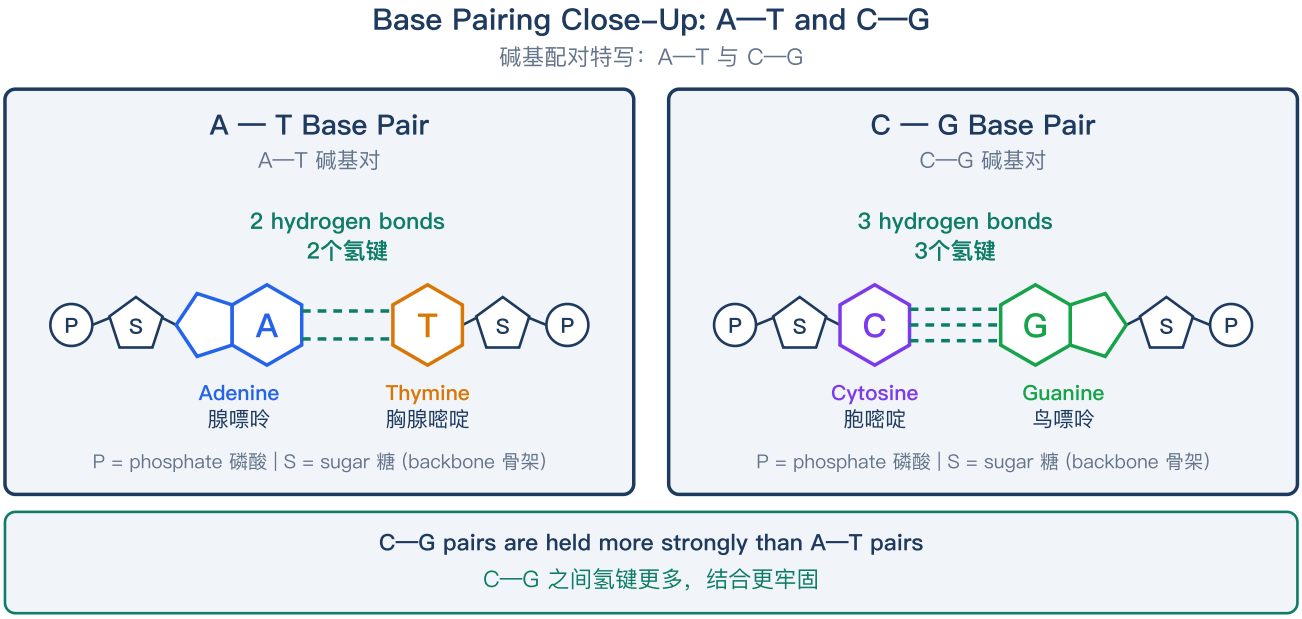
Each strand has two chemically different ends, labelled 5 prime and 3 prime. In a double helix the 5 prime end of one strand lines up with the 3 prime end of the other, so the strands run in opposite directions — like the two carriageways of a divided highway. For Year 11 you state that the strands are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

> 每条链有两个化学性质不同的末端，标作 5' 端和 3' 端。在双螺旋中，一条链的 5' 端对着另一条链的 3' 端，所以两条链方向相反——像高速公路的上下行两条车道。11 年级只需说出“两条链是反向平行 (antiparallel) 的”即可；复制过程中 5' 到 3' 的那套机制属于 12 年级内容。

EXAMPLE Think of a shell pressed into wet sand 想象把贝壳按进湿沙里

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.

> 把贝壳按进湿沙里再拿开：留下的不是另一枚贝壳，贝壳上凸起的地方在沙里变成凹的，凹的变成凸的。它是「反的」，却保留了贝壳的全部细节——光凭沙印就能从一堆贝壳里认出原来那一枚。这就是「互补(complementary)」的意思。A—T—G—C 对面那条链不是 A—T—G—C，而是 T—A—C—G，每个碱基都换成它唯一固定的搭档。两条链彼此相反，却载有同样的信息，所以知道一条就能精确推出另一条。比喻失效之处：沙印会糊掉、而且只记录一次；碱基配对却是精确且双向的，任何一条链都能逐个字母确定另一条。另外，沙印毕竟是沙、不是贝壳；而 DNA 的两条链都是同样的 DNA，没有哪一条是「正版」、另一条只是它的印痕。



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.

DNA 两种碱基对特写：A—T 由两个氢键相连，C—G 由三个氢键相连，每个碱基外侧都连着骨架上的糖和磷酸。

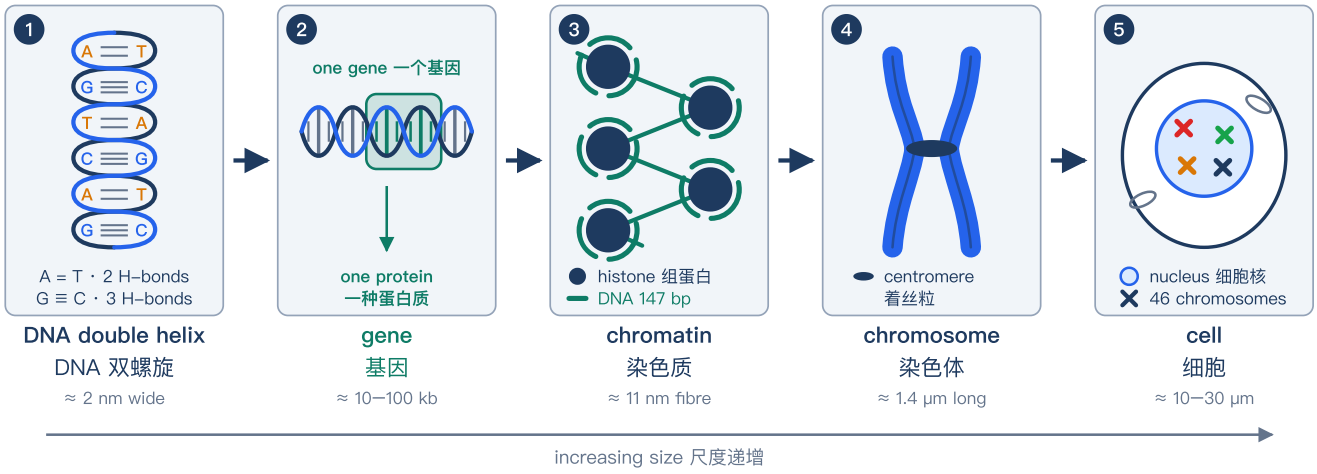
From base pair to genome: getting the sizes in order

从碱基对到基因组：把尺度排好序

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.

> 这一段是“本来能拿、却常常丢掉”的分数所在，因为很多同学把 DNA、基因 (gene)、染色体 (chromosome) 当成可以随便替换的词。它们既不能互换，也不是三种不同的物质——而是同一种物质在不同尺度上的名称。你必须能把它们从小到大排序，并说清每一层和上一层的关系。先用“菜谱书”这个画面：一个个字母是碱基，一道菜谱是一个基因，一整本书是一条染色体，书架上整套书就是基因组 (genome)。这个画面用来排序非常好用，但别推得太远——菜谱书是一页一道、从头读到尾，而细胞在任何时刻只读它需要的那几个基因，其余的都不理会。



The size hierarchy of genetic material: DNA double helix to gene, chromatin, chromosome and finally the cell nucleus.
遗传物质的尺度层级：DNA 双螺旋 → 基因 → 染色质 → 染色体 → 细胞核。

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.

> 现在用真正的术语，从小到大。碱基对 (base pair) 就是梯子的一根横档：两个碱基靠氢键相连。基因 (gene) 是一段 DNA——通常几百到几千个碱基对长——携带制造一种蛋白质的指令（本阶段按“一个基因对应一种蛋白质”处理）。DNA 分子是一条极长的双螺旋，上面沿途排着许多基因。

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.

> 多数时候，这条分子并不是课本上那种整齐的 X 形染色体。它缠绕在包装蛋白（组蛋白 histone）上，以染色质 (chromatin) 的形式存在：细长、缠绕的丝状物，散布在整个细胞核中——这才是 DNA 在细胞一生中大部分时间的样子。只有当细胞准备分裂时，染色质才高度螺旋化、缩短变粗，形成染色体 (chromosome)，短而粗，在光学显微镜下才看得见。基因组 (genome) 是一个细胞或一个生物体内全部 DNA 的总和。每一层都包在更大的一层里：碱基对组成基因，基因排在 DNA 分子上，DNA 分子被包装成染色体，染色体在细胞核里，细胞核在细胞里。

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.

> 用几个数字来固定尺度感。人的一个体细胞 (somatic cell) 含 46 条染色体，排成 23 对，这就是我们说这个细胞是二倍体 (diploid) 的意思。注意“体细胞”三个字。卵细胞和精子不是二倍体，而是单倍体 (haploid)，只有 23 条染色体，每一对里各取一条。所以“人的每个细胞都有 46 条染色体”是错的——是每个体细胞才有 46 条。单倍体细胞怎么来的，是后面的课题。完整的一套——人类基因组——约有 30 亿个碱基对，携带大约 2 万个编码蛋白质的基因；一个体细胞里有两套，加起来就是前面说的约两米长的 DNA，全部折叠进只有几微米宽的细胞核。所以当考题问“基因在哪里”，满分答案是顺着层级往下说：基因是 DNA 分子上的一段，这条 DNA 分子与蛋白质一起包装成染色体，染色体在细胞核内，细胞核在细胞内。把这一串层级关系大声念到脱口而出为止。

KEY TERMS · 关键术语

gene 基因

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).

一段由几百至几千个碱基对组成的 DNA，携带制造一种蛋白质的指令（本阶段按“一个基因对应一种蛋白质”处理）。

chromatin 染色质

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

DNA 缠绕在包装蛋白（组蛋白 histone）上、尚未高度螺旋化时的常态形式：细长的丝状物，散布在细胞核中。

chromosome 染色体

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

一条长 DNA 分子与蛋白质一起包装成的结构；细胞分裂前染色质高度螺旋化、缩短变粗，在显微镜下才可见。

genome 基因组

The complete set of DNA in a cell or organism.

一个细胞或一个生物体内全部 DNA 的总和。

diploid 二倍体

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

含有两套完整染色体（分别来自双亲）的状态；人的体细胞是二倍体，共 46 条染色体（23 对）。

haploid 单倍体

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

只含一套完整染色体的状态；人的配子（卵细胞和精子）是单倍体，含 23 条染色体。

⚠ COMMON MISTAKE **A chromosome is not always X-shaped 染色体并不总是 X 形**

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.

> 课本上 X 形的图出现得太多，很多同学就以为 DNA 一直长那样。并不是。细胞一生的大部分时间里，DNA 是染色质 (chromatin)——细长、尚未螺旋化缩短、单条根本看不见。染色体只有在分裂前高度螺旋化、缩短变粗时才可见；而且未复制的染色体是一根单丝，不是 X 形。X 形只有在 DNA 被复制之后才出现。那两个半边叫姐妹染色单体 (sister chromatid)、在着丝粒 (centromere) 处相连——后面的课再讲。

✦ TIP **Say the ladder of sizes out loud** 把尺度阶梯念出声

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.

> 念：碱基对 → 基因 → DNA 分子 → 染色质 → 染色体（高度螺旋化、缩短变粗后）→ 基因组。六级，顺序固定。然后接上“容器”：染色体在细胞核里，细胞核在细胞里。能在几秒内背出来，这一层次的排序题和填图题就都能拿分。

⚑ IN THE EXAM **Distinguish between a gene and a chromosome** 考点：区分基因与染色体

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.

> Distinguish（区分）要求给出明确的差异点。满分答案要点出二者的关系，而不是分别下两个定义：基因是 DNA 上编码一种蛋白质的一小段，而 (whereas) 染色体是一整条与蛋白质包装在一起、携带许多基因的 DNA 分子。那个 whereas 是真起作用的——写答案时要用。

◈ EXAMPLE **Think of a charging cable wound up before a flight** 想象出门前把充电线绕成一小捆

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.

> 充电线丢在包里时，是一根又细又长、缠住所有东西、根本理不清头尾的线；出门前把它缠成一小捆，就变成又短又粗、一眼看得全、也不会勾住别的东西。没有加线，也没有剪断——同一根线、里面的铜线一分不多一分不少，只是被收拢进小得多的空间。染色质 (chromatin) 与染色体 (chromosome) 的区别正是如此：同一份 DNA 的两种状态，不是两种物质、也不是分别存在于两种细胞里。只有当细胞准备分裂时，染色质才高度螺旋化、缩短变粗，在光学显微镜下可见，也便于整齐地被分开搬动。比喻失效之处：绕好的线圈里面是空的，而 DNA 即使在松散的染色质状态下，也早已缠绕在组蛋白 (histone) 这类包装蛋白上；高度螺旋化只是把这条「已经缠着组蛋白的丝」再进一步盘绕折叠，并不是这时才把组蛋白加上去。

How to answer your worksheet boxes

你的学案空格该怎么填

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.

> 你课上学案里有一个标着 DNA 的方框，提示写着它由“NUCLEOTIDES（核苷酸）”构成。这种框要的是紧凑的定义，不是作文，而分数就落在几个具体的词上。写成接近这样：DNA（脱氧核糖核酸）是储存制造蛋白质的遗传指令的分子。它是由重复单位——核苷酸 (nucleotide)——构成的多聚体。每个核苷酸由一个磷酸基团、一个脱氧核糖和四种含氮碱基之一（A、T、C 或 G）组成。核苷酸连成两条链，外侧是磷酸—脱氧核糖骨架，两条链拧成双螺旋。四句话，涵盖了功能、单体名称、三个组成部分、四种碱基和整体形状——阅卷老师想找的点全在里面。

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.

> 第二个框标着 BASE PAIRING（碱基配对），提示说两条链靠碱基配对连在一起。这里要当心：大多数同学就停在这句提示上，而停在这里就拿不到分。要写成：两条链靠碱基互补配对原则 (complementary base pairing) 连在一起。腺嘌呤总是与胸腺嘧啶配对（A—T），胞嘧啶总是与鸟嘌呤配对（C—G）。每一对由弱氢键 (hydrogen bond) 相连——A 与 T 之间 2 个，C 与 G 之间 3 个。这样的氢键有几百万个，合起来把双螺旋牢牢拉住；但因为每个都很弱，可以被打断，两条链就能分开。注意这比提示多了什么：原则的名称、两组具体配对、键的种类、数目，以及“弱但多”这一点。只写 held together by base pairing，等于把题目原样抄回去。

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.

今晚用两个习惯把它们固定下来。第一，把上面两段范文遮住，凭记忆默写，然后逐字对照，把漏掉的圈出来——漏掉的几乎总是那些术语（核苷酸、互补、氢键、骨架）。第二，把配对规则练成条件反射：随手写一条链，比如 T—A—C—G—G—A—T—C，写出它的互补链，再逐个字母检查。如果两个学案框都能默写出来、互补链也能不假思索地写完，Day 1 就过关了。最后提醒一个措辞陷阱：绝不能说“两条链靠骨架连在一起”。骨架是沿着每一条链各自延伸、把那一条链连成整体的；把两条链彼此拉在一起的是碱基配对。

IN THE EXAM **The verb ladder for this topic** 这一课题的动词阶梯

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.

> Identify（识别）核苷酸的组成部分——只需说出名称，别的不写。Describe（描述）DNA 的结构——有条理地给出特征（单体、骨架、配对、螺旋），不需要因果推理。Explain（解释）为什么 DNA 能被拉开而不断裂——这时必须用 because / so that / therefore 把因果串起来。同样的知识，三种不同的答法。动笔前先看清动词。

TIP **Write structure answers in the same fixed order** 结构题一律按同一个固定顺序写

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.

> 永远按“由内到外、由小到大”的固定顺序写：核苷酸（三个部分）→ 单链与磷酸—脱氧核糖骨架 → 碱基配对与氢键 → 双螺旋。每次都用同一个顺序，考试紧张时就不会漏掉某一部分，阅卷老师也能一眼找到每个得分点。

COMMON MISTAKE **Do not answer with the analogy alone** 不要只用比喻来作答

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.

> “拧过的梯子”“拉链”是学习工具，不是答案。写成“DNA 像一把拧过的梯子，像拉链一样拉开”几乎得不到分。落笔前要把每个比喻换成术语：边框 → 磷酸—脱氧核糖骨架；横档 → 碱基对；拉开 → 互补碱基之间的氢键被打断。

DAY 1 RECAP · 本日要点回顾

- DNA stores the genetic instructions for making proteins, and it is a polymer built from repeating nucleotides.
  DNA 储存制造蛋白质的遗传指令；它是由核苷酸 (nucleotide) 重复连接而成的多聚体。
- One nucleotide = a phosphate group + a deoxyribose sugar + one nitrogenous base (A, T, C or G), with the sugar in the middle.
  一个核苷酸 = 磷酸基团 + 脱氧核糖 + 一个含氮碱基（A、T、C 或 G），糖在中间做连接件。
- 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.
  核苷酸之间以“糖—磷酸”的强共价键相连，形成每条链外侧的磷酸—脱氧核糖骨架，碱基朝内伸出。
- 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.
  碱基互补配对原则是固定的：A 总配 T（2 个氢键），C 总配 G（3 个氢键）；因此一条链就精确决定了另一条链。
- 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.
  氢键单个很弱，但数量有几百万个：所以双螺旋既被牢牢拉住，又能在碱基处被“拉开”，而两条骨架都不会断。
- The two strands wind into a double helix, run in opposite directions (antiparallel) and keep a constant width all the way along.
  两条链缠绕成双螺旋，走向彼此相反（反向平行 antiparallel），而且从头到尾粗细恒定。
- 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.
  要背熟的尺度顺序：碱基对 → 基因 → DNA 分子 → 染色质 → 染色体（高度螺旋化、缩短变粗后）→ 基因组；染色体在细胞核内，人的体细胞是二倍体、含 46 条染色体（23 对），而配子是单倍体、含 23 条。

Check Yourself — Day 1

自我检测 · 第 1 天（先合上笔记独立作答）

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 · 答案与解析

Write your answer out first. A question you have read the answer to is not practice.
先自己写完再对答案，看过答案就不算练习了。

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

DNA 储存制造蛋白质的遗传指令；在真核细胞中几乎全部位于细胞核内（线粒体、植物叶绿体中另有少量）。选项 B 功能说对了，却把 DNA 放到细胞膜上；加速反应是酶的工作（选项 C）、运氧是血红蛋白的工作（选项 D）——它们都是按 DNA 的指令造出来的蛋白质。

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

正确答案是“磷酸基团 + 脱氧核糖 + 一个含氮碱基”。每个核苷酸只带一个碱基（选项 B 错在写成两个）；选项 C 只是三种碱基的名字，碱基仅是核苷酸的一部分；选项 D 混淆了层次——骨架、氢键、碱基对都是由许多核苷酸组装后才出现的结构。糖在中间，一边连磷酸、一边连碱基。

3. b) T–C–G–A–A–G

答案是 T—C—G—A—A—G。逐个碱基套规则：A 配 T，G 配 C，C 配 G，T 配 A，T 配 A，C 配 G。选项 A 是把原链照抄（错误观念：两条链“相同”，其实是互补 complementary）；选项 C 是错误地按 A 配 G、C 配 T 来配；选项 D 是把正确答案倒着写——由于两条链反向平行，如果按另一条链自己的方向读确实是 G—A—A—G—C—T，但本题要求按相同的左右顺序作答，所以选 B。写完一定要逐个字母核对。

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

正确答案是 C。选项 A 把两种键完全弄反了（骨架是共价键，碱基对之间是氢键）；选项 B 忽略了 C—G 是 3 个氢键；选项 D 是最常见的错误——骨架只是把“同一条链”连起来，把“两条链”彼此拉住的是碱基之间的氢键。

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

正确顺序是：碱基对 → 基因 → DNA 分子 → 染色体 → 基因组。其余选项各有各的错：选项 A 把基因排在碱基对之前（基因由几百上千个碱基对组成，不可能比碱基对小）；选项 B 把 DNA 分子排在基因之前（基因只是 DNA 分子上的一段）；选项 C 把基因组塞在中间、又把 DNA 分子放到最后（基因组是全部 DNA 的总和，应排在最上面）。只有选项 D 五级全对：碱基对组成基因，许多基因排在一条 DNA 分子上，这条分子与蛋白质包装成染色体，全部 DNA 合起来就是基因组。

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

断的是配对碱基之间的氢键 (hydrogen bond)。磷酸—脱氧核糖骨架上的共价键保持完整，所以每条链分开后仍是完整的一条，还能作为碱基顺序的完整记录。选项 A 是最常被扣分的错误观念；选项 B 会把碱基从自己的糖上扯下来，破坏核苷酸；选项 D 会把分子拆散，那样就没有可用的模板了。

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.

答案要点按固定顺序写：①DNA 是由核苷酸 (nucleotide) 重复连接成的多聚体；②每个核苷酸 = 磷酸基团 + 脱氧核糖 + 一个含氮碱基（A、T、C 或 G）；③前一个核苷酸的糖与后一个的磷酸以强共价键相连，形成外侧的磷酸—脱氧核糖骨架，碱基朝内；④两条链靠碱基互补配对原则连在一起：A—T（2 个氢键）、C—G（3 个氢键）；⑤两条链方向相反（反向平行 antiparallel），拧成粗细一致的双螺旋 (double helix)。注意题目动词是 Describe（描述），只需给出特征，不必解释原因。

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.

这是 Explain（解释），必须写出因果链，句句相扣：①氢键很弱，可以被一个一个打断、耗能很少，所以两条链能被分开（双螺旋能“拉开”），DNA 里的信息才能被读取和复制；②与此同时，每条链自身的磷酸—脱氧核糖骨架是强共价键，因此分开时链本身不会断，每条链都还是完整的碱基顺序记录；③一条 DNA 上有几百万个氢键，数量多，所以平时又能把双螺旋牢牢拉住；④反过来说，如果两条链之间是共价键，要分开就得把分子打碎，DNA 就无法被复制。

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.

Distinguish（区分）要求给出明确的差异点，并点出二者关系：基因 (gene) 是 DNA 分子上较短的一段（几百至几千个碱基对），携带制造一种蛋白质的指令；而 (whereas) 染色体 (chromosome) 是一整条与蛋白质包装在一起的 DNA 分子，上面沿途排列着许多基因。二者不是两种不同的物质——基因位于染色体上，染色体是包含许多基因的更大结构。

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.

每个核苷酸画成三个形状：磷酸基团接在脱氧核糖的一边，含氮碱基接在另一边。第一个核苷酸的糖与第二个核苷酸的磷酸相连；把“磷酸—糖—磷酸—糖”这条线标为磷酸—脱氧核糖骨架。两个碱基都朝同一侧、从骨架上伸出来。

DAY 2

about 65 min · 约 65 分钟

The Cell Cycle and Interphase

细胞周期与间期

THE BIG IDEA · 核心观念

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.

细胞不能说分就分、碰运气分成两半：它必须先经历一个漫长而忙碌的（分裂）间期 (interphase)——在 G1 期（第一间隙期）长大、在 S 期（合成期）完成 DNA 复制、在 G2 期（第二间隙期）检查并做准备。原因很简单：有丝分裂 (mitosis) 只能把「已经存在的两份拷贝」分开，它本身不会「造」出新的遗传物质，所以复制必须在分裂开始之前就全部完成。

BY THE END OF TODAY YOU WILL BE ABLE TO · 今天学完你将能够

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.
   解释 (Explain) 细胞为什么要分裂，要讲到生长、修复与更新，以及表面积与体积比 (surface area to volume ratio) 对细胞体积设下的上限。
2. Outline the cell cycle as a repeating sequence of interphase (G1, S and G2) followed by M phase (mitosis and cytokinesis).
   概述 (Outline) 细胞周期 (cell cycle)：（分裂）间期（G1 期 → S 期 → G2 期）之后进入 M 期（分裂期），M 期 = 有丝分裂 (mitosis) + 胞质分裂 (cytokinesis)，并且不断循环。
3. Describe the events of G1, S and G2, and state in which sub-phase DNA is replicated.
   描述 (Describe) G1、S、G2 三个亚期各自发生了什么，并说出 DNA 复制 (DNA replication) 究竟发生在哪一期（S 期）。
4. Justify why DNA replication must be completed during interphase, before mitosis begins.
   论证 (Justify) 为什么 DNA 复制必须在（分裂）间期内、在有丝分裂开始之前就全部完成。
5. Interpret a cell cycle diagram or a set of phase durations, and calculate the percentage of the cycle spent in interphase.
   解读 (Interpret) 细胞周期图或给定的各时期时长数据，并计算 (Calculate) 间期占整个细胞周期的百分比。
6. Distinguish between the cell cycle and mitosis, and between a chromosome before and after S phase.
   区分 (Distinguish)「细胞周期」与「有丝分裂」这两个概念，以及一条染色体在 S 期前后的不同形态：S 期前是一条 DNA 细丝，S 期后由两条姐妹染色单体组成。

Why cells divide at all

细胞为什么非分裂不可

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.

> 在学细胞周期的具体步骤之前，先要知道「为什么要有这个周期」。细胞分裂有三个理由，你要能脱口而出：第一是生长——你最初只是一个受精卵，现在由数以万亿计的细胞构成，靠的就是细胞一次又一次地分裂。请注意：生物体长大主要靠「细胞数量变多」，而不是把原有的细胞吹得越来越大。第二是修复与更新（组织修复 tissue repair）：受损的组织会重新长好，用旧了的细胞会由新细胞替换掉。第三是无性生殖 (asexual reproduction)：仅靠一个亲本的细胞分裂就产生一个全新的个体——例如酵母和水螅的出芽生殖，或草莓长出匍匐茎繁殖新植株。考试里问得最多的是前两个；这三点在后面讲有丝分裂的作用时还会展开细讲。

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.

> 最容易被忽视的是「修复与更新」，因为大家总以为长大以后细胞就不分裂了。并非如此。你皮肤最外层的细胞每天都在脱落，由表皮深层不断分裂的细胞补上；肠道内壁的细胞每隔几天就整批更新一次，因为消化过程对它们的化学侵蚀太厉害；成熟的红细胞根本没有细胞核 (nucleus)、完全不能分裂，所以新的红细胞是由骨髓里的前体细胞分裂产生的。伤口愈合其实就是同一个过程集中发生在一个地方：切口边缘的细胞不断分裂，直到把缺口填满。就在你读这句话的此刻，你体内有数以百万计的细胞正处在细胞周期的某一步。

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.

于是有个很自然的问题：既然要长大，为什么不让一个细胞一直变大，非要分裂？限制来自几何学。细胞需要的一切（氧气、葡萄糖）和必须排掉的一切（二氧化碳、代谢废物）都要穿过细胞膜，所以「表面积」就是这个细胞的供给线，而内部细胞质的「体积」就是需求量。细胞一变大，体积增长的速度比表面积快，于是表面积与体积比（surface area to volume ratio）下降，平均每单位细胞质能分到的膜面积越来越少；同时从细胞膜到细胞中心的距离也变远，而距离越长，扩散就越慢。超过一定大小，细胞就真的供不起自己的内部了。所以它不再继续变大，而是分裂——分成两个较小的子细胞（daughter cell），各自又重新拥有比较有利的表面积与体积比。

KEY TERMS · 关键术语

surface area to volume ratio 表面积与体积比

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.

细胞外表面积与其内部细胞质体积之比；细胞越大这个比值越小，因而限制了细胞能长到多大。

tissue repair 组织修复

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

通过细胞分裂替换受损或老化的细胞，例如伤口愈合、皮肤更新和肠道内壁更新。

asexual reproduction 无性生殖

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.

仅由一个亲本通过细胞分裂产生新个体，不需要配子和受精；后代与亲本的遗传物质完全相同。例如酵母和水螅的出芽生殖、草莓靠匍匐茎繁殖。

EXTENSION **Extension: do the cube arithmetic yourself 拓展：亲手算一遍立方体**

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.

把细胞想成一个立方体来算。边长 1 cm：表面积 = 6 个面 × 1 cm2 = 6 cm2，体积 = 1 cm3，比值 6:1。边长翻倍到 2 cm：表面积 = 24 cm2，体积 = 8 cm3，比值只剩 3:1。边长 3 cm：54 cm2 对 27 cm3，比值 2:1。可见供给（表面积）完全跟不上需求（体积）。真实细胞当然不是立方体，有些细胞靠把自己压扁、或长出许多分支来增大表面积，从而绕开这个问题，但这套算术正好解释了为什么绝大多数细胞都保持在显微尺度、宁可分裂也不一味长大。

⚠ COMMON MISTAKE

Cell division is not only for growing children

误区：以为只有小孩长身体时才有细胞分裂

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.

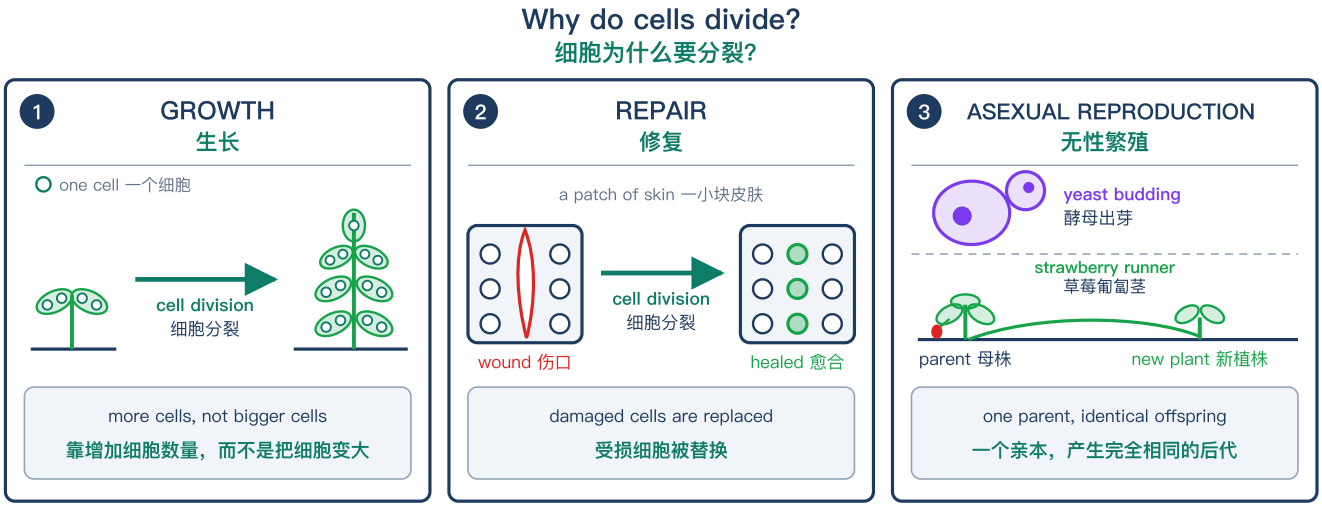
> 很多同学写「细胞分裂发生在生物体生长的时候」，好像成年人的细胞就不分裂了。其实成年人体内的皮肤、肠道内壁、血细胞终生都在持续更新，伤口愈合任何年龄都会发生。题目问细胞分裂的作用时，只写「生长」只答对了一部分，必须同时写出「更新与修复」。

◈ EXAMPLE

Think of a thick hot chip 想想一根很粗的薯条

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.

> 用薯条打比方讲表面积与体积比。细薯条能熟透，粗薯角外面焦了里面还是生的：因为热量只能从表面进去，再往里传。细胞是同一个道理，而且有两层：一，细胞需要的一切都要穿过细胞膜 (cell surface membrane)，所以表面积＝供给线，内部细胞质的体积＝需求量；薯角越粗，体积增长比表面积快，表面积与体积比 (SA:V) 就下降。二，距离问题：越粗，中心离表面越远，而扩散距离越长越慢。类比的边界（必须点明）：薯角在烤箱里多烤一会儿，中心总归会熟；但细胞不能靠「多等一会儿」解决问题——它对氧气和葡萄糖的需求一刻不停，废物也在不断产生，所以穿过细胞膜的供给必须持续跟上，而不是「迟早补上」。另外，薯角没法把自己变成两根细薯条，而细胞恰恰就是这么做的——不再长大，而是分裂。



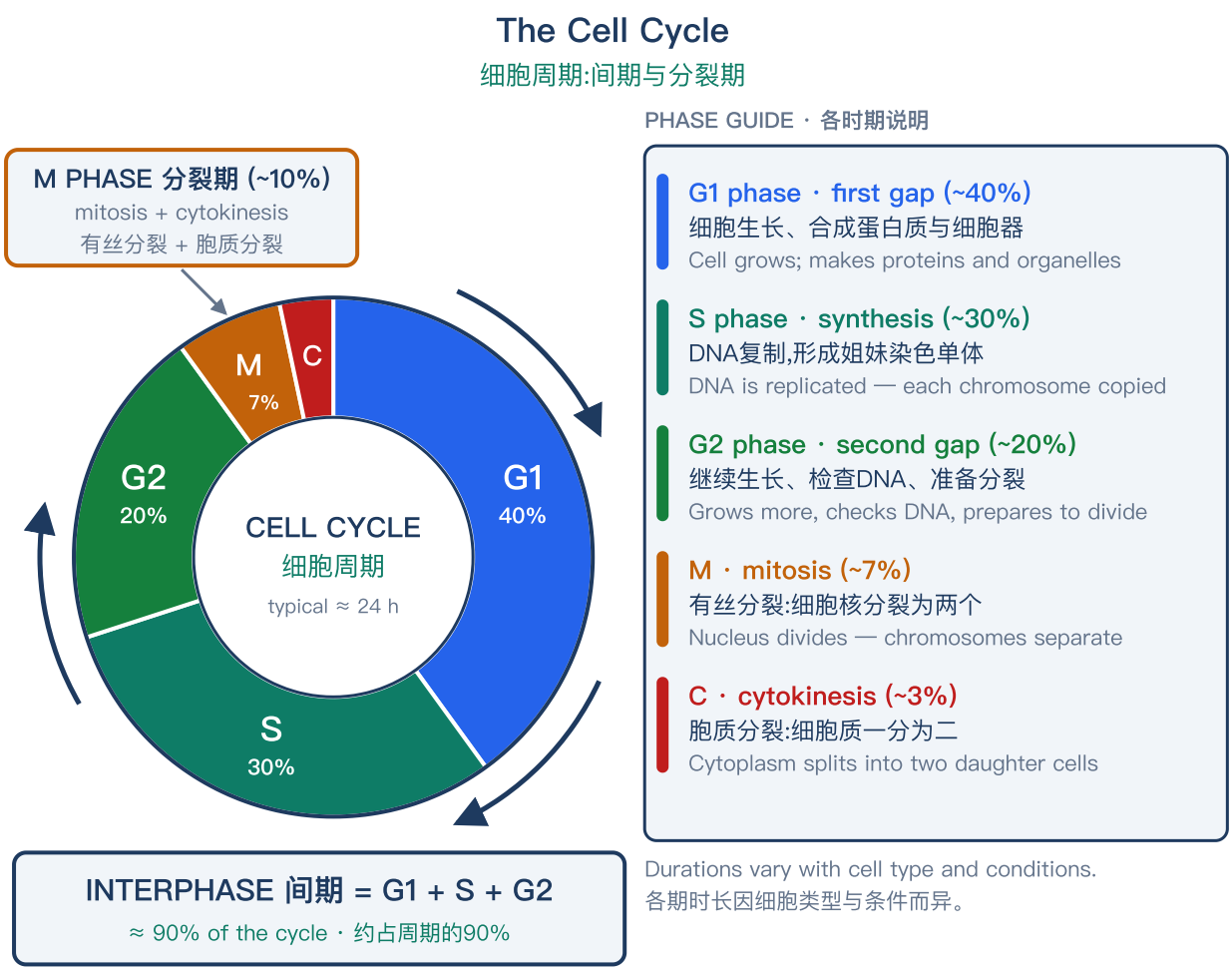
Cells divide for three reasons: to grow, to repair damage, and to reproduce asexually.
细胞分裂的三个原因：生长、修复受损组织，以及无性繁殖。

The cell cycle: one loop with two very unequal parts

细胞周期：一个循环，两个长短悬殊的部分

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.

> 细胞周期 (cell cycle) 指的是：从一个细胞刚刚形成，到它自己分裂成两个细胞为止，按固定顺序不断重复的一整套事件。它分两大部分，这里的用词一定要准，全年都在考。第一部分是（分裂）间期 (interphase)，内部又按顺序分成三个亚期：G1 期（第一间隙期）、S 期（合成期）、G2 期（第二间隙期）。第二部分是 M 期（分裂期），它由两步组成：先是有丝分裂 (mitosis)，也就是细胞核的分裂；紧接着是胞质分裂 (cytokinesis)，把细胞质分开，形成两个独立的细胞。请特别注意这句话没说的部分：间期不是有丝分裂的一个时期，它是排在有丝分裂之前的那一段细胞周期。有丝分裂本身只有四个时期，第 4 天再讲。



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.

细胞周期:漫长的间期(G1、S、G2,约占周期的90%)之后是短暂的分裂期(有丝分裂与胞质分裂),按顺时针方向循环进行。

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.

> 现在看图，并且注意各个扇形的大小——那不是随便画的。你会遇到的绝大多数细胞里，间期占整个周期约 90% 甚至更多。课本上常用的例子是实验室培养的快速分裂的人体细胞：一个完整周期约 24 小时，其中 M 期大约只有 1 小时，其余全是间期。不同资料给出的具体比例略有差别，所以答题时一律以题目给的数据为准，不要背死一个百分比。课堂上之所以花大量时间讲有丝分裂，是因为它有一堆需要背的时期名称和图，这反而让同学在时间感上产生严重错觉。从时间上看，有丝分裂只是漫长准备之后那个短暂的收尾动作，而不是细胞一生中的主戏。

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.

> 这张图还有两点要抓住。第一，它是个「循环」：箭头绕一整圈——胞质分裂产生的两个子细胞各自从自己的 G1 期重新开始，整套流程再来一遍。第二，周期的长度不是固定的，不同细胞类型、不同生物之间差别极大：人体肠道内壁的细胞大约一天分裂一次，而有些细胞可能几个月甚至几年才分裂一次。碰到 Construct / Label（画图并标注）的题目，请这样画：间期画成很大的一段弧，按 G1 → S → G2 的顺序细分；M 期画成很窄的一块，再细分成有丝分裂和胞质分裂；并在 S 期旁边写上「DNA replication」。分数就落在这些标注上。

KEY TERMS · 关键术语

cell cycle 细胞周期

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.

从一个细胞形成到它分裂成两个子细胞为止、按顺序不断重复的一整套事件；由（分裂）间期和 M 期（分裂期）组成。

interphase （分裂）间期

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

细胞周期中位于 M 期之前的部分，包含 G1、S、G2 三个亚期；它是周期中最长、代谢最活跃的一段。

M phase M 期（分裂期）

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

细胞周期中负责分裂的部分：先是有丝分裂（细胞核分裂），随后是胞质分裂（细胞质分开）。

mitosis 有丝分裂

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

细胞核的分裂：把每条染色体的两条姐妹染色单体分开，形成两个完全相同的细胞核。

cytokinesis 胞质分裂

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

有丝分裂之后把细胞质分开的过程，最终形成两个独立的子细胞。

⚠ COMMON MISTAKE **Interphase is a phase of the CELL CYCLE, not a phase of mitosis** 误区：把间期当成有丝分裂的一个时期

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.

> 非常常见的错误是把间期当成有丝分裂的「第五个时期」，和前期、中期、后期、末期并列。有丝分裂只有四个时期，没有第五个。间期属于细胞周期，而且在前期 (prophase) 开始之前就已经结束了。如果题目问「有丝分裂有哪几个时期」而你把间期写进去，等于直接告诉阅卷老师你把这两个概念搞混了。

⚠ COMMON MISTAKE **Do not read the pie diagram backwards** 误区：把细胞周期饼图读反了

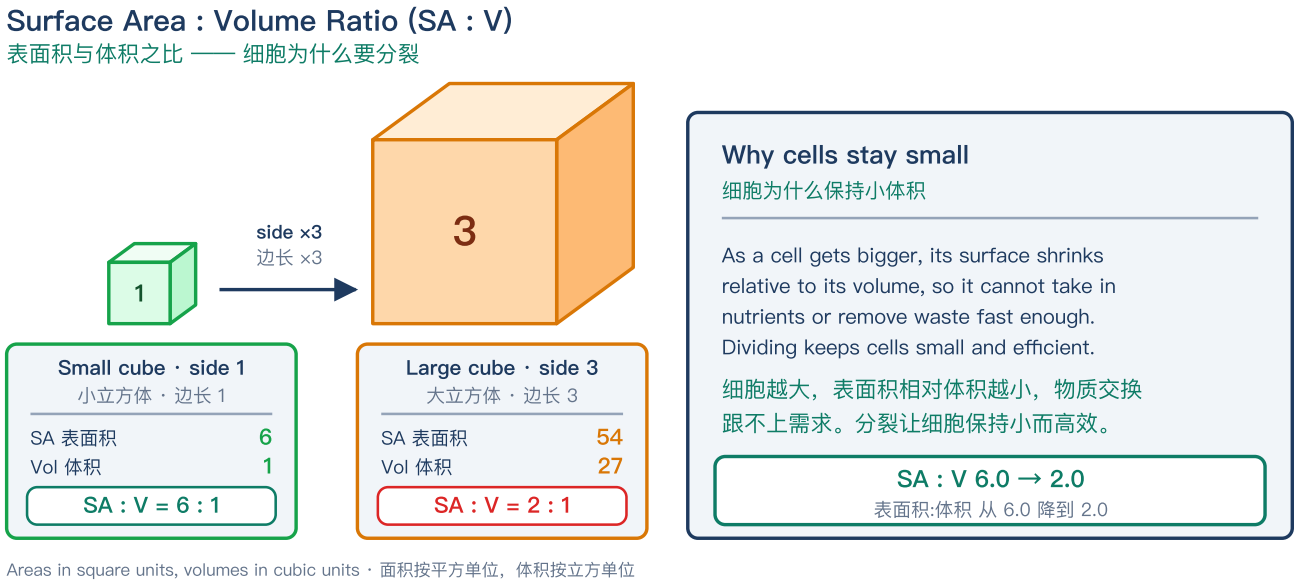
Because lessons and textbook pages devote most of their space to mitosis, students often draw or interpret the cell cycle circle as though mitosis takes up most of the cycle. Time spent teaching a phase has nothing to do with how long the phase lasts. On a correctly drawn diagram the M phase wedge is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

> 因为课堂和课本把大部分篇幅给了有丝分裂，同学画图或读图时常常把 M 期画成/看成占了大半个圆。请记住：讲课花多少时间和这个时期实际持续多久毫无关系。画对的细胞周期图上，M 期只是一小条窄扇形，间期占了圆的绝大部分。

✦ TIP **Four words for four phases** 四个字记四个时期

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.

> 大声念到形成条件反射：G1 长大、S 复制、G2 检查、M 分裂；后面再补一句「胞质分裂把细胞质分开」。这一句话同时帮你记住顺序、每一期的核心事件，还提醒你胞质分裂是独立于有丝分裂的一步。另外，这两个词千万别混着用：有丝分裂只指「细胞核」的分裂，而「细胞分裂」= 有丝分裂 + 胞质分裂。把整个细胞分裂笼统写成「有丝分裂」是要扣分的。



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.

边长为 1 的立方体表面积与体积之比为 6:1，边长为 3 时只有 2:1 —— 细胞长大时表面积跟不上体积，所以细胞靠分裂而不是靠变大。

Inside interphase: G1, S and G2

走进间期：G1、S、G2 到底在干什么

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.

> G1 期（第一间隙期，即 DNA 合成前期）里的 G 是 gap（间隙）——但它只是「排在上一次分裂和 DNA 合成之间」这个意义上的间隙，绝不是闲着。在 G1 期，刚形成的细胞重新长回正常大小，合成大量蛋白质，并制造新的细胞器 (organelle)，例如核糖体和线粒体，以便将来能把两套完整的「生产设备」分给两个子细胞。与此同时它还在照常干本职工作：肝细胞在 G1 期照样在处理化学物质，叶肉细胞照样在进行光合作用。对多数细胞来说，G1 是最长的一个亚期，细胞平时「过日子」的时间基本都在这里。

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.

> S 期（合成期）的 S 是 synthesis（合成），这是全课最不能记错位置的一个时期：DNA 复制 (DNA replication) 就发生在 S 期。每一条染色体都被复制一份，于是细胞里每条染色体都有了两份完全相同的拷贝，即整个基因组多出了一份完全相同的副本。它带来的结构变化正是考试答案里反复出现的那句话：原本是一条 DNA 细丝的染色体，现在由两条完全相同的姐妹染色单体 (sister chromatid) 组成，二者在着丝粒 (centromere) 处连在一起。下面这句请逐字看清，得分失分全在这里：细胞核内 DNA 的「数量」翻倍了，但染色体的「条数」没有变。人的体细胞在 S 期结束时仍然是 46 条染色体，只不过有 92 条染色单体。至于复制到底是怎么进行的，是明天（第 3 天）的内容。

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.

> G2 期（第二间隙期）是第二个间隙期，作用相当于起飞前的最后检查。细胞继续长大，复制剩下的细胞器，并合成分裂本身要用到的蛋白质——包括日后组装成纺锤丝 (spindle fibre) 的蛋白质亚基；纺锤丝就是有丝分裂时附着在染色体着丝粒上、把染色单体拉开的那些蛋白质「缆绳」。同样重要的是：刚复制出来的 DNA 会被检查，能修复的错误会被修复，免得细胞带着一份有损伤的拷贝进入分裂。只有 G2 期全部完成，细胞才进入 M 期。只要你能给每个亚期各说出一句准确的话——G1：细胞长大、合成蛋白质和细胞器；S：DNA 被复制，每条染色体变成由着丝粒连着的两条姐妹染色单体；G2：继续长大、检查复制好的 DNA、合成分裂所需的蛋白质——间期的 Describe 题基本就都能答了。

KEY TERMS · 关键术语

G1 phase G1 期（第一间隙期）

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

间期的第一个亚期：细胞长大、合成蛋白质、制造新的细胞器，同时照常执行自己的日常功能。

S phase S 期（合成期）

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.

间期中进行 DNA 复制的亚期；复制后每条染色体由两条完全相同、在着丝粒处相连的姐妹染色单体组成。

G2 phase G2 期（第二间隙期）

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.

间期的最后一个亚期：继续生长、检查并修复复制好的 DNA、合成分裂所需的蛋白质（包括构成纺锤体的成分）。

sister chromatid 姐妹染色单体

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

一条染色体复制后形成的两个完全相同的拷贝之一，两者在着丝粒处相连。

centromere 着丝粒

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

把两条姐妹染色单体连在一起的区域；有丝分裂时纺锤丝就附着在这里。

⚠ COMMON MISTAKE **Interphase is NOT a resting phase** 误区：把间期说成「休息期」

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.

> 老课本和偷懒的总结把间期叫「静止期 / 休息期」，同学于是写「细胞在分裂前休息一下」——这种答案零分。间期是整个周期里最长、代谢最活跃的一段：细胞在长大、造细胞器和蛋白质、照常干活，还要把整个基因组复制一遍。想写「休息」的时候，改成写 G1、S、G2 三个亚期各一件事。

⚠ COMMON MISTAKE **DNA is not replicated at the start of mitosis** 误区：以为 DNA 在有丝分裂开始时才复制

'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.

> 「DNA 在前期自我复制」是这一章被扣分最狠的错误之一。复制在有丝分裂开始之前就已经完成——正因为如此，前期显现出来的染色体一上来就是两条染色单体的样子。如果复制真发生在前期，那么后期 (anaphase) 时纺锤体就根本没有东西可分。

⚠ COMMON MISTAKE **A chromosome does not always look like an X** 误区：以为染色体永远是「X 形」

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.

> 课本上画的几乎都是复制完的「X 形」染色体，于是同学以为染色体永远有两条染色单体。并非如此。在整个 G1 期——也就是细胞一生中最长的一段时间——每条染色体都只是一条尚未复制的细丝，只有一条染色单体、一个着丝粒。两条染色单体的「X 形」只存在于 S 期结束到后期之间；后期着丝粒一分裂，每条染色单体就各自成为一条独立的染色体。还要记住：课本上那种能画出形状的「粗短」染色体只有在分裂时才看得见，整个间期里同样的 DNA 都是松散伸展的细丝状态。

○ EXTENSION **Extension: G0, the cells that step off the cycle** 拓展：G0 期——离开循环的细胞

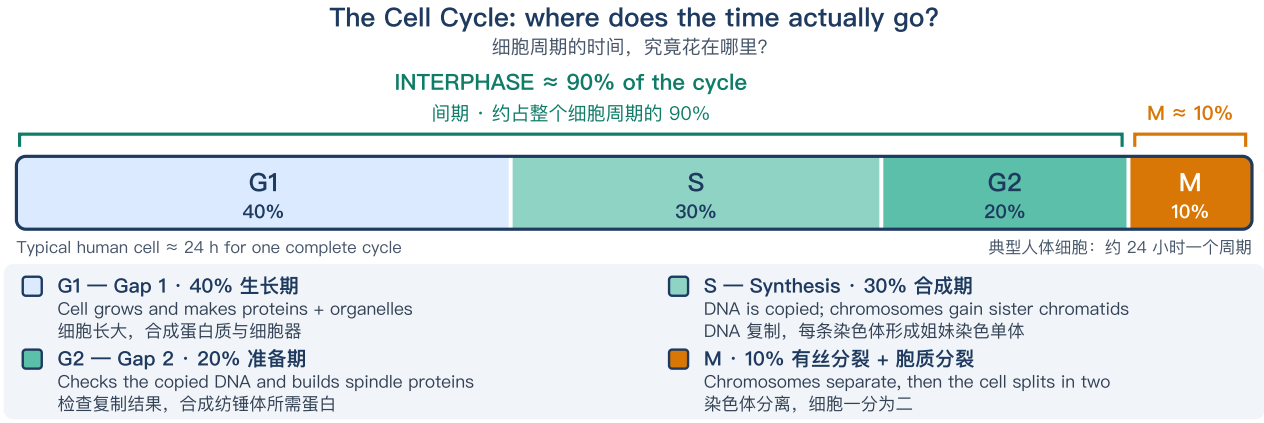
Not every cell keeps cycling. Some leave the cycle after G1 and enter a state called G0, where they carry out their function without preparing to divide. Mature neurons and cardiac muscle cells are normally in G0 permanently, which is part of why nerve and heart damage does not heal the way a cut in 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.

> 并不是所有细胞都一直转这个圈。有些细胞在 G1 期之后就离开细胞周期，进入所谓的 G0 期：只履行自己的功能，不再为分裂做准备。成熟的神经元和心肌细胞通常永久停留在 G0 期，这也是神经和心脏的损伤不像皮肤伤口那样能长好的原因之一；肝细胞平时也在 G0 期，但器官受损时能重新回到细胞周期。这一点在三个州的大纲里都属于拓展内容——当背景知识理解即可，不是必考点。

◈ EXAMPLE **Think of a stapled handout** 想想订书钉订好的双页讲义

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.

> 用「订书钉订起来的双页讲义」讲染色体 vs 染色单体。老师发一份两页、角上订了订书钉的讲义给 46 个学生：发出去的是 46 份讲义，不是 92 份，尽管确实有 92 张纸出了教室——数的是订书钉，不是纸张。S 期结束时的计数完全一样：每条染色体都复制了，现在由一个着丝粒连着的两条完全相同的姐妹染色单体组成，着丝粒就是那枚订书钉。DNA 的量翻倍，但仍然是 46 条染色体，因为「一个着丝粒 = 一条染色体」。只有到后期 (anaphase) 着丝粒分裂、每条染色单体各得一个着丝粒时，条数才变成 92。类比的边界（有两处）：第一，讲义的两页内容不同，而姐妹染色单体携带的 DNA 完全相同——这份「相同」正是复制的全部意义；第二，订书钉是事后夹上去的一个外来物件，而着丝粒并不是「加」到染色体上的，它本身就是染色体自身 DNA 上的一个区域，在 S 期里和其余部分一起被复制。



Interphase is NOT a rest — it is the busiest part of the cycle
间期不是休息期，而是细胞最忙碌的阶段

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

核心问题：为什么 DNA 必须在有丝分裂之前复制好?

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.

> 这就是你们班上问的那个问题，它值得一个像样的回答，而不是「反正就得这样」。先想清楚有丝分裂到底在干什么：有丝分裂是一个「分开」的过程，不是「复印」的过程。纺锤丝附着在每条染色体的着丝粒上，把两条姐妹染色单体各拉向一极——有丝分裂的本事到此为止。它没有任何制造新遗传物质的机制。所以，如果分裂开始时拷贝还没准备好，就根本没有东西可分；分得再仔细，也变不出缺失的 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.

> 把数字数一遍就一目了然了。人的体细胞是二倍体 (diploid)，有 46 条染色体。S 期里每条染色体都被复制，所以细胞进入有丝分裂时是 46 条染色体、共 92 条染色单体。到后期，着丝粒分裂，每对姐妹染色单体各有一条被拉向一极，于是每个新细胞核都拿到 46 条染色体——一整套，而且和另一边那套完全相同。现在设想细胞跳过了 S 期：它进入有丝分裂时是 46 条只有单条染色单体的染色体，纺锤体只能把这 46 条在两极之间「分家」，各得大约 23 条——那是随机而残缺的半套遗传物质。这样的子细胞会缺掉编码某些必需蛋白质的基因，根本无法正常工作；再分裂一次还会丢得更多。正因为先复制，子细胞才既「完整」又「遗传物质完全相同」。

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.

> 那为什么复制发生在间期，而不是在有丝分裂过程中？有两条理由可以直接写进答案。第一，DNA 只有在解螺旋、松散伸展成由 DNA 和蛋白质构成的细丝（这种形态叫染色质 chromatin）、可以被酶接触到的状态下才能被复制，而这正是它整个间期的状态；从前期开始，DNA 就高度螺旋化、压缩成便于搬运的形态，此时既不被读取也不被复制。第二，复制需要时间，而且复制出来的新拷贝必须先接受检查再分开——这正是 G2 期的任务。所以周期的顺序不是随便排的：S 期复制 → G2 期检查 → M 期分开。请练到能一口气把整条因果链说完：DNA 在 S 期完成复制，所以每条染色体由着丝粒连着的两条完全相同的姐妹染色单体组成；后期时着丝粒分裂，每对中的一条被拉向一极；因此每个子细胞核都得到每一条染色体的一份完整且相同的拷贝。

KEY TERMS · 关键术语

DNA replication DNA 复制

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

在 S 期把一个 DNA 分子复制成两个完全相同的分子，将来两个子细胞各得一份。

chromatin 染色质

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.

由 DNA 和蛋白质构成的长而松散的细丝，遗传物质在整个间期都以这种形态存在；只有在这种可被接触的形态下，DNA 才能被复制和读取。

diploid 二倍体

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

含有两套完整染色体（父本、母本各一套）的状态；人的体细胞是二倍体，有 46 条染色体（23 对）。

daughter cell 子细胞

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

一个亲代细胞完成有丝分裂和胞质分裂后产生的两个细胞中的任意一个。

genetically identical 遗传物质完全相同

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

携带完全相同的 DNA 序列；有丝分裂产生的两个子细胞彼此之间、以及与亲代细胞之间，遗传物质完全相同。

⚑ IN THE EXAM

Model answer: 'Justify why DNA replication must occur before mitosis'

范例答案：论证「为什么 DNA 复制必须在有丝分裂之前」

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.

> Justify（论证）要求「证据 + 明确结论」。可以套这个结构：「有丝分裂只是把每条染色体的两条姐妹染色单体分开，它并不复制 DNA。如果事先没有复制，就没有姐妹染色单体可分，亲代细胞那 46 条染色体只能在两极之间分摊，每个子细胞得到的是残缺的一套、缺少必需的基因。正因为 S 期的 DNA 复制让每条染色体有了两条完全相同的染色单体，有丝分裂才能给每个子细胞送去一整套完全相同的遗传物质。所以复制必须在有丝分裂开始之前完成。」三步：有丝分裂做什么 → 不复制会怎样 → 结论。

⚠ COMMON MISTAKE

'The DNA is shared evenly between the two cells' earns nothing

误区：答「DNA 被平均分给两个细胞」是不给分的

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.

> 这是整章里最常见的「弱答案」。把原有的 DNA 平均分，两个子细胞各得半套基因组，而不是各得一整套。子细胞之所以完整且遗传物质完全相同，靠的是 S 期那一步「复制」，不是靠分得公平。你的句子里如果没有出现「复制 (replicated / copied)」这个词，它就还算不上一个解释。

⚠ COMMON MISTAKE

S phase doubles the DNA, not the chromosome number

误区：以为 S 期之后染色体数目翻倍

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.

> S 期之后，人的细胞是 46 条染色体、92 条染色单体，而不是 92 条染色体。复制后的染色体仍然算「一条」染色体，因为它只有一个着丝粒，只不过现在有两条染色单体。数着丝粒，不要数「胳膊」。染色体的条数只在后期才改变：着丝粒分裂后，每条染色单体都有了自己的着丝粒，因而各自成为一条独立的染色体，此时细胞内瞬时共有 92 条染色体；随后这 92 条被平均拉向两极，所以每个新细胞核又各得 46 条只含单条染色单体的染色体——和亲代细胞开始时完全一样。也就是说，子细胞核的染色体条数与亲代相同：有丝分裂过程中，染色体的条数不会减半。

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

把细胞周期写成分数：动词、数字、作图与质量控制（检查点）

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.

> 这一章丢分，多半丢在「动词」而不是生物学本身，所以答案要对准题目要求的动词。Outline（概述）细胞周期：给一条简短的顺序即可——间期（G1 生长、S 完成 DNA 复制、G2 准备与检查），然后有丝分裂，然后胞质分裂。Describe（描述）S 期发生了什么：只讲事实和特征，不讲因果——DNA 被复制，于是每条染色体由着丝粒连着的两条完全相同的姐妹染色单体组成。Explain（解释）和 Justify（论证）则要求因果链，句与句之间要用 because / so that / therefore 串起来。把「描述」包装成「解释」，只能拿到描述的分——好答案和满分答案的差距往往就在这里。

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.

> 题目也常常直接给你数字，只要把过程写出来，算术并不难。比如一个细胞完成一整个周期用 24 小时，其中 M 期约 1 小时，那么处于间期的时间是 24 − 1 = 23 小时，占比 = 23 ÷ 24 × 100 = 95.8%。一定要写出算式并带上百分号，Calculate（计算）题两样都给分。这个推理反过来也成立：如果图或表显示某个时期占了很大一块，就说明这个时期持续时间长。这正是为什么画对的细胞周期圆图里间期是巨大的一段弧、M 期只是窄窄的一小条扇形，也是为什么把圆平均分成四份的图即使标签全对也要被判错。

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.

> 最后，要养成不用提醒就使用专业术语的习惯。考试一紧张，最容易脱口而出的答案是「细胞分成了两个」——这句话零分，因为它没点出任何一个时期、结构或过程。训练自己每个答案里都同时出现这三样，例如：「在间期的 S 期，DNA 被复制，于是每条染色体由着丝粒连着的两条完全相同的姐妹染色单体组成。」这一句里同时有时期、过程、结构和结果。把这套「活词汇」在整章里一直用下去：（分裂）间期、G1 期、S 期、G2 期、M 期、有丝分裂、胞质分裂、复制、姐妹染色单体、着丝粒、染色质、二倍体、子细胞、遗传物质完全相同。

KEY TERMS · 关键术语

checkpoint 检查点

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

（拓展内容）细胞周期中的控制节点：先评估条件是否合格，合格才允许细胞进入下一个时期。

EXTENSION

Extension: checkpoints — the cell cycle's quality control

拓展：检查点——细胞周期的质量控制

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.

> 细胞周期并不是一个自动空转的圈：只有条件合格，细胞才被「放行」进入下一个时期，而这种评估发生在检查点 (checkpoint)。G1/S 检查点上，细胞相当于在问：我够大了吗？营养和生长信号有没有？我的 DNA 有没有损伤？都合格才承诺进入 S 期。G2/M 检查点：我的 DNA 是否全部复制完成？复制出来的拷贝有没有损伤？合格才进入有丝分裂。纺锤体（M）检查点在中期，检查每一条染色体是否都已通过着丝粒与纺锤丝正确相连，然后才允许后期开始。细胞周期调控在维州 VCE Unit 1 属于必考内容；在新州和昆州属于很有价值的拓展。检查点背后的分子机制（各种蛋白）不在你的考纲内，不用背。

EXTENSION

Extension: what happens when control is lost

拓展：调控失灵会怎样

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'.

> 如果检查点失灵，细胞就可能在不该分裂的时候分裂，也可能带着受损的 DNA 直接进入分裂，而不是停下来修复。这种不受控制的反复分裂会形成不断增大的细胞团块，也就是肿瘤 (tumour)；这些细胞分裂频率高于正常细胞、无视「停止分裂」的信号，还可能丧失原有的特化功能。这在 VCE Unit 1 是必须掌握的后果（细胞周期调控失灵与癌症），在新州和昆州则是很好的拓展。答题时保持在这个层次：把癌症和「细胞周期调控失效」明确挂钩，别只笼统写「细胞乱长」。

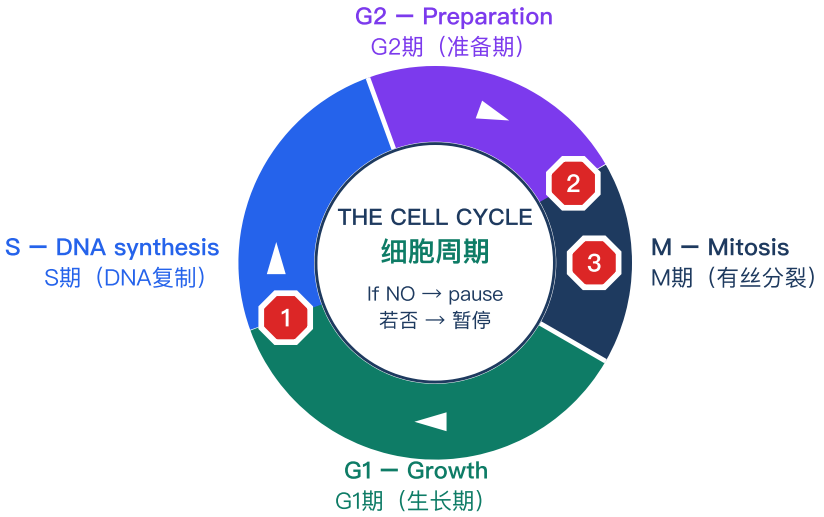
⚑ IN THE EXAM **Which parts of today does your course actually assess?** 今天这些内容，你的课程到底考哪些?

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.

> 正文五个部分的内容，对新州 Module 5 和维州 VCE Unit 1 都是核心必学。昆州 QCAA Unit 1 只把细胞周期作为干细胞与细胞分化的背景带过，具体内容放在 Unit 4 考——所以无论如何，今天的内容都是必要的基础。差别出现在边缘部分：维州 VCE Unit 1 要求掌握细胞周期各亚期，还要求检查点、调控失灵与癌症，但对 S 期只要求知道「DNA 被复制」这一句——具体机制放在 Unit 3。新州 Module 5 和昆州 Unit 4 则要求掌握复制的细节本身，那正是明天的课。如果你不确定自己属于哪一种，就按「核心 + 检查点」来学：检查点在一个州是必考，在其他州也是有用的背景知识。

Cell Cycle Checkpoints — Quality Control Before Dividing

细胞周期检查点 —— 分裂前的质量控制



1 G1/S Checkpoint
G1/S 检查点

Is the cell big enough?
Is the DNA undamaged?
细胞够大吗？DNA有损伤吗?

2 G2/M Checkpoint
G2/M 检查点

Was the DNA copied completely and correctly?
DNA复制完整无误吗?

3 Spindle Checkpoint
纺锤体检查点

Are all chromosomes attached to the spindle?
所有染色体都连上纺锤丝了吗?

⚠ If a checkpoint fails and division continues anyway, cells can divide out of control — **this is the link to cancer.**
检查点失效仍继续分裂，细胞就可能失控增殖，这与癌症有关。

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.
细胞周期环（G1 → S → G2 → M）及三个质量控制检查点——G1/S、G2/M 与纺锤体检查点，以及检查点失效为何与癌症有关。

DAY 2 RECAP · 本日要点回顾

- 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.
  细胞分裂的三个理由：生长、修复与更新（替换用旧了的细胞）、无性生殖（例如酵母和水螅的出芽、草莓的匍匐茎）；而且皮肤、肠道内壁和血细胞终生都在持续更新，不是只有小孩才分裂。
- 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.
  细胞不能无限长大：体积增长比表面积快，表面积与体积比 (surface area to volume ratio) 下降，细胞膜供不起内部所需，所以只能靠分裂来解决。
- 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.
  细胞周期 = （分裂）间期（G1 期 → S 期 → G2 期）+ M 期（先有丝分裂，后胞质分裂），并且不断循环：每个子细胞都从自己的 G1 期重新开始。有丝分裂只指细胞核的分裂；细胞分裂 = 有丝分裂 + 胞质分裂。
- 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.
  间期是周期中最长、最忙的一段（约占 90% 以上）；它既不是「休息期」，也不是有丝分裂的某个时期。
- 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.
  G1 长大（合成蛋白质和细胞器）；S 复制（DNA 复制，每条染色体变成着丝粒相连的两条姐妹染色单体）；G2 检查复制结果并合成分裂所需蛋白质（包括纺锤体成分）。
- 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.
  S 期让 DNA 的数量翻倍，但染色体条数不变：人的细胞仍是 46 条染色体，只是有了 92 条染色单体。数着丝粒，不数「胳膊」；也要记住，细胞一生中大部分时间里染色体只是一条尚未复制的细丝，并不是「X 形」。
- 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.
  复制必须在有丝分裂之前完成，因为有丝分裂只能「分开」已经存在的姐妹染色单体；没有事先复制，子细胞只会拿到残缺的半套遗传物质，无法正常行使功能。子细胞之所以遗传物质完全相同，靠的是「复制」这一步，不是靠「分得公平」。

Check Yourself — Day 2

自我检测 · 第 2 天（先合上笔记独立作答）

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 · 答案与解析

Write your answer out first. A question you have read the answer to is not practice.
先自己写完再对答案，看过答案就不算练习了。

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

正确答案是 B：间期是细胞周期中最长的一段，细胞在其中生长、完成 DNA 复制并为分裂做准备，通常占整个周期约 90% 以上，包含 G1、S、G2 三个亚期。选项 A 是最经典的误区——「休息期」的说法早已过时，间期是代谢最活跃的阶段；选项 C 把间期当成了有丝分裂的一个时期（它属于细胞周期，且在前期之前就结束了）；选项 D 描述的是有丝分裂的后期 (anaphase)。

2. b) S phase

答案是 S 期（合成期）。S = synthesis（合成），这是间期中完成 DNA 复制的亚期，复制后每条染色体由着丝粒相连的两条完全相同的姐妹染色单体组成。G1 期是生长和合成蛋白质、细胞器；G2 期是继续生长、检查复制结果并准备分裂；选「前期 (prophase)」是本章最常被扣分的错误——复制在有丝分裂开始之前就已经完成了。

3. b) 46 chromosomes and 92 chromatids

答案是「46 条染色体、92 条染色单体」。复制使 DNA 的数量翻倍，但染色体的条数不变：复制后的染色体仍算一条，因为它仍然只有一个着丝粒把两条姐妹染色单体连在一起。选项 A 是漏了复制这一步；选项 C 是把染色单体当成染色体来数（典型错误）；选项 D 把有丝分裂错当成了减数分裂 (meiosis)。记住口诀：数着丝粒，不数「胳膊」。

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

答案是 C：比值从 6:1 降到 3:1，平均每单位细胞质能分到的膜面积变少了。表面积从 6 cm2 增到 24 cm2（4 倍），体积却从 1 cm3 增到 8 cm3（8 倍），体积增长得更快——这正是细胞宁可分裂也不一味长大的原因。选项 A 错在忽略了两者增长速度不同；选项 B 把方向搞反了；选项 D 前半段算对了，但后半段错误：细胞变大后，从细胞膜到中心的扩散距离也变长了，情况只会更糟。

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.

答案是 C：细胞分裂终生都在进行，用来替换用旧了的细胞。生长只是分裂的三个理由之一，修复与更新则伴随一生，伤口愈合任何年龄都会发生：皮肤外层不断脱落更新，肠道内壁每隔几天整批更换，红细胞由骨髓中的前体细胞分裂补充。选项 A 是本章最常见的误区；选项 B 把更新窄化成了只在受伤处；选项 D 说的是配子形成（减数分裂），不是本课内容。

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

答案是 A：G1 → S → G2 → 有丝分裂 → 胞质分裂。先是间期（G1、S、G2），随后进入 M 期：有丝分裂负责分细胞核，胞质分裂随后把细胞质分开。选项 B 把 S 期塞进了有丝分裂中间（DNA 复制绝不在分裂过程中进行）；选项 C 把胞质分裂放到了有丝分裂之前，顺序颠倒；选项 D 把 S 期和 G2 期对调了——记住 S 一定夹在两个间隙期之间。

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.

参考答案：S 期中细胞的 DNA 被复制，每条染色体都产生两份完全相同的拷贝；结果每条染色体由在着丝粒处相连的两条完全相同的姐妹染色单体组成。DNA 的数量翻倍，但染色体的条数不变（人的细胞仍是 46 条染色体，此时共有 92 条染色单体）。注意题目动词是 Describe（描述）：只写「发生了什么」，不要展开写「为什么必须先复制」——那是 Explain / Justify 的活。三个得分点分别是：① DNA 被复制；② 每条染色体由着丝粒相连的两条完全相同的姐妹染色单体组成；③ DNA 数量翻倍而染色体条数不变——第三点最容易漏，千万别省。

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.

参考答案（Justify 要求「证据 + 明确结论」）：有丝分裂是「分开」而不是「复制」的过程——纺锤丝附着在着丝粒上，把每条染色体的两条姐妹染色单体拉向两极。如果 DNA 没有在 S 期事先复制好，就没有姐妹染色单体可分，亲代细胞的染色体只能在两极之间分摊，每个子细胞得到的将是缺少必需基因的残缺一套，无法正常工作。正因为 S 期

的复制让每条染色体都有了两条完全相同的染色单体，有丝分裂才能给每个子细胞送去完整且相同的一套染色体。所以复制必须在有丝分裂开始之前完成。写作要点：三步走（有丝分裂做什么 → 不复制会怎样 → 结论），句子之间用 because / so that / therefore 连起来。

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.

参考答案：间期时长 = 24 − 1 = 23 小时；百分比 = 23 ÷ 24 × 100 = 95.8%（约 96%）。这说明画细胞周期图时，间期必须占绝大部分，M 期只是窄窄的一小条扇形；把圆平均分成四份即使标签全对，也严重歪曲了时间比例。Calculate（计算）题一定要写出算式并带百分号，两处都给分；最后那句「所以图该怎么画」是第三个得分点，别省。另外要注意：有些资料给出的比例是 G1 40%、S 30%、G2 20%、M 10%，所以一律按题目给的数据算，不要背死一个百分比。

DAY 3

about 70 min · 约 70 分钟

DNA Replication: Making an Exact Copy

DNA 复制：制作一份精确的副本

THE BIG IDEA · 核心观念

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.

细胞分裂之前必须先把全部 DNA（脱氧核糖核酸）复制一遍：双螺旋 (double helix) 被「拉开拉链」，每条旧链都作为模板链 (template strand) 指导合成一条新链，所以每个新 DNA 分子都是「一旧一新」。子细胞遗传物质完全相同 (genetically identical) 的根本原因是这一步「复制」，而不是把原有 DNA「平均分给两边」。

BY THE END OF TODAY YOU WILL BE ABLE TO · 今天学完你将能够

1. Identify S phase of interphase as the only stage of the cell cycle in which DNA replication occurs.
   识别 (Identify)：DNA 复制只发生在（分裂）间期 (interphase) 的 S 期（合成期），不发生在有丝分裂 (mitosis) 过程中。
2. Describe the sequence of events in DNA replication, from the unwinding of the double helix to the formation of two complete DNA molecules.
   描述 (Describe)：按顺序说出 DNA 复制的全过程——从双螺旋解开，到最终形成两个完整的 DNA 分子。
3. Explain why replication is described as semi-conservative, and why the hydrogen bonds break while the sugar-phosphate backbone stays intact.
   解释 (Explain)：为什么这个过程叫半保留复制 (semi-conservative replication)；为什么断开的是氢键 (hydrogen bond)，而磷酸—脱氧核糖骨架 (sugar-phosphate backbone) 完好不断。
4. Construct the complementary strand for a given template strand sequence using the base-pairing rules A-T and C-G.
   写出 (Construct)：给定一条模板链的碱基序列，依据碱基互补配对 (complementary base pairing) 规则 A–T、C–G 写出与之互补的新链。
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.
   区分 (Distinguish)：复制后的染色体（两条姐妹染色单体在着丝粒处相连）与未复制的单条染色体、以及与同源染色体对，三者的差别。
6. Justify why DNA replication must be completed before mitosis begins, referring to the consequences for chromosome number in the daughter cells.
   论证 (Justify)：为什么 DNA 复制必须在有丝分裂开始之前完成——从子细胞染色体数目的后果来说明理由。

1. Where and when replication happens: S phase

1. 复制发生在哪里、什么时候：S 期

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.

> 昨天你已经认识了细胞周期 (cell cycle)：漫长的（分裂）间期 (interphase) 由 G1 期、S 期、G2 期组成——它是细胞周期中最繁忙的阶段，绝不是「休息期」——之后才是短短的 M 期（有丝分裂 + 胞质分裂 cytokinesis）。今天我们把镜头推近到间期正中间的那个 S。S 代表 synthesis（合成），合成的东西就是 DNA。整个细胞周期里，

> 只有这一刻细胞会把自己全部的 DNA 分子完整地再复制一份。S 期之前，一个人类体细胞 (somatic cell) 有 46 条染色体，每条染色体是一个 DNA 分子；S 期之后，它仍然是 46 条染色体，但每条染色体里现在装着两个一模一样的 DNA 分子。请记住这句话：**数目不变，内容加倍**。这节课结束时还会用到它。

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.

> 复制发生在细胞核 (nucleus) 内部，因为染色体在那里。它需要三样东西同时到位：DNA 本身、细胞核内游离的核苷酸 (nucleotide) 原料、以及负责干活的酶。这些游离核苷酸是**早就准备好的**——细胞在 S 期之前的 G1 期就通过正常代谢把它们造好并储备在核内，复制进行时还会继续补充。这一点听着平常，其实很关键，因为很多同学脑子里的画面是「有一种酶按需现造出每一个核苷酸」，像厨师听到点单才现炒一道菜。实际上没有这么「聪明」：原料早已在锅里，过程只是按碱基互补配对 (complementary base pairing) 的规则，在每个位置上挑出正确的那一个。

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.

> 还有一个时间点，评分老师年年都在看：**复制在有丝分裂开始之前就已经完成了**。S 期结束时，每条染色体都已完成复制；接下来的 G2 期用来继续生长、检查复制质量、并合成将来构成纺锤丝 (spindle fibre) 的蛋白质。这些都做完，前期 (prophase) 才开始。如果你在考试里写「DNA 在前期复制」或者「在有丝分裂一开始复制」，这一分立刻就没了——更糟的是，你后面的答案会整个说不通，因为有丝分裂里从头到尾都没有「复制」这个步骤。

KEY TERMS · 关键术语

S phase S 期（合成期）

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

（分裂）间期的中间阶段，细胞核内每一个 DNA 分子都在这一阶段完成复制。

free nucleotides 游离核苷酸

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).

细胞核中已经存在的、现成的核苷酸单体（DNA 复制用的是游离的脱氧核苷酸），是合成新 DNA 链的原料，并非临时制造。每个核苷酸由一个磷酸基团、一个脱氧核糖和一个含氮碱基（A、T、C 或 G）组成。

somatic cell 体细胞

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

除生殖细胞（配子）以外的普通身体细胞；人类体细胞是二倍体 (diploid)，含 46 条染色体。

⚠ COMMON MISTAKE **"DNA copies itself during mitosis"** 误区：「DNA 是在有丝分裂时复制的」

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.

> 这是本章最顽固的错误。有丝分裂只负责**分开**已经存在的姐妹染色单体，复制是更早的 S 期完成的。把这句话当成一个整体背下来：「S 期复制，后期 (anaphase) 分离」。

⚑ IN THE EXAM **Command verb watch: Describe vs Explain** 命令动词提醒：Describe 与 Explain 的差别

'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.

> 「Describe what occurs during S phase」要的是**现象和特征**（DNA 被复制；每条染色体变成由着丝粒连接的两条完全相同的姐妹染色单体）。「Explain why replication must occur before mitosis」要的是**因果链**，句子之间要用 so that / because / therefore 串起来。内容一样，结构不同——先看动词再动笔。

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

2. 半保留复制：「一半旧、一半新」到底指什么

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.

> 「半保留」这个词描述的是复制的**结果**，一定要说准，因为每年都有两种典型的说错方式。半保留复制 (semi-conservative replication) 的意思是：复制出的两个 DNA 分子，每一个都由**一条完整的原有旧链**和**一条完整的新合成链**组成。原来的分子既没有被销毁，也没有被整个保留下来，而是从中间被分成两条链，这两条旧链分别进入两个新分子，各自配上一条全新的链。conserve = 保留，semi = 一半，所以「每个新分子保留了亲代的一半」。

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.

> 错误说法一：「每条新链一半是旧的、一半是新的」。不对——**每条链要么整条是旧的，要么整条是新的**；「一半一半」说的是**分子**，不是链。错误说法二：「一个分子全是旧的，另一个全是新的」——那叫全保留复制 (conservative)，事实并非如此。一个好办法是动手画：亲代分子画两条线，一条涂蓝、一条涂黑；再画出两个子代分子，每个都必须是「一蓝一黑」。如果你画出来是「蓝蓝」一个、「黑黑」一个，那你画的就是错误的全保留模型——自己就能在考试之前抓住这个错。

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.

> 这在生物学上为什么重要，而不只是一个名词？因为「每个产物里都保留一条旧链」正是**保证准确性**的关键。旧链就是模板链 (template strand)，它一个碱基一个碱基地规定新链必须是什么。如果两条旧链都被丢掉、从零开始造 DNA，那就没有任何指令可循，也无从判断复制对不对。所以「半保留」不只是描述一种模式，它本身就是「复制忠实可靠」的原因。这条因果链——旧链当模板 → 复制准确 → 子细胞遗传物质完全相同——正是长题答案里评分老师要找的东西。

KEY TERMS · 关键术语

semi–conservative replication 半保留复制

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

复制方式：每个新形成的 DNA 分子都含有一条原来的亲代链和一条新合成的链。

template strand 模板链

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

原有的那条 DNA 链，它的碱基顺序决定了以它为模板新合成的那条链的碱基顺序。

daughter strand 子链

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

以模板链为依据、按碱基互补配对新合成出来的那条 DNA 链。

✦ TIP **The two–colour test** 记忆法：两色检验法

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.

> 把亲代分子画成「一蓝一黑」。正确的子代分子必须**每个都是一蓝一黑**。只要有哪个分子整个只剩一种颜色，就说明你画成了错误的全保留模型。

⬡ EXTENSION

Extension: how do we actually know it is semi-conservative? 拓展：我们怎么知道它真的是半保留的?

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.

> 拓展内容（超出核心要求，了解即可）。沃森 (Watson) 和克里克 (Crick) 提出双螺旋之后，生物学家曾就三种可能的复制模型展开争论：全保留复制（conservative）、半保留复制（semi-conservative）、以及弥散复制（dispersive，新旧材料在同一条链上混杂）。梅塞尔森 (Meselson) 和斯塔尔 (Stahl) 先用含较重氮同位素（^{15}N）的培养基培养细菌，让细菌 DNA 中的氮全部变「重」，再把细菌转移到含普通氮（^{14}N）的培养基中，每分裂一轮就按密度分离一次 DNA。**关键是逻辑，不是技术细节**：第一轮之后所有分子都是中间密度，这就排除了全保留复制（它预测应出现「一重一轻」两类）；第二轮之后出现中间密度和轻密度两类混合，这又排除了弥散复制。只有半保留复制能同时预测出这两个结果。你不需要背实验细节，只需要明白：这个模型是有证据支撑的，不是随口断言。

◈ EXAMPLE

Think of two dance partners 把它想成两位舞伴

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.

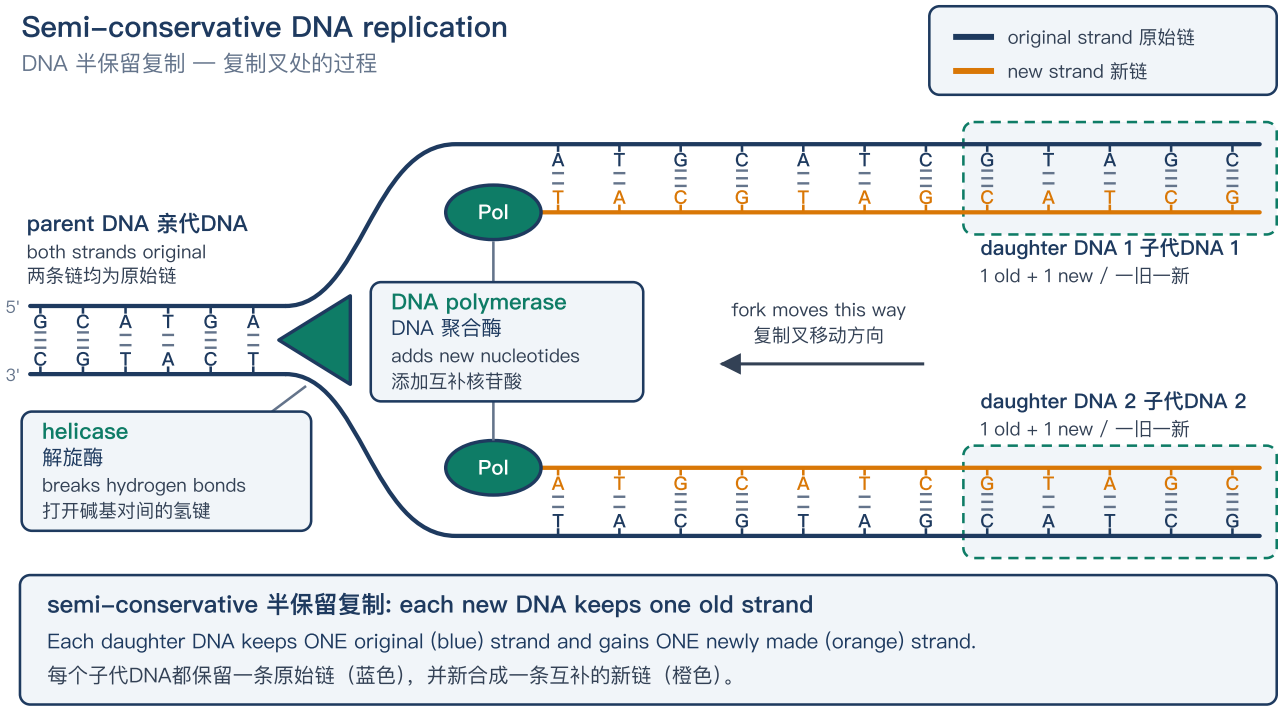
> 这个例子用来打掉最常见的错写法：「每条新链一半旧一半新」。比喻：一对跳了整晚的舞伴分开，各自马上和一个新人组成新的一对，于是场上有两对，每一对都是「一个旧人 + 一个新人」——这就是半保留复制：每一对就是一个新 DNA 分子，由**一条完整的旧链（模板链）**和**一条完整的新合成链**组成。但要注意「一半一半」的是**对**（分子），不是**人**（链）：没有谁走成了半个人，每条链要么整条是旧的、要么整条是新的。失效之处有两点：第一，真实舞伴可以自由挑人，而模板链毫无选择余地，旧链的碱基顺序一个碱基一个碱基地规定新链必须是什么；第二，那个「新人」并不是现成走进场的——新链不是一条已经做好的链走过来配对，而是以模板链为依据、由游离核苷酸一个一个接起来合成出来的。

3. The steps of replication, in order

3. DNA 复制的步骤（按顺序）

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.

> **第一步——双螺旋「拉开拉链」**。一种叫解旋酶 (helicase) 的酶沿着 DNA 前进，把每一对碱基之间的氢键 (hydrogen bond) 打断。因为氢键很弱，可以在不破坏其他结构的情况下被打开，两条链就此分离。现在重读一遍，注意**没有被打断的是什么**：磷酸—脱氧核糖骨架 (sugar–phosphate backbone)。沿骨架排列的那些很强的共价键 (covalent bond) 完全保持完整。这正是第 1 天讲过的结构精妙之处——链的内部是强键、中间横档是弱键——现在派上用场了。如果你写「骨架断开」，那描述的是一条断碎的染色体，而不是一条正在复制的染色体。两条链已经分开、正在合成新链的那个 Y 形区域叫做复制叉 (replication fork)——NSW Module 5 要求掌握这个名词，VCE Unit 1 认得即可。



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.

复制叉示意：解旋酶打开亲代双螺旋的氢键，DNA聚合酶按碱基互补配对在每条模板链上合成新链，因此每个子代DNA分子都是一条原始链加一条新链。

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.

> **第二步——每条旧链充当模板链**。碱基现在暴露出来了，每条单链就成了一份可读的说明书：一条读作 A–T–G–C 的链，其配对链只可能是 T–A–C–G。**第三步——游离核苷酸进来配对**。核内本来就漂浮着的核苷酸排到暴露的碱基旁边，只有互补的那一个能配得上并结合：腺嘌呤 (adenine) 配胸腺嘧啶 (thymine)（2 个氢键），胞嘧啶 (cytosine) 配鸟嘌呤 (guanine)（3 个氢键）。**准确性就来自这里**——不是某种酶「记得」序列是什么，而是只有正确的碱基才能在正确的位置形成正确的氢键，所以留下来的自然是正确的那一个。

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.

> **第四步——把新核苷酸连接起来**。DNA 聚合酶 (DNA polymerase) 把每个新到位的核苷酸与前一个连接起来，沿着每条模板链逐渐建成一条连续的新磷酸—脱氧核糖骨架。**第五步——两个完整分子重新盘绕**。每条模板链现在都配上了一条完整的新链，各自重新扭成双螺旋。原来一个 DNA 分子，现在变成两个；按第 2 节的规则，每一个都是「一条旧链 + 一条新链」。这里可以用**复印机**打比方——放进一张纸，出来两张一样的——但要看清它在哪里失效：复印机保留原件完整、另外产出一份副本，那其实是**全保留模型**，DNA 并不是这样。更接近事实的比喻是「拉链拉开，每半条各自长出一排新的齿」，尽管现实中也没有哪条拉链会这么干。

KEY TERMS · 关键术语

helicase 解旋酶

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

负责打断配对碱基之间氢键的酶，使双螺旋解开、两条链分离。

DNA polymerase DNA 聚合酶

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

沿着模板链把游离核苷酸连接成一条连续新链的酶。

replication fork 复制叉

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.

DNA 分子上两条链已经分开、正在合成新链的那个 Y 形区域。(NSW Module 5 要求掌握并考查；VCE Unit 1 认得即可。)

hydrogen bond 氢键

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

横跨双螺旋、把互补碱基连在一起的弱键；A 与 T 之间 2 个，C 与 G 之间 3 个。

⚠ COMMON MISTAKE **"The strands separate because the backbone breaks"** 误区：「两条链分开是因为骨架断了」

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.

> 磷酸—脱氧核糖骨架靠很强的共价键 (covalent bond) 连接，在整个复制过程中始终完整。断开的只有配对碱基之间的**弱氢键**。正是因为有这种强弱对比，DNA 才能被反复打开、再合上而不散架——原因全在于此。

⬡ EXTENSION **Extension: leading and lagging strands** 拓展：前导链与后随链

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.

> 拓展内容（超出核心要求）。因为双螺旋的两条链方向相反，也就是反向平行 (antiparallel)，在复制叉处两条新链无法用完全相同的方式合成：一条随着复制叉打开被连续合成为一整条；另一条则先合成一段段短片段，再由连接酶 (ligase) 接起来。它们分别叫前导链 (leading strand) 和后随链 (lagging strand)。这在三个州的 Year 11 核心内容中都属于**超纲**——认得它、看到课本插图不至于困惑就够了，不必花力气记细节，Year 11 不会考。

TIP **Which enzyme names do I actually need?** 酶的名字我到底要不要背?

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).

> 解旋酶、DNA 聚合酶、连接酶 (ligase，作用是把新合成的短片段接起来——见上面的拓展卡片) 这几个名字，在新南威尔士 NSW Module 5（属 Year 12 / HSC 课程）里是要考的，在昆士兰 QCE 也属 Year 12 内容。如果你读的是维州 VCE Unit 1–2，S 期只要求写「DNA is replicated」，酶的名字要到 Unit 3 才学。**五个步骤无论哪个州都要会**；酶的名字则按你实际考的课程决定要不要背。但无论哪种情况，你都必须说得出：被打开的是碱基之间的氢键，没有断开的是磷酸—脱氧核糖骨架。

IN THE EXAM **Model the process (NESA command verb)** 考试要求：Model（NESA 命令动词）

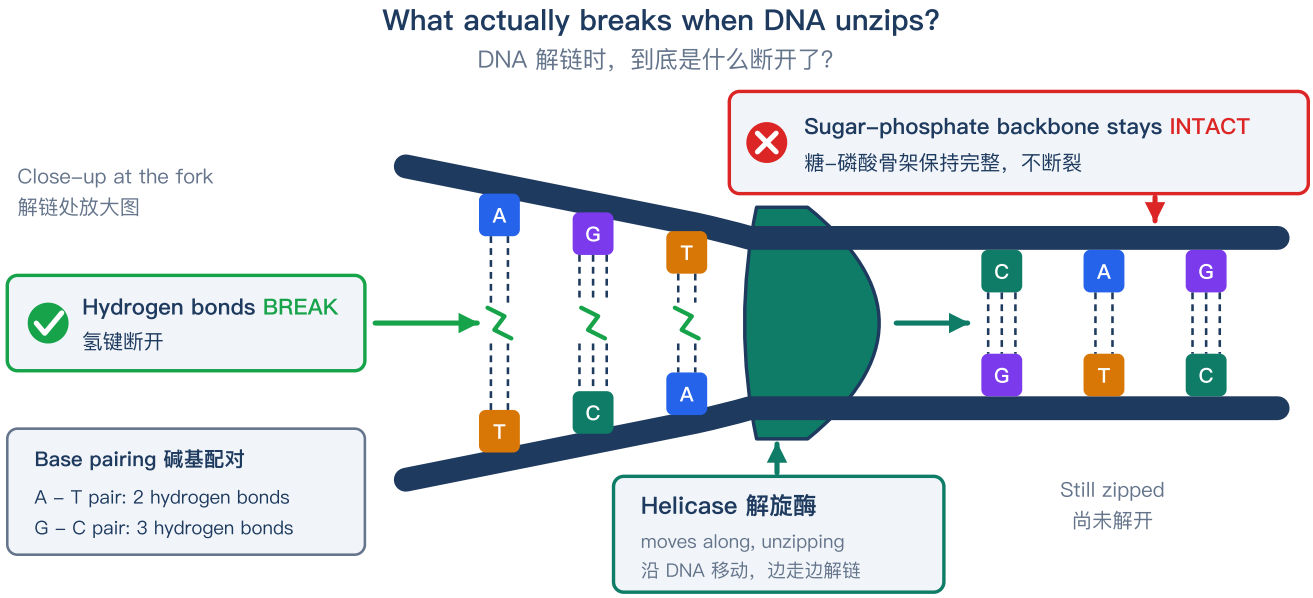
The NSW Module 5 dot point uses the verb 'Model'. That signals a labelled diagram or annotated sequence, not prose alone. Practise drawing a diagram of replicating DNA (a replication fork, if your course uses the term) with these labels: original strand, new strand, free nucleotides, hydrogen bonds broken,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

> NSW Module 5 的考纲条目用的动词是 Model（建模），意思是要求**带标注的图或注释式流程**，不能只写文字。练习画一张正在复制的 DNA 的图（如果你的课程用「复制叉」这个名词，那画的就是复制叉），并标注：原有链、新链、游离核苷酸、被打断的氢键、完整未断的磷酸—脱氧核糖骨架、解旋酶、DNA 聚合酶。分数就落在这些标注上。

EXAMPLE **Think of your fridge door** 把它想成家里的冰箱门

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.

> 这一段要解决的困惑是：复制为什么会准？很多同学以为有一种酶「记得」序列、主动挑选。比喻：往冰箱门上贴一张纸，它会滑下来；贴一块磁铁，它就留住了——冰箱门并没有在「挑」，它根本不知道你拿来的是什么，只是**留得住的才留下**。游离核苷酸也是如此：它们在核内四处漂移，不断撞上模板链暴露出来的碱基；那些不能在正确位置形成正确氢键的又漂走了，只有互补的那一个（A 配 T、C 配 G）能停留足够久，让 DNA 聚合酶把它接到正在延长的新链上。准确性就来自「只有对的那个才留得住」，不是来自某种记忆。失效之处有两点：第一，磁铁贴在门上哪个位置都行，而每种碱基只能与它唯一的配对对象结合；第二，磁铁吸得很牢很久，而一对碱基之间只有 2 个或 3 个**弱**氢键——弱到下次复制时解旋酶还能把它们重新打开。真正把新核苷酸固定进新链的，是 DNA 聚合酶在磷酸—脱氧核糖骨架上连成的共价键，而不是横在中间的那几个氢键。



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.

解链处放大图：解旋酶只打断碱基对之间的氢键，两条糖–磷酸骨架始终完整、并不断裂。

4. Worked example: building the complementary strand

4. 例题精讲：写出互补链

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.

> 如果你考的是 NSW Module 5 或 QCAA Unit 4，这是本章**最稳定会考、也最容易拿分**的一项技能，只要习惯变成自动的，就是白送的分。维州 VCE 学生要到 Unit 3 才正式学到它——但现在就练，因为后面整个遗传学都建立在这一步上。题目形式：给出一条链的碱基序列，要求写出以它为模板新合成的那条链的序列。你只需要一条规则——碱基互补配对：A 配 T，C 配 G。**一个碱基一个碱基地对着写，写在正下方**。不要在脑子里默算，也不要把字母顺序倒过来写。

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.

> **例题**。模板链：5'–T A C G G A T C–3'。一个一个来：T 配 A；A 配 T；C 配 G；G 配 C；G 配 C；A 配 T；T 配 A；C 配 G。所以新合成的互补链是 3'–A T G C C T A G–5'。写完用两种方法检查。第一，**数长度**：进去 8 个碱基，出来也必须是 8 个，长度不一致就说明漏了一个。第二，**扫一遍有没有违规配对**：出现 A 对着 G，或者 C 对着 T，就是错的。这两种错配恰恰是同学在考场紧张时真正会写出来的，所以值得专门检查一遍。

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.

> 关于 5' 和 3' 这两个标记。你会在考试图和课本的链上看到它们，在这个阶段它们只是记录了**两条链方向相反**这一事实——这就是反向平行 (antiparallel) 的含义。Year 11 阶段，你需要能说出「两条链是反向平行的」，并注意到互补链的标记是反过来写的。你**不需要**解释脱氧核糖 3'、5' 碳原子的化学结构，也不需要推理合成沿哪个方向进行。题目给你 5'–...–3'，问互补链，你就写成 3'–...–5'，然后做下一题。

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.

> 现在再养成一个额外习惯：如果题目给你一段序列，问「形成的这段双链之间共由多少个氢键维系」，就按 A–T 每对 2 个、C–G 每对 3 个来数。上面例题中有 4 对 A–T 和 4 对 C–G，所以 (4×2)+(4×3)=20 个氢键。NSW 的出题老师喜欢这种问法，因为它能检验你是不是**真的记得哪种配对有几个氢键**，而不是只会背 A 配 T、C 配 G 这几个字母。

KEY TERMS · 关键术语

complementary base pairing 碱基互补配对

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

腺嘌呤总是与胸腺嘧啶配对、胞嘧啶总是与鸟嘌呤配对的规则，配对靠氢键维持。

antiparallel 反向平行

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

描述 DNA 双螺旋的两条链彼此方向相反这一特征。

✦ TIP **Two letters, two shapes** 记忆法：用字母形状记配对

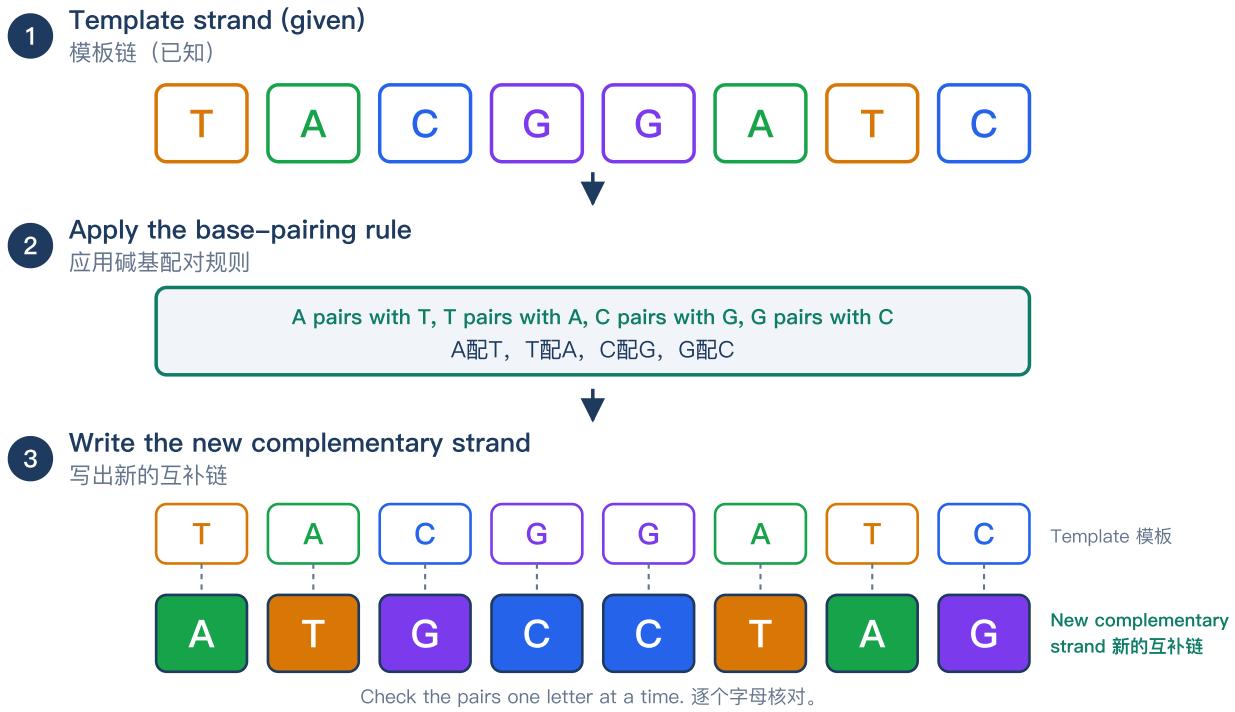
A and T are both drawn with straight lines; C and G are both drawn with curves. Straight goes with straight, curved goes with curved. It is purely a memory hook with no biological meaning — it is about the shapes of the letters as you write them, not the shapes of the molecules, which pair according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

> A 和 T 这两个字母都由直线构成，C 和 G 都带弯曲的弧线：直的配直的，弯的配弯的。这纯粹是个记忆钩子、没有任何生物学含义——这里说的是你写出来的字母形状，不是分子的形状；真正决定配对的是氢键（见下一个卡片）——但在考场紧张时能有效防止你写出 A–G 这种错配。

⚠ COMMON MISTAKE **"Bases fit together because of their shape, and are held by covalent bonds"** 误区：「碱基是靠形状卡在一起的，而且用共价键连接」

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.

> 大小和形状确实有作用，但**具体谁配谁是由「哪两种碱基之间能形成氢键」决定的**——而且这些是弱键，不是共价键。如果碱基对之间是共价键，双螺旋根本无法为了复制而「拉开拉链」。



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.

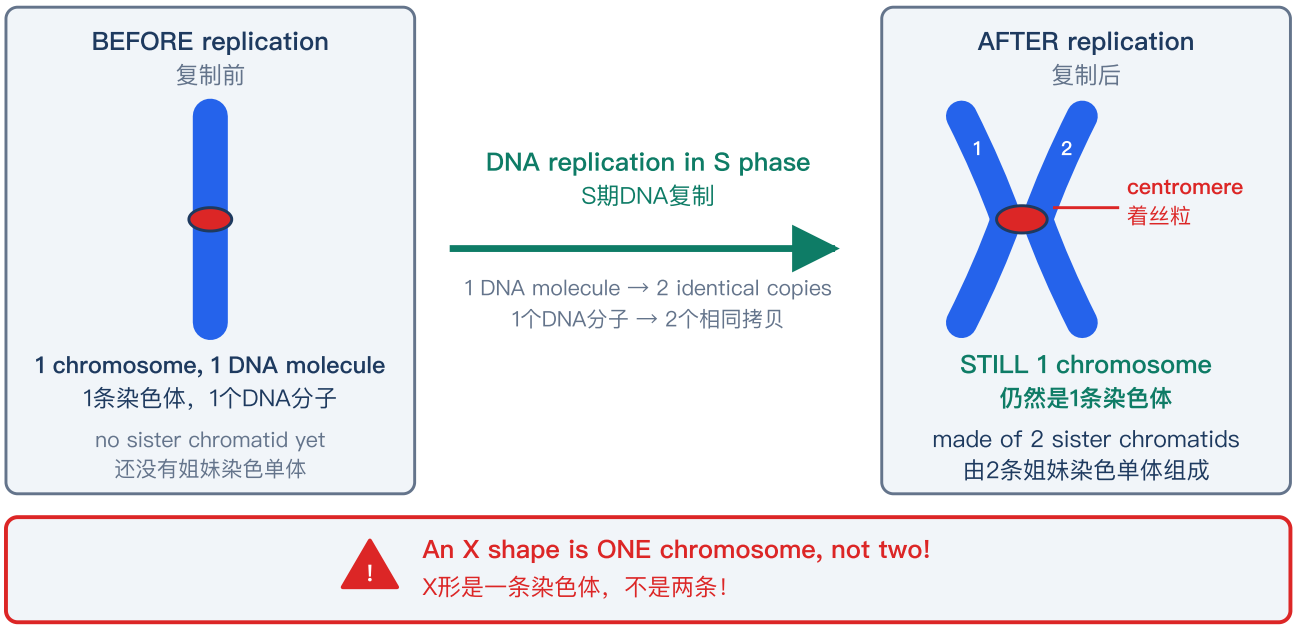
范例：已知模板链 T A C G G A T C，按碱基配对规则（A配T，C配G）写出新的互补链 A T G C C T A G。

5. After replication: sister chromatids and the X shape

5. 复制之后：姐妹染色单体与那个「X 形」

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.

> 现在把分子层面和你在显微镜下真正看得到的结构连起来。S 期之前，一条染色体是**一个**很长的 DNA 分子与蛋白质缠绕在一起——一根丝，携带这条染色体上全部基因的一份拷贝。S 期复制之后，同一条染色体里含有**两个完全相同的 DNA 分子**。等到前期染色体高度螺旋化变粗时，这两份拷贝就显现为并排的两根棒，中间由一个「细腰」连着。每一根棒叫一条染色单体 (chromatid)；由于两者互为精确拷贝，所以称为姐妹染色单体 (sister chromatid)。把它们连在一起的那个位置就是着丝粒 (centromere)。这样连着，就构成了课本插图里那个熟悉的 X 形。



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.
DNA复制前后对比：一条棒状染色体复制后成为X形，但仍然只是1条染色体，由在着丝粒处相连的2条完全相同的姐妹染色单体组成。

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.

> 下面这句话是整章**得分和丢分的分水岭**：一个 X 形结构仍然是**一条**染色体。它是由两条姐妹染色单体组成的一条染色体，**不是两条染色体**。刚完成 S 期的人类细胞仍然有 46 条染色体，不是 92 条——它有 46 条染色体、92 条染色单体。之后到了后期，着丝粒分裂、姐妹染色单体被拉开，每条分离出来的染色单体从那一刻起才各自算作一条独立的染色体。细胞内的染色体数目只在后期着丝粒分裂的那一瞬间短暂变成 92 条，胞质分裂后每个子细胞各得 46 条，与亲代细胞相同，因此细胞的倍性 (ploidy) 自始至终没有改变。**复制本身从未使染色体数目加倍。** 那些认为「前期加倍、后期减半」的同学，是把减数分裂 (meiosis) 的逻辑硬套到有丝分裂上，整道题都会因为这一个错误而塌掉。

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.

> 还有两个坑要堵上。**第一**，染色体并不总是 X 形。细胞一生的大部分时间里，它是未复制、未螺旋化的染色质 (chromatin)——一根细丝，在光学显微镜下根本分辨不出是独立结构。X 形只有在复制后的染色体于前期高度螺旋化之后才看得见，并且到后期着丝粒分裂时就消失。S 期结束到前期之间，染色体虽然已经复制，但仍是未螺旋化的染色质细丝——**已复制并不等于看得见 X 形**。**第二**，不要把姐妹染色单体和同源染色体 (homologous chromosomes) 混为一谈。姐妹染色单体是**同一条**染色体复制出来的两份完全相同的拷贝，由着丝粒连在一起；同源染色体是**两条独立**、彼此配对的染色体，一条来自父方、一条来自母方，以相同的顺序携带相同的基因，但基因的具体版本不一定相同，而且它们**从不**由着丝粒相连。

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.

> 最后是那条**因果链**。这才是真正被考的能力，请把它当作一个连贯的序列来记，而不是四条互不相干的事实。DNA 在 S 期进行半保留复制，**所以**每条染色体现在由两条完全相同、在着丝粒处相连的姐妹染色单体组成；到了后期，着丝粒分裂，每对中的一条染色单体被拉向一极；**因此**每个子细胞核都获得每一条染色体的一份完整而相同的拷贝，两个子细胞彼此之间、以及与亲代细胞之间都遗传物质完全相同——它们是克隆 (clone)。两个子细胞仍然都是二倍体 (diploid)：每种染色体各有两条，共 46 条，构成 23 对同源染色体。只有配子 (gamete) 只带一套染色体，而配子并不是由有丝分裂产生的。注意如果把第一步删掉会怎样：没有事先复制，有丝分裂就只是把现有染色体分一分，每分裂一次数目就减半。这就是「为什么复制必须先发生」的论证 (Justify) 依据。

KEY TERMS · 关键术语

sister chromatid 姐妹染色单体

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

同一条染色体经 DNA 复制产生的两份完全相同拷贝中的一条，二者在着丝粒处相连。

centromere 着丝粒

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

染色体上缢缩的部位，把姐妹染色单体连在一起，有丝分裂时纺锤丝在此附着。

chromatin 染色质

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

细胞周期大部分时间里存在于细胞核中的、未螺旋化的丝状 DNA 与蛋白质复合物。

genetically identical 遗传物质完全相同

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

碱基序列完全一致；用于描述有丝分裂产生的子细胞之间的关系。

⚠ COMMON MISTAKE

"An X-shaped chromosome is two chromosomes"

误区：「X 形的就是两条染色体」

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.

> **数着丝粒，不要数棒**。一个着丝粒 = 一条染色体，不管它上面挂着几条染色单体。人类细胞在 S 期结束时是 46 条染色体、92 条染色单体——染色体数目并没有变。

⚠ COMMON MISTAKE

"Daughter cells are identical because the DNA is shared out evenly"

误区：「子细胞相同是因为 DNA 被平均分了」

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.

> 评分时这种答案会扣分，因为它漏掉了「复制」这一步。把 46 条染色体平均分给两个细胞，每个只会得到 23 条。子细胞之所以相同，是因为 DNA **先**在 S 期被复制了，**然后**才被分配。

⚑ IN THE EXAM **Compare vs Distinguish** 考试提醒：Compare 与 Distinguish 的区别

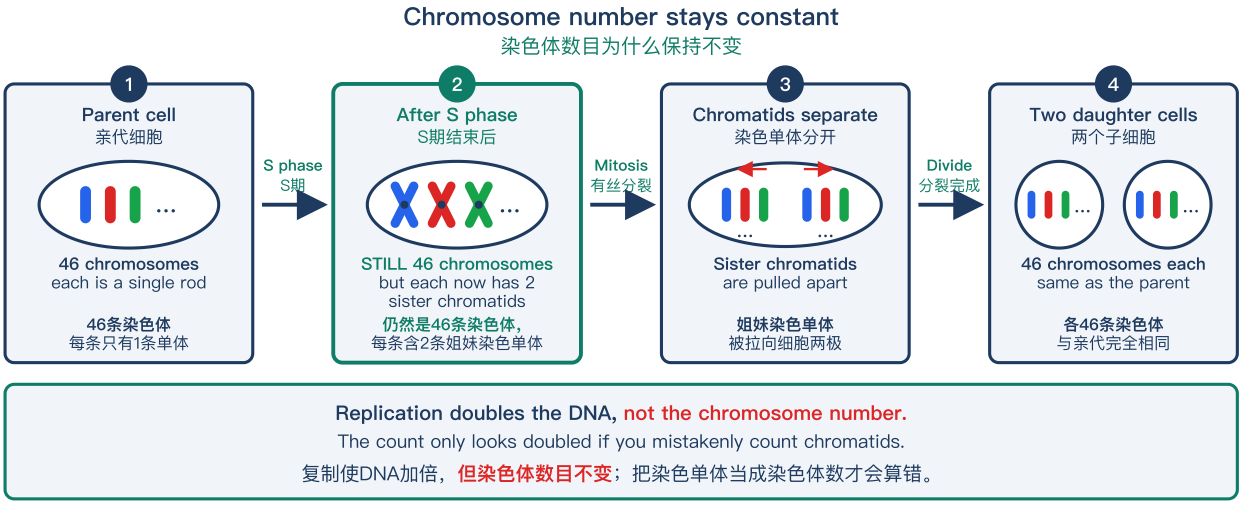
'Compare sister chromatids and homologous chromosomes' needs similarities AND differences, ideally in the same sentence (both are chromosome-level structures carrying the same genes, BUT sister chromatids are identical and joined at a centromere while homologues are non-identical and separate). 'Distinguish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

> 「Compare sister chromatids and homologous chromosomes」要求同时写出**相同点和不同点**，最好放在同一句里（两者都是染色体层面的结构、携带相同的基因，**但**姐妹染色单体完全相同且在着丝粒处相连，而同源染色体并不完全相同且彼此分离）。「Distinguish between」则只需要明确说出**差别点**那一句。

◈ EXAMPLE **Think of a song and its cover version** 把它想成一首歌和它的翻唱版

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.

> 这个例子专门分辨姐妹染色单体和同源染色体（本节最容易混的一对）。比喻：手机里存了一首歌，把这个文件复制一份，两个文件一模一样——这就是姐妹染色单体：S 期由**同一条**染色体复制出的两份完全相同的拷贝，并在着丝粒处相连。再想另一支乐队的**翻唱版**：同一首歌、同样的段落、同样的顺序，但录音不同——这就是同源染色体：**两条独立**的染色体，一条来自父方、一条来自母方，携带的基因种类和顺序相同，但每个基因的版本不一定相同；而且翻唱版是另一个文件，同源染色体**从不**由着丝粒相连。失效之处有两点：第一，翻唱可以多加或删掉一整段，而同源染色体的基因位置一一对应，差别只在每个基因的**版本**——而且很多基因上两条同源染色体的版本其实是相同的，「不一定相同」不等于「一定不同」。第二，复制文件会留下一个原封不动的原件加一个新副本，DNA 复制不是这样：两条姐妹染色单体各自都是「一条旧链 + 一条新链」，谁也不算「原件」——这就是第 2 节讲的半保留规则。



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.

复制使DNA加倍，但染色体数目不变：S期之后仍是46条染色体，只是每条含2条姐妹染色单体，分裂后每个子细胞仍是46条。

DAY 3 RECAP · 本日要点回顾

- 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.
  DNA 复制发生在（分裂）间期的 S 期——在有丝分裂开始之前就已完成；有丝分裂本身完全没有「复制」这一步。间期是细胞周期中最繁忙的阶段，不是「休息期」。
- 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.
  复制是半保留的：每个新分子保留一条完整旧链、新增一条完整新链。**每条链**要么全旧要么全新；「一半一半」指的是**分子**。
- 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.
  解旋酶打断的是碱基之间的弱氢键；由强共价键构成的磷酸—脱氧核糖骨架始终不断。正是因为有这种强弱对比，DNA 才能安全地「拉开拉链」再合上。
- 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.
  游离核苷酸（每个由一个磷酸、一个脱氧核糖和一个碱基组成）早已存在于细胞核中，靠碱基互补配对（A–T、C–G）被挑到正确位置；随后 DNA 聚合酶沿着每条模板链把它们连接成一条连续的新链。
- 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.
  复制后，每条染色体由两条完全相同、共用一个着丝粒的姐妹染色单体组成，即 X 形。那个 X 仍然是**一条**染色体：数着丝粒，不数棒。
- 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.
  染色体只有在前期高度螺旋化之后才看得见 X 形，到后期着丝粒分裂时 X 形就消失。S 期结束到前期之间，它虽然已经复制，却仍是未螺旋化的染色质细丝——**已复制不等于看得见 X 形**。
- 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.
  要背的因果链：S 期复制 → 形成两条相同的姐妹染色单体 → 后期着丝粒分裂、每极各得一条 → 因此两个子细胞各获得一套完整且相同的遗传信息，仍是二倍体（46 条、23 对同源染色体），是遗传物质完全相同的克隆（clone）。

Check Yourself — Day 3

自我检测 · 第 3 天（先合上笔记独立作答）

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 · 答案与解析

Write your answer out first. A question you have read the answer to is not practice.
先自己写完再对答案，看过答案就不算练习了。

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

答案是（分裂）间期的 S 期。复制在有丝分裂开始前就已完成：G1 期是生长，G2 期是分裂前的准备，而有丝分裂只负责分开已经存在的姐妹染色单体。选「前期」是本章最常见的错误。

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

被解旋酶打断的是互补碱基之间的**弱氢键**。磷酸—脱氧核糖骨架由强共价键维系，始终完整——正因如此，DNA 才能反复打开、闭合而不散架。选项 C 的错误在于把碱基之间说成共价键。选项 D 说的是磷酸与脱氧核糖之间的共价键（骨架的一部分），同样不会断开；而且磷酸从不与碱基直接相连，磷酸接的是糖，碱基也接在糖上。

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

每个新 DNA 分子含有**一条完整的原有（模板）链和一条完整的新链**，这就是半保留复制的含义。选项 A 是全保留复制 (conservative) 模型；选项 C 和选项 D 描述的都是弥散复制 (dispersive) 那一类结果——新旧材料混在**同一条链**里，二者都不是实际情况。半保留复制中，每条链要么整条是旧的、要么整条是新的；「一半一半」说的是**分子**，不是链。（拓展：全保留复制和弥散复制是如何被 Meselson–Stahl 实验排除的，见第 2 节的拓展卡片。）

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).

1. 解旋酶打断配对碱基之间的弱氢键，双螺旋解开、两条链分离；由强共价键构成的磷酸—脱氧核糖骨架不断开。2. 分开后的每条旧链充当模板链，碱基暴露出来。3. 细胞核中原本就存在的游离核苷酸按碱基互补配对与暴露的碱基配对：A 配 T，C 配 G。4. DNA 聚合酶沿着每条模板链把新到位的核苷酸连接成一条连续的新链。5. 每条模板链与其新链重新盘绕成双螺旋，形成两个完全相同的 DNA 分子，每个都含一条旧链和一条新链（半保留复制）。写答案时按 1—5 的顺序分点写，评分老师是按顺序给分的。

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.

互补链为 3'–ATGCCTAG–5'（逐个对应：T→A、A→T、C→G、G→C、G→C、A→T、T→A、C→G，不要颠倒顺序）。其中有 4 对 A–T（每对 2 个氢键）和 4 对 C–G（每对 3 个氢键），所以 (4×2)+(4×3)=20 个氢键。检查要点：长度必须同为 8 个碱基，且不能出现 A 对 G 或 C 对 T 的错配。

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.

答案是 5'–CCGTAATG–3'。逐个碱基配对：G→C、G→C、C→G、A→T、T→A、T→A、A→T、C→G。5' 与 3' 的标记要对调，因为两条链是反向平行 (antiparallel) 的，方向相反。Year 11 阶段只需知道「标记要反过来写」，不需要解释 3'、5' 碳的化学。

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

46 条染色体、92 条染色单体。复制使 DNA 的量加倍，但**染色体数目不变**：46 条染色体中的每一条现在都由两条完全相同的姐妹染色单体组成，二者共用一个着丝粒。判断方法是**数着丝粒，不数棒**。选「92 条染色体」，就是把染色单体当成染色体来数了，这是最常见的失分点。

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.

姐妹染色单体是**同一条**染色体在 S 期经复制产生的两份遗传物质完全相同的拷贝，二者在着丝粒处相连。同源染色体是**两条独立**、彼此配对的染色体，一条来自父方、一条来自母方，以相同的顺序携带相同的基因，但基因的具体版本不一定相同，并且它们**从不**由着丝粒相连。答题时把「是否完全相同」和「是否由着丝粒相连」这两个差别点明确写出来即可。

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.

有丝分裂本身不复制 DNA，它只负责把**已经存在**的姐妹染色单体分开。DNA 在 S 期进行半保留复制，所以每条染色体变成由着丝粒相连的两条完全相同的姐妹染色单体；到后期着丝粒分裂，每对中的一条移向一极，因此每个子细胞核都获得每条染色体的一份完整拷贝，二倍体的 46 条（每种染色体两条，构成 23 对同源染色体）得以维持。如果没有事先复制，有丝分裂就只是把现有的 46 条分给两个细胞，每个各得 23 条——每分裂一次数目减半，子细

胞得到的是不完整、也不相同的遗传信息。所以复制必须先于有丝分裂完成，才能产生遗传物质完全相同的子细胞。
（Justify 类题目一定要用 so that / because / therefore 把因果串起来，并给出明确结论。）

DAY 4

about 70 min · 约 70 分钟

Mitosis and Why It Matters

有丝分裂及其意义

THE BIG IDEA · 核心观念

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.

有丝分裂 (mitosis) 分的是细胞核 (nucleus)：S 期（合成期）已经使每条染色体 (chromosome) 都含有由着丝粒 (centromere) 连在一起的两条完全相同的姐妹染色单体 (sister chromatid)，有丝分裂做的事就是把它们精确地拉开、每极一条；随后胞质分裂 (cytokinesis) 把细胞质也分开，母细胞就变成了两个遗传物质完全相同 (genetically identical) 的子细胞 (daughter cell)，每个子细胞的染色体数目与母细胞相同（人的体细胞就是 46 条，属于二倍体 diploid）。生物体正是靠这一点来生长 (growth)、修复和替换磨损的组织 (tissue repair)，有些物种还靠它进行无性生殖 (asexual reproduction)。

BY THE END OF TODAY YOU WILL BE ABLE TO · 今天学完你将能够

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.
   描述 (Describe) 前期 (prophase)、中期 (metaphase)、后期 (anaphase)、末期 (telophase) 各自发生了什么，说清楚染色体 (chromosome)、核膜 (nuclear envelope)、纺锤丝 (spindle fibre) 在每一期的变化。
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.
   看图或看显微照片就能识别 (Identify) 出这是有丝分裂的哪一期，并能指出那个“一眼定案”的可观察特征来论证 (Justify) 你的判断。
3. Distinguish mitosis from cytokinesis, and distinguish cytokinesis in an animal cell from cytokinesis in a plant cell.
   区分 (Distinguish) 有丝分裂与胞质分裂 (cytokinesis)；并区分动物细胞和植物细胞的胞质分裂方式（分裂沟 vs 细胞板）。
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.
   解释 (Explain) 两个遗传物质完全相同、且染色体数目与母细胞相同的子细胞是怎么产生的：把 S 期的半保留复制 (semi-conservative replication) 和后期姐妹染色单体的分开连成一条完整因果链。
5. Compare mitosis and meiosis using number of divisions, number of daughter cells, chromosome number, genetic outcome and function.
   比较 (Compare) 有丝分裂和减数分裂 (meiosis)：按分裂次数、子细胞数目、染色体数目、遗传结果、功能这五条标准逐条对照（注意 Compare 要求同时写异同）。
6. Assess the importance of mitosis to living organisms, supporting your judgement with named examples of growth, tissue repair and replacement, and asexual reproduction.
   评估 (Assess) 有丝分裂对生物体的重要性，并用具体、能点出名称的实例（生长、组织修复与替换、无性生殖）来支撑你的判断。

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

有丝分裂分的是细胞核——“细胞分裂”= 有丝分裂 + 胞质分裂

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.

> 先想象一个**人体细胞**刚走完 G2 期（第二间隙期）、踏进 M 期（分裂期）的那一刻。因为 S 期已经把细胞核里每个 DNA 分子都复制过一遍，此时它的 46 条染色体，每一条都由着丝粒 (centromere) 连着的两条完全相同的姐妹染色单体 (sister chromatid) 组成。接下来细胞面对的是“分配”问题，而不是“复制”问题：一个细胞核里现在装着两整套遗传信息，它必须让即将形成的两个细胞各拿到完整的一套。解决这个问题的过程就是有丝分裂 (mitosis)。请注意这个词严格的含义：有丝分裂分的是**细胞核** (nucleus)——染色体被分开，形成两个新的细胞核。有丝分裂本身并不把细胞分成两个。

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.

> 把细胞本身一分为二，是另一件事，叫胞质分裂 (cytokinesis)——细胞质被分开，才真正出现两个各自独立的子细胞 (daughter cell)。两件事合起来，就是阅卷老师想看到的那个等式：有丝分裂 + 胞质分裂 = M 期 = 细胞分裂。这不是抠字眼。如果你用“mitosis”笼统指整个细胞分裂，那么遇到“比较植物细胞和动物细胞怎样分细胞质”这类题，你会发现自己没词可用；而且你也解释不了一个真实的生物学现象（超纲，但足以说明问题）：在人体某些组织（最典型的是肝脏）里，偶尔会出现只做有丝分裂、不做胞质分裂的情况，结果是一个细胞里有两个细胞核。如果两者是同一件事，这种现象根本不可能存在。

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.

> 下面这句“结论句”值得几乎逐字背下来：有丝分裂加上胞质分裂，产生两个遗传物质完全相同 (genetically identical) 的子细胞，每个子细胞的染色体数目与母细胞相同。对人的体细胞来说，就是每个子细胞都有 46 条染色体、23 对，属于二倍体 (diploid)，和它的来源细胞一模一样。有丝分裂发生在体细胞 (somatic cell) 里——皮肤、肝脏、根尖、肠道内壁这些普通的身体细胞——也发生在进入减数分裂之前不断增殖的生殖细胞前体中。在动物里，产生卵细胞和精子的不是它，而是减数分裂 (meiosis)，今天最后一节会专门对比。还有一点要有比例感：有丝分裂占了课堂的大半时间，但在真实的细胞周期 (cell cycle) 里只占很小一段，（分裂）间期 (interphase) 要长得多。

KEY TERMS · 关键术语

mitosis 有丝分裂

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

细胞核的分裂过程：把姐妹染色单体分开，形成两个遗传物质完全相同的子细胞核。

cytokinesis 胞质分裂

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

细胞核分裂之后，细胞质被分开的过程，最终形成两个彼此独立的子细胞。

M phase M 期（分裂期）

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

细胞周期中由有丝分裂和胞质分裂共同构成的一段，是整个周期里最短的部分。

somatic cell 体细胞

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

除生殖细胞（配子）以外的普通身体细胞；人的体细胞是二倍体，含 46 条染色体。

daughter cell 子细胞

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

母细胞完成有丝分裂和胞质分裂后产生的那两个细胞中的任意一个。

⚠ COMMON MISTAKE **"Mitosis" is not a synonym for "cell division"** 误区：把“有丝分裂”当成“细胞分裂”的同义词

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.

> 有丝分裂只完成了一半工作——细胞核那一半。细胞分裂 = 有丝分裂 + 胞质分裂。末期 (telophase) 结束时，你得到的是**一个细胞里的两个细胞核**；只有胞质分裂才把它变成两个细胞。写答案时先问自己：这句话讲的是染色体和细胞核（有丝分裂），还是细胞质和细胞膜（胞质分裂）？然后用对应的那个词。

✦ TIP **Two jobs, two words** 记忆法：两件事，两个词

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.

> 想象把一间共用的图书室分成两间。第一步，把书分成完整且完全相同的两摞——这是有丝分裂；第二步，在屋子中间砌一堵墙——这是胞质分裂。这个比喻有一处要修正：真实细胞里的“书”早在 S 期就已经复印过一份，所以两摞才可能都是完整的，没有任何一本书被撕成两半。

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

考法：Outline / Describe / Explain 是三种不同的任务

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.

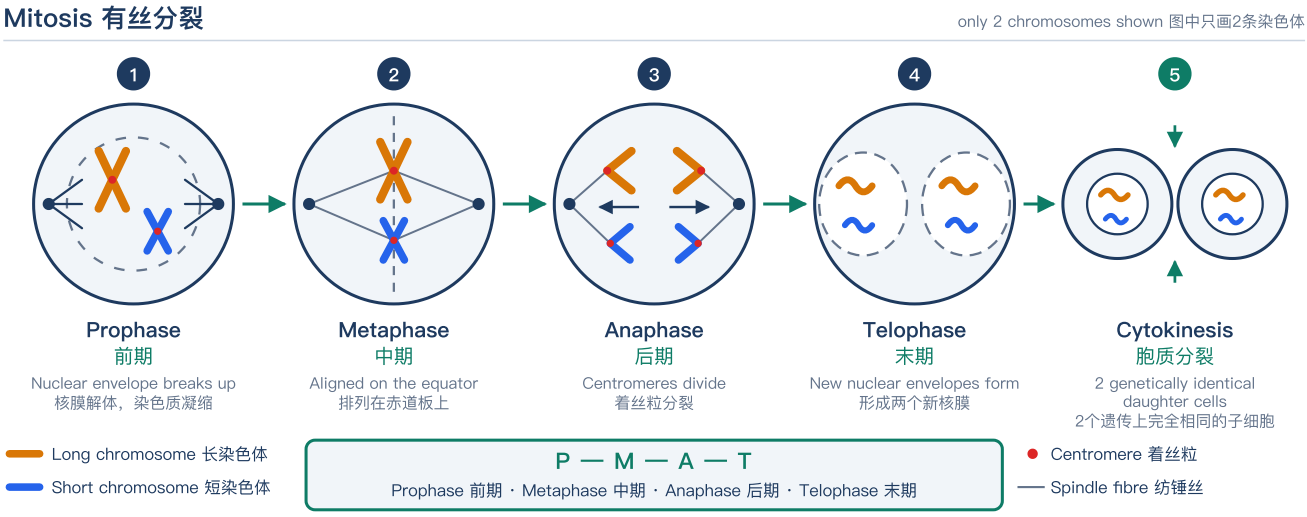
> Outline the events of the cell cycle（概述）= 按顺序列出主要环节，几行字，不讲机制。Describe what occurs during anaphase（描述）= 详细说出“发生了什么”，不需要讲原因；只报出期的名字、不说里面发生什么，一分不得。Explain how genetically identical daughter cells are produced（解释）= 必须是因果链，句与句之间要用 because / so that / therefore 串起来。动笔前先看清命令动词。

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

PMAT 四期：每一期发生什么，以及怎么一眼认出来

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.)

> 有丝分裂其实是一个连续的过程，但生物学家把它切成四个有名字的时期：前期（prophase）、中期（metaphase）、后期（anaphase）、末期（telophase），缩写 PMAT。这些名字是按“显微镜下看得见什么”来分的；真实细胞是从一期平滑滑进下一期的，所以这些界线主要是为了方便描述和考试。（有些教材会在前期和中期之间插一个 prometaphase（前中期）。澳洲高中生物课程考查的就是 PMAT 这四期，记这四个就够了；prometaphase 只当背景知识了解。）



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.

有丝分裂五个阶段（前期、中期、后期、末期、胞质分裂），只用两条染色体（一长一短）追踪，说明两个子细胞为何遗传上完全相同。

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.

> 前期 (prophase)。染色质 (chromatin)——DNA 在整个间期里那种细长、缠绕的形态——开始高度螺旋化、凝缩，直到每条染色体变得又短又粗、染色后在显微镜下清晰可见。因为 S 期早已完成，此时每条染色体呈现为由着丝粒连着的两条姐妹染色单体，也就是我们熟悉的“X 形”。但别把这个 X 形当成染色体的定义。染色体只有在 S 期之后、后期之前才呈 X 形。细胞一生的大部分时间里——包括刚分裂完的两个子细胞里——每条染色体都只是一条未复制的、单条的染色质细丝，细到根本看不见。核仁 (nucleolus) 消失，核膜 (nuclear envelope) 解体，染色体不再被“围”在核里；纺锤丝 (spindle fibre)——一种蛋白质细丝——从细胞两极形成并延伸出来。动物细胞里有一对中心粒 (centriole) 移向每一极；植物细胞没有中心粒，照样能组装出纺锤体。

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.

> 中期 (metaphase)。纺锤丝附着在每条染色体的着丝粒区域——更准确地说，是附着在着丝粒上组装起来的一种蛋白质结构，叫动粒 (kinetochore)——而不是附着在染色体两端，后者是画图时最常见的错误之一。纺锤丝牵引染色体，直到所有染色体都排列在细胞中央的同一个平面上。这个平面就是赤道板 (equator / metaphase plate)。中期是最容易辨认的一期：细胞正中一条整整齐齐的染色体“横队”，两极什么都没有。可以把它理解成细胞在“验货”：每条染色体都被两侧的纺锤丝同时抓住之后，才允许开始分开。

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.

> 后期 (anaphase)。每条染色体的着丝粒分裂，两条姐妹染色单体终于被分开。纺锤丝缩短，把每一对中的一条拉向这一极、另一条拉向那一极。着丝粒一分开的那一瞬间，每条染色单体就不再叫染色单体，而各自成为一条独立的染色体。显微镜下的后期长这样：两簇 V 形或 J 形的染色体正在向两边移动，中间的空隙越来越大——之所以呈 V 形，是因为它们都被着丝粒“领着走”，两条臂在后面拖着。

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.

> 末期 (telophase)。染色体到达两极，有丝分裂开始“倒放”前期的动作：染色体解螺旋、松散回染色质状态，核膜在两组染色体外重新形成，核仁重新出现，纺锤体解体。末期结束时，出现了两个完整且完全相同的细胞核——但此刻它们仍然待在**同一个**细胞里。有丝分裂到此结束，接下来才轮到胞质分裂。

KEY TERMS · 关键术语

prophase 前期

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

有丝分裂第一期：染色质凝缩成可见的染色体，核膜解体，纺锤丝形成。

metaphase 中期

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

有丝分裂第二期：染色体排列在赤道板上，纺锤丝附着在其着丝粒（上的动粒）上。

anaphase 后期

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

有丝分裂第三期：着丝粒分裂，姐妹染色单体被拉向细胞两极。

telophase 末期

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

有丝分裂最后一期：染色体到达两极并解螺旋，两个新的核膜形成。

spindle fibre 纺锤丝（纺锤体）

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.

从分裂细胞的一极伸出的蛋白质细丝（微管）；其中附着到染色体着丝粒上的动粒 (kinetochore) 的那些负责牵引染色体移动，另一些则只是把两极撑开。

⚑ IN THE EXAM

Identify the stage shown — one giveaway feature each 考法：识别是哪一期——每期一个“定案特征”

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.

> Identify（识别）本身只要答出名字就得分；但题目若加了 justify（论证），就要说出你**真正看得见**的那一个特征。间期：看不到清晰的染色体，核膜完整。前期：染色体已可见但散乱分布，没有核膜，也没排队。中期：正中一条整齐的“横队”。后期：两簇 V 形染色体正在分开，中间有空隙。末期：两簇染色体已到两极、正在解螺旋，核膜正在重新形成。遇到 Sequence（排序）题，就按这套“看得见的逻辑”排，而不是靠背图的顺序。

⚠ COMMON MISTAKE **Chromosome number does not double at prophase or halve at anaphase** 误区：染色体数目在前期加倍、在后期减半

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.

> 认真数一遍。进入有丝分裂的人类细胞有 46 条染色体，每条含 2 条姐妹染色单体——那是 92 条染色单体，但**染色体仍是 46 条**，前期、中期都一样。到后期着丝粒一分裂，每条染色单体就变成一条染色体，于是这**一个**细胞里瞬间有 92 条染色体，其中 46 条奔向这一极、46 条奔向那一极。所以每个子细胞核最后拿到 46 条。开始时是二倍体 (diploid)，结束时两个子细胞也都是二倍体：有丝分裂全程倍性 (ploidy) 不变。

⚠ COMMON MISTAKE **DNA is not replicated during prophase** 误区：DNA 在前期（或“分裂一开始”）才复制

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.

> 染色体是到前期才变得可见的，所以同学们常常以为 DNA 就是这时候复制的。有丝分裂全程不复制任何 DNA。复制早在 S 期就已完成（可能是几小时之前）——这正是为什么染色体一凝缩就已经是两条姐妹染色单体。在前期看到两条染色单体，恰恰证明复制**已经发生过**，而不是正在发生。

⬡ EXTENSION **Extension: the mitotic index** 拓展：有丝分裂指数 (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.

> 【拓展内容】这是澳洲实验与数据题的经典考法。在染色好的洋葱根尖或白鲑囊胚切片上，数出各个时期的细胞数。有丝分裂指数 = 处于有丝分裂中的细胞数 ÷ 计数的细胞总数 × 100%。因为切片是把一群细胞“定格”在同一瞬间，某一期被“抓拍”到的细胞比例，正比于该期持续的时间长短，所以可以估算：某期时长 = 该期细胞比例 × 整个细胞周期的时长。这也解释了为什么任何切片上大多数细胞都处在间期——不是因为间期乏善可陈，而是因为它太长了。

◈ EXAMPLE **Think of two keys on one keyring** 想象一个钥匙环上挂着两把一样的钥匙

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.

> 把着丝粒想成钥匙环：环上挂着两把完全相同的钥匙（姐妹染色单体），你仍然只会说“一个钥匙环”。所以前期和中期的人类细胞是 46 个环 = 46 条染色体，尽管上面挂着 92 把钥匙（92 条染色单体）——数目并没有加倍。到后期着丝粒分裂，这个环本身一分为二，每把钥匙各自带着一个环离开，这就是“每条染色单体变成一条独立染色体”的含义，也是那一瞬间一个细胞里有 92 条染色体（每极 46 条）的原因。比喻的失效处：这个“环”不是从外面扣到染色体上的一个卡扣——着丝粒是染色体自身 DNA 的一个区域，分开之后每条新染色体仍然各有一个。这一点很要紧：纺锤丝正是抓在那里，“领着”染色体先走，后期看到的那些 V 形就是这么来的。这个例子专攻“数染色体还是数染色单体”这一最易失分处。

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

胞质分裂：分细胞质，以及植物为什么另有一套办法

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.

> 胞质分裂 (cytokinesis) 通常在后期后段就已开始，贯穿末期，在有丝分裂结束后不久完成。在动物细胞里，紧贴细胞膜内侧、沿赤道板环绕细胞一圈的蛋白质细丝会收缩，就像把一根抽绳慢慢拉紧。细胞膜被向内拉，形成一道凹槽，叫分裂沟 (cleavage furrow)；凹槽越陷越深，最后把细胞“掐”成两个独立的细胞。抽绳这个比喻不错，但要注意两点：这根“绳”在细胞**内**，由蛋白质细丝构成；而且不需要打结收口——细胞膜在中间相遇后直接融合封闭。

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.

> 植物细胞“掐不动”。它外面包着一层坚硬的纤维素细胞壁 (cell wall)，不会那样变形，所以植物细胞改用“砌墙”的办法。携带细胞壁材料的具膜小囊泡聚集到赤道板位置，彼此融合，形成一个叫细胞板 (cell plate) 的结构。细胞板从细胞中央**向外**生长，直到与原有的细胞壁相接；板内的材料形成新的细胞壁，两侧各形成一层新的细胞膜。考试要写的“定案特征”就是方向：动物的胞质分裂是由外向内，植物的胞质分裂是由内向外。

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.

> 还有一个准确的小细节值得记住。细胞质和其中的细胞器 (organelle) 是**大致**平分的，不是精确平分——某个子细胞可能多分到几个线粒体，这没关系。子细胞“遗传物质完全相同”这件事来自细胞核，具体说是来自 S 期的复制加上后期染色单体的精确分离。植物与动物细胞的胞质分裂在 VCE Unit 1 里是点名要求的内容，而且是各地都爱考的比较题，所以两套机制都要用规范术语记牢。

KEY TERMS · 关键术语

cleavage furrow 分裂沟

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.

动物细胞分裂时，赤道处环绕细胞一圈的蛋白质细丝收缩，把细胞膜向内拉出的凹槽，最终把细胞缢缩成两个。

cell plate 细胞板

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.

植物细胞分裂时，囊泡在赤道处融合形成的结构，向外扩展并最终形成两个子细胞之间的新细胞壁。

cell wall 细胞壁

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

植物细胞膜外坚硬的纤维素层；正因为有它，植物细胞无法靠向内缢缩的方式分裂。

⚠ COMMON MISTAKE

Plant cells do not pinch, and the cell plate does not close inwards

误区：植物细胞“缢裂”，或细胞板“由外向内合拢”

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.

> 这里两个错误常常结伴出现。第一，植物细胞不会形成分裂沟，因为坚硬的细胞壁不可能被向内拉。第二，细胞板不是像相机快门那样从四周向中间合拢——它从**中央**开始、向**外**延伸，最后与原有细胞壁融合。如果你既能写出机制，又能写出原因（因为有细胞壁），那么 Describe 的分和 Explain 的分你都拿到了。

IN THE EXAM "Distinguish" wants one explicit point of difference 考法：Distinguish 要的是“一句话说清一个差别”

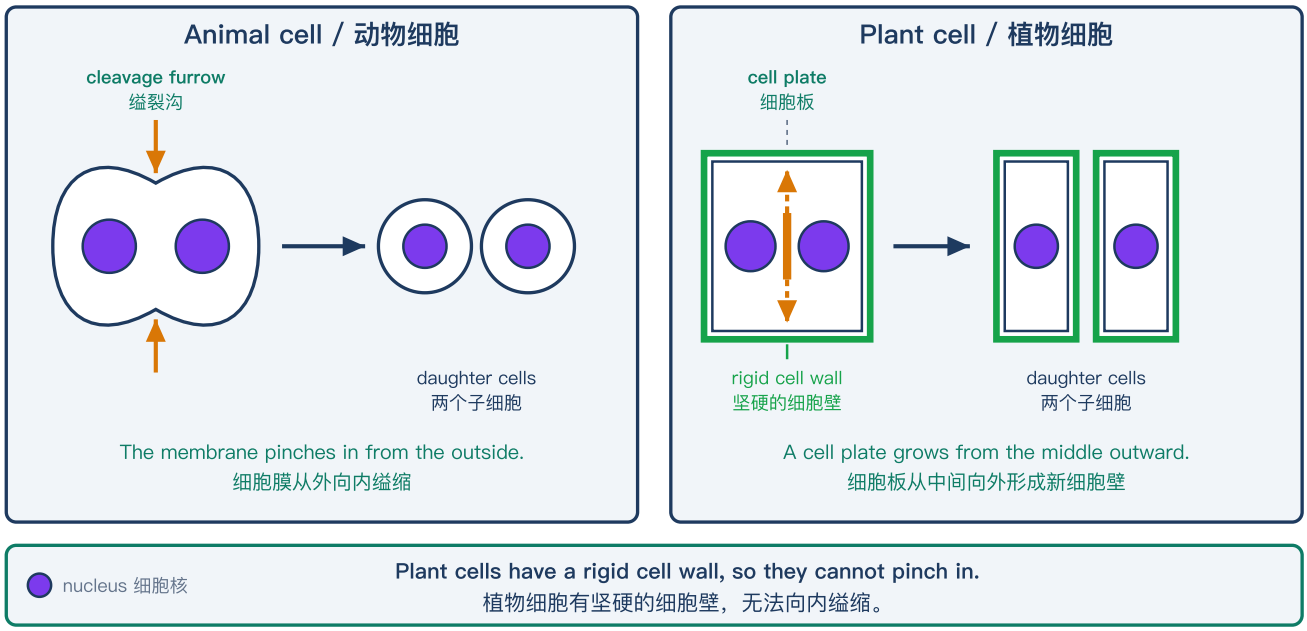
Distinguish between cytokinesis in plant and animal cells is answered in a single sentence that names the criterion and applies it to both: "In an animal cell the membrane is pinched inwards by a cleavage furrow, whereas in a plant cell a cell plate forms at the equator and grows outwards to become a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

> Distinguish between cytokinesis in plant and animal cells（区分两者）应当用**一句话**答完，句中点明比较标准并同时套用到两边：“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.”（动物细胞靠分裂沟向内缢缩，而植物细胞在赤道形成细胞板并向外扩展成新细胞壁。）把两段描述各写各的、并排放着，常常拿不到分——那个 whereas 是实打实在起作用的。

TIP Animals pinch in, plants build out 记忆法：动物“往里掐”，植物“往外砌”

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.

> 考场上先抓住这十个字：动物往里掐，植物往外砌。然后再用规范术语展开——“往里掐”是分裂沟 (cleavage furrow)，“往外砌”是细胞板 (cell plate) 形成新的细胞壁——最后补上原因：植物细胞壁是刚性的。



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.
胞质分裂对比：动物细胞靠细胞膜从外向内缢缩形成缢裂沟，而植物细胞因有坚硬细胞壁无法缢缩，改由细胞板从中间向外形成新细胞壁。

How two genetically identical daughter cells are actually produced

两个“遗传物质完全相同”的子细胞到底是怎么来的

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.

> 这是这四天内容里最大的一个问题，答案是一条因果链。第一步：S 期里每个 DNA 分子都进行半保留复制 (semi-conservative replication)——碱基之间的氢键 (hydrogen bond) 断裂，双螺旋解开，每条母链作为模板链 (template strand)，细胞核中原本就存在的游离核苷酸 (nucleotide) 按碱基互补配对 (complementary base pairing) 原则配上去，A 配 T、C 配 G。第二步：因为配对规则是固定的，新链的序列完全由母链决定，所以生成的两个 DNA 分子完全相同。第三步：这两个相同的分子并不分开，而是作为姐妹染色单体，由着丝粒连在一起。

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.

> 复制这一半讲完了；接下来三步讲的是怎么把拷贝送出去。第四步：中期时，每条染色体的着丝粒都被来自两极的纺锤丝抓住。第五步：后期每个着丝粒分裂，每一对中的一条去一极——每一极拿到的是**每一条**染色体的一份拷贝，绝不是随机的一半。第六步：末期和胞质分裂把每一套分别包进各自的核膜和细胞质里。

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.

> 注意真正“干活”的是哪一步。很多同学会写：子细胞之所以相同，是“因为 DNA 被平均分给了它们”。阅卷老师不接受这种说法，而且这是对的：把一样东西平分，每边得到的是它的**一半**，而不是它的**完整拷贝**。相同性来自两件事——先在 S 期复制，再在后期精确分离。如果考试只让你记一句话，就记这句：复制负责“做出拷贝”，后期负责“把拷贝分出去”。这也正是复制必须在 S 期完成、在有丝分裂开始之前就结束的原因。有丝分裂只负责把已经存在的染色单体分开，它本身不制造任何新的 DNA。如果一个人类细胞没复制就进入分裂，那 46 条单染色单体的染色体只会被分到两极去，每个子细胞只拿到约 23 条、基因残缺不全，而且每分裂一次染色体数就再减半一次。

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.

> 最后，要弄清楚“遗传物质完全相同 (genetically identical)”这句话主张了什么、没有主张什么。它的意思是：两个子细胞彼此之间、以及与母细胞之间，携带相同的 DNA 序列，也就是相同的基因 (gene)。它**不**意味着它们永远长得一样、干一样的活。多细胞生物在发育过程中，细胞会分化 (differentiation)：你体内的肌细胞和神经细胞含有完全相同的 DNA，但开启的基因不同，于是形态和功能天差地别。同一本说明书，只是翻开的页码不同。

KEY TERMS · 关键术语

genetically identical 遗传物质完全相同
Having exactly the same DNA sequence, and therefore the same genes, as another cell or organism.
与另一个细胞或个体拥有完全相同的 DNA 序列，因而携带相同的基因。

clone 克隆（无性系个体）
A cell or organism that is genetically identical to the one it came from, because it was produced by mitosis rather than sexual reproduction.
由有丝分裂（而非有性生殖）产生、与来源细胞或个体遗传物质完全相同的细胞或生物体。

differentiation （细胞）分化
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.
细胞在 DNA 不变的前提下，通过选择性地开启部分基因而变得具有特定功能的过程。

diploid 二倍体
Having two complete sets of chromosomes, one from each parent; human somatic cells are diploid with 46 chromosomes in 23 pairs.
含有两套完整染色体（分别来自双亲）的状态；人的体细胞是二倍体，共 46 条、23 对。

⚠ COMMON MISTAKE

"The DNA is shared out evenly" is not an explanation

误区：用“DNA 被平均分了”来解释相同性

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.

> 这是本章扣分最狠的一句话，因为它把“复制”这一步弄丢了。把一套说明书在两个细胞之间“分一分”，结果是两边都不完整。真实过程是：每条染色体在 S 期被复制成两条完全相同的姐妹染色单体，后期再把每一对中的一条送往一极。任何没有提到复制的答案，无论 PMAT 描述得多流畅，都拿不到满分。

IN THE EXAM A model 4–mark "Explain" answer 范例：4 分的 Explain 答案该怎么写

"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.

> “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.” 四句话：间期 S 期复制 → 中期排队被抓住 → 后期着丝粒分裂、每极各得一条 → 因此两个子细胞遗传物质完全相同。四个逻辑连接词，四分到手。

EXTENSION Extension: cell cycle checkpoints 拓展：细胞周期检查点 (checkpoint)

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.

> 【拓展内容】这是 VCE Unit 1“细胞周期调控失常”那条要求的必备背景，对其他州的同学则是很好的加深。细胞周期由若干检查点 (checkpoint) 把关。**G1 检查点**（S 期之前）：细胞够不够大、养分和生长信号是否充足、DNA 有没有损伤——本质上是在问“值不值得开工”。**G2 检查点**（有丝分裂之前）：检查 DNA 复制是否已经正确完成。**M 期（纺锤体）检查点**（中期）：检查是否每条染色体都被来自两极的纺锤丝正确抓住，通过了才允许进入后期。任何一关不过，细胞周期就会暂停以便修复，或者干脆把这个细胞清除掉。

◈ EXAMPLE **Think of splitting a fifty at dinner** 想象两个人平分一张五十元钞票

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.

> 两人平分一张五十元，各得二十五——是钱的一半，不是各自五十。靠“平分”永远不可能让两边都拿到完整的一份，除非事先复制过。这就是为什么“DNA 被平均分配”是本章扣分最狠的答案：把一套染色体分给两个细胞，每边只有约 23 条、基因残缺，正是课文说的“没复制就进入分裂”的后果。两个子细胞都拿到完整的 46 条，靠的是 S 期已把每个 DNA 分子半保留复制完毕，后期只负责把已经存在的拷贝分发出去——“复制做拷贝，后期分拷贝”。比喻的失效处：和钱不同，复制 DNA 是有真实代价的——消耗游离核苷酸、酶和 S 期数小时的时间。另外，母细胞并不是“自己留一套、把拷贝发出去”：它本身就变成了那两个子细胞；而且因为复制是半保留的，每条子细胞染色体上都带着母细胞原来的一条链，另一条才是新合成的。

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

有丝分裂的意义：生长、修复替换、无性生殖

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.

> **生长 (growth)。** 你曾经只是一个细胞——一个受精卵；如今身体里数十万亿个细胞，全都是它经有丝分裂一代代增殖而来的。多细胞生物的生长主要是细胞**数目**的增加（同时也伴随细胞体积增大和分化），而由于有丝分裂复制得极其忠实，每个细胞都继承了同样完整的一套指令。植物的生长集中在分生组织 (meristem) 区域——这正是为什么观察有丝分裂的标准材料是根尖：那是少数“任一瞬间都有大量细胞在分裂”的部位之一。

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.

> **修复与替换 (tissue repair)。** 停止长个子并不代表有丝分裂就停了，这一点最容易被忽略。皮肤在不断脱落、不断更新；肠道内壁因为长期受消化酶的“摧残”，每隔几天就要更换一批；骨髓持续生产新的红细胞和白细胞，部分原因是成熟红细胞没有细胞核、不能分裂，寿命大约只有四个月。当你划破手指，正是有丝分裂把伤口合上：切口边缘的细胞分裂来填补缺口，并且在与邻近细胞接触后通常就停止分裂。

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.

> **无性生殖 (asexual reproduction)。** 有些生物直接用有丝分裂产生新个体。酵母和水螅 (Hydra) 靠出芽生殖：有丝分裂长出的小芽体最终脱落、独立生活。草莓通过匍匐茎 (runner) 生根长成新植株，园丁扦插用的也是同一种能力——两者都属于营养繁殖 (vegetative propagation)。涡虫被切成两段可以再生出缺失的一半，某些海星也能由断片再生。所有这些情况下，后代都由有丝分裂产生，因此与亲本遗传物质完全相同，即克隆 (clone)。

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.

> **二分裂 (binary fission)。** 细菌也是无性生殖，但它们**不做有丝分裂**，而是二分裂——这个对比在 VCE Unit 1 里是点名要求的内容。细菌没有细胞核、没有纺锤体，遗传物质是一条环状 DNA（单个环状染色体）。二分裂过程中，这条染色体先被复制，两份拷贝随细胞伸长而分向两端，随后细胞膜和细胞壁向内生长，把细胞一分为二。它比真核细胞周期简单得多、也快得多：在理想的实验室条件下，大肠杆菌 (E. coli) 大约每 20 分钟就能分裂一次。所以题目问细菌怎么繁殖时，写“mitosis”就是错的。

KEY TERMS · 关键术语

asexual reproduction 无性生殖

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

只有一个亲本、不涉及配子的生殖方式，产生的后代与亲本遗传物质完全相同。

binary fission 二分裂

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.

原核细胞一分为二的繁殖方式：环状染色体先复制，细胞再分裂；全程没有细胞核，也没有纺锤体。

tissue repair 组织修复

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

通过有丝分裂替换受损或磨损细胞的过程，例如伤口愈合、皮肤与肠道内壁的持续更新。

vegetative propagation 营养繁殖

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

植物用匍匐茎、块茎、插条等非生殖器官进行的无性生殖，后代与亲本遗传物质完全相同。

⚠ COMMON MISTAKE **Mitosis is not only for children** 误区：有丝分裂只发生在长身体的时候

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.

> 很多同学把有丝分裂只和“长个子”挂钩，以为成年后就不用了。事实上成年人的身体每天都在进行大量有丝分裂——仅仅为了替换皮肤、肠道内壁和血细胞，以及修复损伤。凡是要求 assess（评估）有丝分裂重要性的题，除了生长，还必须写出替换与修复，并且要有具体例子。

⚠ COMMON MISTAKE **Clones are not identical in every respect** 误区：克隆后代“方方面面都一样”

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".

> 无性生殖产生的后代，在产生的那一刻与亲本遗传物质完全相同，但有两点必须补充。第一，任何复制过程都不可能百分之百完美，突变可能出现，遗传差异会随时间累积。第二，表现型 (phenotype) 由基因和环境共同决定：两株遗传上完全相同的草莓，种在不同的土壤和光照下，长得不会一样大。所以要写“遗传物质完全相同”，而不是“完全一模一样”。

EXTENSION **Extension: advantages and disadvantages of asexual reproduction** 拓展：无性生殖的优点与缺点

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.

> 【拓展内容】本章不要求，但常作为后续追问。无性生殖的优点是快、不需要寻找配偶、能把已经很适应环境的基因型原样保留下来。缺点是缺乏遗传变异：每个个体的弱点都一样，一场新的疾病或一次环境剧变就可能让整个种群覆没。

EXTENSION **Extension: stem cells and potency** 拓展：干细胞与潜能等级

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.

> 【拓展内容】这是 VCE Unit 1 和 QCAA Unit 1 的必学内容，对其他州的同学则是有益的加深。干细胞 (stem cell) 是尚未特化的细胞，既能通过有丝分裂自我增殖，又能分化 (differentiation) 成特化细胞。“潜能 (potency)”描述它能变成多少种类型：**全能性 (totipotent)**——受精卵和极早期胚胎细胞，能形成包括胎盘等胚外组织在内的所有细胞类型；**多能性 (pluripotent)**——胚胎干细胞，能形成机体所有类型的细胞，但不能形成那些胚外组织；**多潜能性 (multipotent)**——如骨髓中的造血干细胞，只能形成一小类相关的细胞；**单能性（专能性，unipotent）**——只能产生一种类型，但仍可自我更新。一个受精卵之所以能变成 200 多种不同的细胞，靠的就是有丝分裂 + 分化。

EXTENSION **Extension: G0, the cells that stop dividing** 拓展：G0 期——不再分裂的那些细胞

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.

> 【拓展内容】许多高度特化的细胞会彻底退出细胞周期，进入不再分裂的 **G0 期**。成熟的神经元和心肌细胞会永久停留在那里——这也是为什么心脏和神经损伤往往留下瘢痕组织、难以完全再生，而皮肤和肠道内壁却能完全自我修复。

◈ EXAMPLE **Think of two dots on a balloon** 想象气球上画的两个点

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.

> 在没吹起的气球上画两个靠得很近的点，再把气球吹大，两点就跑到了两端——没有人去拉它们，只是中间的表面长开了。细菌的二分裂大体如此：先复制那条环状染色体，两份拷贝随细胞伸长而分向两端；随后细胞膜和细胞壁向内生长，把细胞一分为二。全程没有细胞核、没有纺锤体，也没有任何纤维抓住 DNA 把它拖走。对照有丝分裂：46 条各自独立的染色体必须被纺锤丝抓住着丝粒、拖向两极，才能保证每极都拿到每一条染色体各一份。比喻的失效处：气球是从外面吹起来的，橡皮只是被拉得更薄；而细菌不是被“吹大”的，它在伸长的同时不断合成新的细胞膜和细胞壁材料。另外，气球永远不会分成两个；两个点画在外表面上，细菌的环状染色体却在细胞内部。

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

有丝分裂 ≠ 减数分裂：这个对比你必须会写

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.

> 一条稳妥的原则是：Compare（比较）应当同时覆盖**相同点和不同点**，所以先说相同点——它们是真实存在的，却常被忽略。有丝分裂和减数分裂 (meiosis) 都是细胞核的分裂；两者之前都只进行**一轮** S 期的 DNA 复制；都靠纺锤丝牵引染色体；都涉及染色体或染色单体被拉向两极；之后都跟着胞质分裂。但如果题目用的是 Contrast（对比），那就只写不同点，上面这些一句都不要写——这两个命令动词不能互换。

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.

接下来逐条讲不同点——记住每一条标准都要在**同一句话**里同时套用到两个过程上。**分裂次数**：有丝分裂是一次核分裂，而减数分裂是连续两次。**子细胞数目**：有丝分裂产生 2 个，而减数分裂产生 4 个。**染色体数目**：有丝分裂保持不变，46 条的人类二倍体细胞产生两个 46 条的二倍体细胞；而减数分裂使其减半，产生 23 条的单倍体 (haploid) 细胞。**遗传结果**：有丝分裂的子细胞与母细胞遗传物质完全相同，而减数分裂产生的细胞彼此之间、以及与母细胞之间在遗传上都不相同。**功能**：有丝分裂发生在体细胞中，用于生长、修复和无性生殖，也发生在进入减数分裂之前不断增殖的生殖细胞前体中；而减数分裂发生在生殖组织中，在动物里产生用于有性生殖的配子 (gamete)。

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.

本章不需要你掌握减数分裂的内部细节——两次分裂的具体过程、交叉互换 (crossing over)、变异是怎么产生的，都在后面。在澳洲不同的课程里，减数分裂和交叉互换出现的时间不一样：有的安排在 11 年级后半段，有的要到 12 年级，具体以你自己的课程大纲为准。现在的任务只有一个：在你的答案里把这两个过程分得清清楚楚——因为这里最经典的失分方式，就是用只适用于减数分裂的事实去描述有丝分裂。

KEY TERMS · 关键术语

meiosis 减数分裂

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

包含连续两次分裂的核分裂方式，产生四个遗传上互不相同的单倍体细胞；在动物中用于形成配子。

gamete 配子（生殖细胞）

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.

卵细胞或精子等生殖细胞，染色体数为体细胞的一半；在动物中由减数分裂产生。

haploid 单倍体

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

只含一套完整染色体的状态；人的配子是单倍体，含 23 条染色体。

⚠ COMMON MISTAKE **Do not import meiosis logic into mitosis** 误区：把减数分裂的逻辑搬到有丝分裂上

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.

> 在有丝分裂的答案里经常出现三种说法，而这三种都是错的：说有丝分裂使染色体数目减半、说它产生四个子细胞、说子细胞在遗传上不同。有丝分裂产生的是**两个**子细胞，染色体数目与母细胞**相同**，遗传物质与母细胞**完全相同**。如果你写有丝分裂时出现了“减半”“四个”“变异”这些字眼，说明哪里出问题了。

⬡ EXTENSION **Extension: when the cell cycle loses control — tumours and cancer** 拓展：细胞周期失控——肿瘤与癌症

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".

> 【拓展内容】这是 VCE Unit 1 的必学内容，对其他州的同学是很好的加深。有丝分裂平时受到严格调控：机体需要时才分裂，该停时就停。一旦检查点 (checkpoint) 失灵，细胞就可能在不该分裂时分裂；反复的失控分裂会形成一团细胞，即肿瘤 (tumour)。良性肿瘤停留在原处；恶性肿瘤会侵入周围组织，其细胞还可能扩散到身体其他部位——这正是癌症 (cancer) 危险的原因。癌细胞通常分裂很快、无视“细胞拥挤时应停止分裂”的信号，而且往往不能正常分化。注意好答案的写法：癌症是**细胞周期调控失灵**的结果，而不是含糊地说“细胞长得不对”。

EXTENSION

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

拓展：细胞凋亡 (apoptosis)——“该发生”的细胞死亡

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.

> 【拓展内容】这是 VCE Unit 1 的必学内容。细胞凋亡 (apoptosis) 是“程序性细胞死亡”：一种受控、干净的自我了断——细胞皱缩，内容物被打包成带膜的小片段，由邻近细胞清除，全程不引起炎症。与之对比的是坏死 (necrosis)：由损伤或缺氧引起的失控死亡，细胞肿胀破裂，内容物外泄并引发炎症。生物体为什么要主动杀死自己的细胞？一是在发育过程中“雕刻”出正确的结构——胚胎手指之间的蹼就是被凋亡清除掉的；二是在受损、被感染或不再需要的细胞造成危害之前把它们清除掉。

Feature 项目	MITOSIS 有丝分裂	MEIOSIS 减数分裂
Number of divisions 分裂次数	1 一次分裂	2 两次分裂
Number of daughter cells 子细胞数目	2 两个子细胞	4 四个子细胞
Genetically 遗传上	identical to parent 与母细胞完全相同	genetically different 各不相同
Chromosome number 染色体数目	stays the same, diploid 不变，二倍体	halved, haploid 减半，单倍体
Where it happens 发生部位	body cells 体细胞	gamete–forming cells 生殖细胞
Purpose 作用	growth, repair, asexual reproduction 生长、修复、无性繁殖	sexual reproduction, genetic variation 有性生殖、产生变异

This guide is about MITOSIS. Meiosis is here only so you do not mix them up.
本手册讲的是有丝分裂，减数分裂列在这里只是为了避免混淆。

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.
有丝分裂与减数分裂对照表，从分裂次数、子细胞数目、遗传结果、染色体数目、发生部位和作用六个方面逐项比较。

DAY 4 RECAP · 本日要点回顾

- 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.

  DNA 是由核苷酸 (nucleotide) 连成的多聚体，每个核苷酸 = 磷酸基团 + 脱氧核糖 + 一个含氮碱基。磷酸—脱氧核糖骨架内部靠强共价键连接；双螺旋的两条链方向相反（反向平行，antiparallel），两链之间则靠弱的氢键维持 A–T、C–G 的碱基互补配对——正因如此，双螺旋才能“拉开拉链”而两条链本身不断裂。

- 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).

  同一种物质在不同尺度上有不同名字，你要能从小到大排出来：碱基对 → 基因 → DNA 分子 → 染色质 → 凝缩的染色体 → 基因组。人的体细胞是二倍体：46 条染色体、23 对同源染色体。注意别把姐妹染色单体（同一条染色体的两个相同拷贝）和同源染色体（来自父方与母方的同一号染色体，并不完全相同）搞混。

- 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.

  细胞周期 = （分裂）间期（G1 期、S 期、G2 期）+ M 期（有丝分裂 + 胞质分裂）。间期是整个周期中最长、也最忙的一段，绝不是“休息期”：G1 期细胞生长并合成细胞器，S 期复制 DNA，G2 期继续生长并合成分裂所需的蛋白质和纺锤体成分。

- 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.

  S 期里每个 DNA 分子都进行半保留复制：氢键断裂、两链分开，每条母链作模板链，细胞核中本就存在的游离核苷酸按互补配对补上去，最终每个新分子 = 一条母链 + 一条新链。此时每条染色体变成由着丝粒连着的两条完全相同的姐妹染色单体——但染色体的**数目**并没有变。

- 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.

  接着由有丝分裂来“分发”这些拷贝：染色体凝缩变得可见、核膜解体、纺锤体形成（前期）；染色体排到赤道板上、纺锤丝附着于着丝粒（中期）；着丝粒分裂、姐妹染色单体被拉向两极（后期）；染色体解螺旋、两个核膜重新形成（末期）。请记牢：复制早在这一切开始之前就已全部完成。

- 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.

  随后胞质分裂把细胞质分开——动物细胞是分裂沟向内缢缩，植物细胞是细胞板向外扩展成新的细胞壁——细胞分裂至此完成，得到两个遗传物质完全相同、染色体数目与母细胞相同的子细胞（人的体细胞就是 46 条、二倍体，与母细胞一致）。再强调一次：有丝分裂分的是**核**；细胞分裂 = 有丝分裂 + 胞质分裂。

- 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.

  而“遗传物质完全相同”正是全部意义所在：它让生物体能从一个受精卵长成完整个体，能修复伤口并持续更新皮肤、肠道内壁和血细胞，还让许多物种可以靠出芽、匍匐茎或再生进行无性生殖（细菌完成同样的任务靠的是二分裂，不是有丝分裂）。而一旦这套周期调控失灵，同一个过程失去控制就会形成肿瘤——这正是为什么值得把这条链条从一个碱基对一路精确地讲到两个完全相同的子细胞。

Check Yourself — Day 4

自我检测 · 第 4 天（先合上笔记独立作答）

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 · 答案与解析

Write your answer out first. A question you have read the answer to is not practice.
先自己写完再对答案，看过答案就不算练习了。

1. b) Metaphase

答案是中期 (metaphase)。染色体排成**一列**位于赤道板 (equator / metaphase plate) 上、纺锤丝附着在着丝粒上，这是中期的“定案特征”。前期染色体虽已可见但散乱、尚未排队；后期是两簇染色体正在分开、中间有空隙；末期两簇已到达两极、正在解螺旋，核膜也在重新形成。

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

答案是 A：46 条染色体，每条由两条姐妹染色单体组成——染色单体总共 92 条，但**染色体仍然只有 46 条**。一条复制过的染色体算**一条**，不算两条。选项 B 描述的是后期着丝粒分裂之后那一瞬间的情形；选项 C 把染色体数减半了，那是减数分裂而不是有丝分裂；选项 D 把染色单体和染色体混为一谈了。

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.

答案是 B：相同性来自“先复制、后精确分离”。选项 A 是最经典的失分答案——把东西平分，每边得到的是一半而不是完整拷贝，而且完全没提复制这一步。选项 C 把减数分裂的逻辑搬了过来，有丝分裂从不使染色体数减半。选项 D 把复制放错了时期：有丝分裂过程中不复制任何 DNA，游离核苷酸是在 S 期用掉的。

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.

答案是 B。植物细胞因为有坚硬的纤维素细胞壁而无法被“掐断”，所以它从中央向外建造细胞板 (cell plate)，直到与原有细胞壁融合；动物细胞则靠环绕细胞一圈的蛋白质细丝收缩，把细胞膜向内拉成分裂沟 (cleavage furrow)。选项 A 把两种机制说反了。选项 C、D 编造了时间差异：两类细胞的胞质分裂都与有丝分裂的末尾重叠，在后期后段或末期开始，都是在核分裂之后才把细胞质分开。

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

答案是 B。染色体数目保持不变正是关键差别：人的二倍体细胞经有丝分裂产生两个 46 条染色体的二倍体细胞，而减数分裂使其减半，产生 23 条的单倍体细胞。选项 A、C、D 对两者**都**成立——遇到 Compare（比较）时应当写进去，遇到 Contrast（对比）时则要略去。

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.

满分要点（注意必须出现“复制”这一步）：① 在（分裂）间期的 S 期，每个 DNA 分子进行半保留复制——氢键断裂两链分开，各自作模板链，游离核苷酸按 A–T、C–G 互补配对，因此得到的两个 DNA 分子序列完全相同；② 于是每条染色体由着丝粒连着的两条完全相同的姐妹染色单体组成；③ 中期，染色体排列在赤道板上，纺锤丝附着于着丝粒；④ 后期，着丝粒分裂，每一对中的一条被拉向一极，因此每一极都获得**每一条**染色体的一份完整拷贝；⑤ 所以末期形成的两个细胞核、以及胞质分裂后形成的两个细胞，DNA 完全相同，染色体数目也与母细胞相同。四句话之间必须有 so / therefore 这样的因果连接。

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.)

① **生长**：多细胞生物靠有丝分裂增加细胞数目——例如受精卵发育成胚胎，植物根尖的细胞不断分裂使根伸长。② **修复与替换**：受损或磨损的细胞由有丝分裂补充——例如皮肤细胞分裂使伤口愈合、肠道内壁每隔几天更新一次、骨髓不断生产新的红细胞。③ **无性生殖**：有些生物用有丝分裂产生与自己遗传物质完全相同的后代——例如酵母和水螅的出芽生殖，草莓靠匍匐茎产生新植株（营养繁殖）。（注意：细菌也是无性生殖，但走的是二分裂，不是有丝分裂。）每一点都必须配一个具体例子才拿得到分。

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.

Compare 要求先写相同点、再写不同点。相同点：两者都是细胞核的分裂，之前都只经过一轮 S 期 DNA 复制，都靠纺锤丝牵引染色体，之后都跟着胞质分裂。不同点（每条都要在同一句里套用到两边）：**分裂次数**——有丝分裂一次核分裂，而减数分裂是连续两次；**子细胞数目**——有丝分裂 2 个，而减数分裂 4 个；**染色体数目**——有丝分裂保持不变（人的 46 条二倍体细胞产生两个 46 条的细胞），而减数分裂减半（产生 23 条的单倍体细胞）；**遗传结果**——有丝分裂的子细胞与母细胞完全相同，而减数分裂产生的细胞彼此之间以及与母细胞之间都不相同。

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.

Assess 要求先亮出判断，再用证据支撑。判断：有丝分裂对多细胞生物是**不可或缺**的，没有它，生物体既长不到成年体型，也无法维持自身。证据：**生长**——人体数十万亿个细胞全都由一个受精卵经有丝分裂而来，植物根尖的分生组织也靠有丝分裂伸长；**修复与替换**——伤口愈合靠它，皮肤持续更新、肠道内壁每隔几天更换一次、红细胞（自身不能分裂）由骨髓不断补充，都靠它；**生殖**——某些物种直接用它产生新个体（酵母和水螅出芽、草莓匍匐茎）。反面证据同样说明其重要性：一旦调控失灵、分裂失控，就会形成肿瘤。结论：有丝分裂不只在长身体的阶段重要，成年后的每一天都在发挥作用。

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.

(a) 处于有丝分裂的细胞数 = 18 + 6 + 3 + 3 = 30；有丝分裂指数 = 30 ÷ 150 × 100% = **20%**。(b) 有丝分裂时长 = 0.20 × 20 小时 = **4 小时**；后期细胞比例 = 3 ÷ 150 = 0.02，后期时长 = 0.02 × 20 小时 = 0.4 小时 = **24 分钟**。所依据的假设：切片是对一群分裂细胞的随机“定格”，因此某一期中被观察到的细胞比例，正比于细胞停留在该期的时间长短。顺带印证一点：150 个细胞里有 120 个（80%）处于间期，这与“间期是细胞周期中最长的一段”完全吻合。

Final Assessment

总测验 · 学完四天后完成，检验掌握程度

Part A · Multiple Choice 15 questions · 选择题

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 · 简答与论述题

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

总测验答案与评分要点

PART A · 选择题

Anything you got wrong — go back to that day and read it again.
每题都附中文解析，答错的题请回到对应那一天重看。

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

Every nucleotide has exactly three parts: a phosphate group, a deoxyribose sugar and ONE nitrogenous base (A, T, C or G). Option B names ribose, which is not the sugar found in DNA. Option C describes two bases on one sugar, which does not exist. Option D confuses components of a nucleotide with a base pair (which needs nucleotides on two different strands) and with a hydrogen bond, which is a bond, not a building block.

每个核苷酸 (nucleotide) 恰好由三部分组成：磷酸基团 (phosphate group)、脱氧核糖 (deoxyribose sugar)、以及一个含氮碱基 (nitrogenous base)（A、T、C 或 G 中的一个）。B 写的是核糖 ribose，那不是 DNA 里的糖。C 说一个糖上接两个碱基，不存在这种结构。D 把"零件"和"连接方式"搞混了：碱基对 (base pair) 需要两条链上的两个核苷酸才能形成，氢键 (hydrogen bond) 是一种化学键，不是核苷酸的组成部分。

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

Interphase (G1, S and G2) occupies most of the cell cycle and is the busiest part of it: the cell grows, makes organelles and proteins, and replicates its DNA. It is not a 'rest' stage. It is also not part of mitosis at all – it is the part of the CELL CYCLE that comes before M phase. Chromosomes stay as long, uncondensed chromatin threads during interphase; condensation happens in prophase.

（分裂）间期 (interphase) 包含 G1 期、S 期、G2 期，占细胞周期 (cell cycle) 的绝大部分时间，而且是最忙的阶段：细胞生长、合成细胞器 (organelle) 和蛋白质，并完成 DNA 复制 (DNA replication)。它绝不是"休息期"（这是最常见的错误说法）。它也不属于有丝分裂 (mitosis)，而是细胞周期中位于 M 期 (M phase) 之前的阶段。间期里 DNA 以细长的染色质 (chromatin) 形式存在，只有到了前期 (prophase) 才会螺旋缩短成显微镜下可见的染色体 (chromosome)。

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

Mitosis divides the nucleus and cytokinesis divides the cytoplasm, producing TWO daughter cells that are genetically identical to each other and to the parent cell, and that keep the parent's chromosome number (diploid, 46 in humans). The other three options import meiosis logic – four cells, halving of chromosome number, genetic variation – none of which happens in mitosis.

有丝分裂 (mitosis) 分的是细胞核，胞质分裂 (cytokinesis) 分的是细胞质，最终产生 2 个子细胞 (daughter cell)：它们彼此之间、以及与亲代细胞之间遗传物质完全相同 (genetically identical)，染色体数目不变，仍是二倍体 (diploid)（人 46 条）。另外三个选项都是把减数分裂 (meiosis) 的特征硬套进来了——4 个细胞、染色体减半、产生差异——有丝分裂一样都不会发生。

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

The pairing rule is fixed: A–T and C–G. The two bases of a pair are held together by weak hydrogen bonds (2 between A and T, 3 between C and G). Option B breaks the pairing rule. Option C names the wrong bond – covalent bonds hold the sugar–phosphate backbone together, not the base pair; if the bases were covalently bonded the helix could not unzip. Option D is the 'it just has to fit' misconception: pairing is specific, not merely a matter of size.

配对规则是固定的：腺嘌呤 (adenine) 只配胸腺嘧啶 (thymine)，胞嘧啶 (cytosine) 只配鸟嘌呤 (guanine)，即 A–T、C–G。配对的两个碱基之间靠弱的氢键 (hydrogen bond) 相连（A–T 之间 2 个，C–G 之间 3 个）。B 违反配对规

则。C 用错了键：共价键 (covalent bond) 连的是磷酸—脱氧核糖骨架 (sugar–phosphate backbone)；如果碱基之间是共价键，双螺旋 (double helix) 就"拉不开"了。D 是"只要大小塞得下就行"的误解——配对是专一的，不是随便凑。

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

'Semi–conservative' means half of each new double–stranded molecule is conserved (kept) from the parent molecule: one whole original strand acts as a template and pairs with one whole new strand. Option B splits each individual strand into old and new halves, which is not what happens. Option C is the conservative model, which Meselson and Stahl's evidence ruled out. Option D discards the original strands entirely, which contradicts the word 'semi–conservative'.

"半保留"的意思是：每个新形成的双链 DNA 分子中，有一半是从亲代分子"保留"下来的——一条完整的原有链作为模板链 (template strand)，与一条完整的新合成子链 (daughter strand) 配对。B 是把"每一条链"切成一半旧一半新，这是对"半保留"的经典误读。C 是全保留模型（一个分子全旧、一个分子全新），已被 Meselson–Stahl 实验的证据否定。D 把原有链全部丢弃，和"半保留"直接矛盾。

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

S phase is the DNA synthesis (replication) phase of interphase. After it, every chromosome is still ONE chromosome but is now made of two identical sister chromatids joined at a centromere. Option B describes prophase, option C describes G1, and option D describes anaphase. Note that replication is finished before mitosis starts – it never happens 'during prophase'.

S 期（合成期）(S phase) 是（分裂）间期 (interphase) 中进行 DNA 复制 (DNA replication) 的阶段。复制完成后，每条染色体 (chromosome) 仍然算 1 条染色体，但已由 2 条完全相同的姐妹染色单体 (sister chromatid) 组成，二者在着丝粒 (centromere) 处相连。B 说的是前期 (prophase)，C 说的是 G1 期，D 说的是后期 (anaphase)。请牢记：复制在有丝分裂开始之前就已全部完成，绝不会"在前期才复制"。

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

Prokaryotes do not undergo mitosis. They divide by binary fission: the single circular chromosome is copied, the copies move apart, and the cell divides – with no nucleus, no nuclear envelope to break down and no spindle fibres. Option B repeats the common error that bacteria 'do mitosis'. Option C invents four daughter cells; binary fission gives two, normally genetically identical. Option D is wrong because the chromosome IS copied first – otherwise the daughter cells would not both get a full set of genes.

原核生物（细菌）不进行有丝分裂 (mitosis)，而是进行二分裂 (binary fission)：那条唯一的环状染色体先复制，两份拷贝分开，细胞随后一分为二——全程没有细胞核 (nucleus)、没有核膜 (nuclear envelope) 解体、也没有纺锤丝（纺锤体）(spindle fibre)。B 是"细菌也做有丝分裂"这个常见错误。C 凭空多出 4 个子细胞；二分裂产生 2 个、通常遗传物质相同的子细胞。D 错在染色体其实是先复制的，否则两个子细胞不可能各得一整套基因。

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

Apply A–T and C–G base by base: T pairs A, A pairs T, C pairs G, G pairs C, G pairs C, C pairs G, A pairs T, T pairs A, giving A–T–G–C–C–G–T–A. Option B is simply the same sequence copied, the classic 'copy not complement' error. Option C leaves C opposite C and G opposite G at positions 3 and 4. Option D breaks the rule at the last two positions (A opposite A, T opposite T).

逐个碱基套用 A–T、C–G 的碱基互补配对 (complementary base pairing)：T→A，A→T，C→G，G→C，G→C，C→G，A→T，T→A，得到 A–T–G–C–C–G–T–A。B 只是把原序列照抄了一遍，是"复制成一样"而非"互补"的典型错误。C 在第 3、4 位出现了 C 对 C、G 对 G。D 在最后两位违反规则（A 对 A、T 对 T）。做题技巧：写完后回头逐位检查，只允许出现 A–T 和 C–G 两种组合。

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

Only the weak hydrogen bonds between paired bases are broken, which is why the two strands can separate while each strand stays intact. The sugar–phosphate backbone is held by strong covalent bonds and is NOT broken – if it were, the strand would fall apart and could not act as a template. Option C would remove bases from the strand, destroying the sequence. Option D describes a structure at the centromere, which has nothing to do with unzipping the helix.

被断开的只是配对碱基之间弱的氢键 (hydrogen bond)，所以两条链能分开、而每条链本身完好无损。磷酸—脱氧核糖骨架 (sugar–phosphate backbone) 由强的共价键连接，不会断——若断了，模板链 (template strand) 就散架了，无法作模板。C 若成立会把碱基从链上摘下来，序列就被毁了。D 说的是着丝粒 (centromere) 处姐妹染色单体 (sister chromatid) 的连接，与解开双螺旋无关。可以这样记："拉链齿（氢键）打开，拉链带（骨架）不断。"

10. a) Metaphase

The decisive clue is that the chromosomes are aligned in a single line on the equator (metaphase plate) with spindle fibres attached at their centromeres – this is metaphase. In prophase the chromosomes are condensing but are scattered and the spindle is still forming. In anaphase the centromeres have already divided and the separated chromatids are moving towards the poles, so nothing is lined up at the equator. In telophase the chromosomes are at the poles, decondensing, and nuclear envelopes are reforming.

判定的关键证据是：染色体排成一列位于赤道板 (equator / metaphase plate) 上，且纺锤丝（纺锤体）(spindle fibre) 附着在着丝粒 (centromere) 处——这正是中期 (metaphase)。前期 (prophase) 时染色体正在螺旋化、分散排列，纺锤体尚在形成。后期 (anaphase) 时着丝粒已经分裂，分开的染色单体正向两极移动，中央不会整齐排一列。末期 (telophase) 时染色体已到两极、开始解螺旋，核膜正在重建。看图题要养成"逐条比对线索"的习惯，而不是凭印象猜。

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

A base pair is a single rung of the DNA ladder; a gene is a length of DNA made of many base pairs; a chromosome is one very long DNA molecule (with its associated proteins) carrying many genes; the genome is the complete set of an organism's DNA – in humans, all 46 chromosomes. The other options invert the gene/base-pair or gene/chromosome relationship, which is the common error of treating 'gene' and 'chromosome' as interchangeable or assuming one chromosome carries one gene.

碱基对 (base pair) 是 DNA"梯子"上的一级横档，最小；基因 (gene) 是一段含有许多碱基对的 DNA；染色体 (chromosome) 是一条极长的 DNA 分子（连同相关蛋白质），上面携带许多个基因；基因组 (genome) 指一个生物体的全部 DNA——在人类即全部 46 条染色体。其余选项把基因与碱基对、或基因与染色体的大小关系颠倒了，反映的正是"把 gene 和 chromosome 当同义词"或"一条染色体只有一个基因"这类误解。

12. a) 16%

Mitotic index = (number of cells in mitosis ÷ total number of cells counted) × 100 = (40 ÷ 250) × 100 = 16%. Option B is the result of dividing the wrong way round (250 ÷ 40). Option C simply reports the raw count as a percentage. Option D is the percentage of cells NOT in mitosis (which, usefully, tells you that most cells are in interphase at any moment).

有丝分裂指数 (mitotic index) =（处于分裂期的细胞数 ÷ 计数的细胞总数）× 100 =（40 ÷ 250）× 100 = 16%。B 是把除法做反了（250 ÷ 40 = 6.25）。C 直接把原始计数 40 当成百分数。D 是"不处于分裂期"的细胞百分比——顺带说明：任一瞬间绝大多数细胞都停在（分裂）间期 (interphase)，这也印证了间期是细胞周期中最长的阶段。考试要求写出算式与百分号单位。

13. a) 46 chromosomes and 92 chromatids

Replication in S phase does not change the chromosome NUMBER. Each of the 46 chromosomes is now made of two identical sister chromatids joined at a centromere, so there are 46 chromosomes but 92 chromatids. Counting chromatids as chromosomes (option B) is the single most common error in this topic: a replicated chromosome is still ONE chromosome. Option D describes a haploid number, which is not what a somatic cell has.

S 期的复制不改变染色体 (chromosome) 的数目。此时 46 条染色体中的每一条，都由 2 条完全相同的姐妹染色单体 (sister chromatid) 通过着丝粒 (centromere) 相连，所以是 46 条染色体、92 条染色单体。把染色单体当成染色体来数（选项 B）是本章最常见的错误：一条复制后的染色体仍然只算 1 条染色体，数染色体就数着丝粒。D 给的是单倍体 (haploid) 数目，体细胞是二倍体 (diploid)，不适用。

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

The identity comes from COPYING followed by equal separation, and a full-mark answer must name both steps. Option B is the answer markers penalise: sharing DNA evenly without copying it first would give each cell only half the genetic information, not a complete identical set. Option C imports meiosis – homologous chromosomes are not paired or separated in mitosis. Option D is simply false: mitosis conserves the chromosome number.

"完全相同"来自两步：先复制、再均分，缺一不可，满分答案必须两步都写出来。选项 B 正是评分老师会扣分的写法——只"平均分配"而没有先复制，每个子细胞只会拿到一半的遗传信息，根本不可能相同。C 把减数分裂 (meiosis) 的情节搬了进来：有丝分裂中同源染色体并不配对，也不被分开。D 是错误陈述：有丝分裂维持染色体数目不变，并不减半。

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

Mitosis only SEPARATES material that already exists; it does not copy DNA. Without S phase, every chromosome is a single unreplicated chromatid, so there is no identical partner to send to the opposite pole and the daughter nuclei cannot each receive a complete set of chromosomes. Option B is the opposite of blocking replication. Option C describes meiosis, which is not what mitosis does under any circumstances. Option D confuses cell size with genetic content – the problem is missing genetic information, not volume.

有丝分裂只负责"分开"已经存在的物质，它本身不复制 DNA。缺了 S 期，每条染色体都只有 1 条未复制的染色单体，也就没有一个完全相同的"搭档"可以送往对侧极，因此两个子细胞不可能各自获得一整套完整的染色体。B 与"阻断复制"的前提正好相反。C 描述的是减数分裂 (meiosis)，有丝分裂在任何情况下都不会产生 4 个单倍体细胞。D 把细胞体积和遗传物质混为一谈——问题出在遗传信息缺失，而不是细胞变小。这道题正是"为什么复制必须在分裂之前完成"的反向验证。

PART B · 简答题评分要点

Compare with the model answer and count how many marking points you actually hit.
对照模范答案，逐条数自己拿到了几个得分点。

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).

> ✓ 得分点 1：写出单体组成——DNA 是由核苷酸 (nucleotide) 聚合而成，每个核苷酸 = 磷酸基团 (phosphate group) + 脱氧核糖 (deoxyribose sugar) + 一个含氮碱基 (nitrogenous base)，并把四种碱基 A、T、C、G 点出来。只写"由核苷酸组成"而不拆开三部分，拿不到这一分。

> ✓ 得分点 2：写出链的骨架与整体形状——糖和磷酸通过共价键 (covalent bond) 相连形成磷酸—脱氧核糖骨架 (sugar–phosphate backbone)；两条链反向平行 (antiparallel) 盘绕成双螺旋 (double helix)。这一分考的是"骨

架"和"双螺旋"两个关键词。

✓ 得分点 3：写出两条链之间靠什么连接——碱基互补配对 (complementary base pairing)：A 配 T、C 配 G，靠弱的氢键 (hydrogen bond) 连接（A–T 两个、C–G 三个，NSW 要求写氢键数目）。注意 Describe 是"描述特征"，此题不需要解释原因，但结构要点必须齐全。

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.

✓ 得分点 1：氢键 (hydrogen bond) 弱 → 容易断开 → 两条链可以"解开拉链"分离，使 DNA 复制 (DNA replication) 得以进行。

✓ 得分点 2：共价键 (covalent bond) 强 → 磷酸—脱氧核糖骨架 (sugar–phosphate backbone) 不会断 → 每条链保持完整、碱基顺序不被破坏 → 才能作为模板链 (template strand)。这一分是本题的核心因果链，务必写出"所以能当模板"。

✓ 得分点 3：数量效应——一个 DNA 分子中氢键数目极多，合起来足以维持双螺旋 (double helix) 的稳定。Explain 题的每一句都要用 because / so that / therefore 把因果串起来，只罗列"氢键弱、共价键强"而不说后果，最多得 1 分。

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.

✓ 得分点 1：G1 期 — 细胞生长、进行正常代谢、合成细胞器 (organelle) 与蛋白质。

✓ 得分点 2：S 期（合成期）— 完成 DNA 复制 (DNA replication)，每条染色体变成由着丝粒 (centromere) 相连的 2 条姐妹染色单体 (sister chromatid)。这是全题最关键的一分。

✓ 得分点 3：G2 期 — 继续生长，合成分裂所需的蛋白质（包括纺锤体成分），并检查 DNA 是否复制正确。

✓ 得分点 4：M 期 (M phase) — 有丝分裂 (mitosis) 按前期→中期→后期→末期分裂细胞核，随后胞质分裂 (cytokinesis) 分开细胞质，形成 2 个独立子细胞 (daughter cell)。注意 Outline 只要"按顺序给出主要事件"，不必展开机制；但四个阶段一个都不能漏，顺序也不能乱。

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.

✓ 得分点 1：指出复制发生在（分裂）间期 (interphase) 的 S 期，这是唯一复制遗传物质的阶段。

✓ 得分点 2：指出有丝分裂 (mitosis) 本身不复制，只是"分开"——后期 (anaphase) 着丝粒 (centromere) 分裂，每对姐妹染色单体各有一条被拉向一极。这是 Justify 题的"证据"部分。

✓ 得分点 3：写出反面后果——若未先复制，就没有相同的拷贝可分给两极，每次分裂 DNA 含量会减半，子细胞得到的遗传信息不完整。用"if…then"的假设推理来支撑论点最有力。

✓ 得分点 4：给出明确结论——因此复制必须先于分裂完成，才能产生两个完整且遗传物质完全相同 (genetically identical) 的子细胞。Justify 一定要有一句收尾的判断句，只讲道理不下结论会失分。

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.

✓ 得分点 1：相同点 — 两者都是紧接有丝分裂 (mitosis) 之后、把细胞质分开的独立过程，结果都是形成 2 个子细胞 (daughter cell)。Compare 要求"异同都写"，只写不同最多得 2 分。

✓ 得分点 2：动物细胞 — 细胞膜在赤道部位向内缢缩形成分裂沟 (cleavage furrow)，逐渐加深把细胞"掐断"成两个。

✓ 得分点 3：植物细胞 — 因有坚硬的细胞壁无法内缢，改由囊泡在赤道处聚集融合形成细胞板 (cell plate)，进而发育成新的细胞壁和细胞膜。写出"因为有细胞壁"这个原因能让答案更完整。答题格式建议用同一标准逐条对照（先说共同点，再用 whereas 对比两者）。

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.

✓ 得分点 1：复制这一步 — 说明在（分裂）间期 (interphase) 的 S 期进行半保留复制 (semi-conservative replication)：氢键 (hydrogen bond) 断裂使双螺旋解开，原有链作模板链 (template strand)，游离核苷酸按碱基互补配对 (complementary base pairing) 结合，新分子=一旧链+一新链，因而是精确拷贝。缺这一步的答案（只说"平均分配 DNA"）会被判为关键遗漏。

✓ 得分点 2：复制的结果 — 每条染色体由 2 条完全相同的姐妹染色单体 (sister chromatid) 组成，在着丝粒 (centromere) 处相连。

✓ 得分点 3：前期与中期 — 前期 (prophase) 染色体螺旋化变得可见、核膜 (nuclear envelope) 解体、纺锤丝（纺锤体）(spindle fibre) 形成；中期 (metaphase) 染色体排列在赤道板 (equator) 上，纺锤丝附着于着丝粒（注意：附着点是着丝粒，不是染色体末端）。

✓ 得分点 4：后期是"相同"的关键机制 — 后期 (anaphase) 着丝粒分裂，每对姐妹染色单体各有一条被拉向相反的极，因此每一极都获得每条染色体的一份完整拷贝。

✓ 得分点 5：收尾 — 末期 (telophase) 染色体解螺旋、两个新核膜重建，随后胞质分裂 (cytokinesis) 分开细胞质，形成 2 个二倍体 (diploid)、彼此及与亲代细胞遗传物质完全相同 (genetically identical) 的子细胞。Explain

> 题要求因果成链：用 so that / because / therefore 把"复制→相同的姐妹染色单体→着丝粒分裂→各得一份→完全相同"一路串到底。

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

中英术语对照表 · 考试写英文，理解看中文

Day 1 · The Structure of DNA · DNA 的结构

ENGLISH TERM	中文	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. DNA（脱氧核糖核酸）是存在于细胞核 (nucleus) 内的大分子，储存着构建和运行整个生物体所需的全部遗传指令，可以把它想成一本写在化学分子上的说明书。
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. 脱氧核糖核酸是 DNA 的全称，它属于核酸 (nucleic acid)，由许多含脱氧核糖 (deoxyribose) 的核苷酸 (nucleotide) 重复连接而成——名字本身就说明了它的两个化学特征。
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. 核苷酸是构成 DNA 的基本单位（单体 monomer），每个核苷酸由一个磷酸基团 (phosphate group)、一个脱氧核糖 (deoxyribose) 和一个含氮碱基 (nitrogenous base) 三部分组成，就像一块乐高积木。
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. 磷酸基团是核苷酸中含磷的部分，它与下一个核苷酸的脱氧核糖相连，从而把核苷酸串成一条链，搭出 DNA 的骨架 (backbone)。
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. 脱氧核糖是 DNA 核苷酸中的五碳糖，一边连接磷酸基团 (phosphate group)，另一边连接含氮碱基 (nitrogenous base)，是核苷酸的中心部件。
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.

含氮碱基是核苷酸中含氮的那一部分，共有腺嘌呤 A、胸腺嘧啶 T、胞嘧啶 C、鸟嘌呤 G 四种；碱基的排列顺序就是遗传信息的载体。

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. 腺嘌呤 (adenine, A) 是一种嘌呤 (purine) 碱基，在双链中总是与对面链上的胸腺嘧啶 (thymine, T) 配对，两者之间形成 2 个氢键 (hydrogen bond)。
thymine *THIGH-meen*	**胸腺嘧啶**	Thymine (T) is a pyrimidine base that always pairs with adenine, held there by two hydrogen bonds. 胸腺嘧啶 (thymine, T) 是一种嘧啶 (pyrimidine) 碱基，总是与腺嘌呤 (adenine, A) 配对，两者之间形成 2 个氢键 (hydrogen bond)。
cytosine *SIGH-toh-seen*	**胞嘧啶**	Cytosine (C) is a pyrimidine base that always pairs with guanine, held there by three hydrogen bonds. 胞嘧啶 (cytosine, C) 是一种嘧啶 (pyrimidine) 碱基，总是与鸟嘌呤 (guanine, G) 配对，两者之间形成 3 个氢键 (hydrogen bond)，所以 C—G 配对比 A—T 更牢固。
guanine *GWAH-neen*	**鸟嘌呤**	Guanine (G) is a purine base that always pairs with cytosine, held there by three hydrogen bonds. 鸟嘌呤 (guanine, G) 是一种嘌呤 (purine) 碱基，总是与胞嘧啶 (cytosine, C) 配对，两者之间形成 3 个氢键 (hydrogen bond)。
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. 嘌呤是具有双环结构的含氮碱基，DNA 中的嘌呤只有腺嘌呤 (adenine) 和鸟嘌呤 (guanine) 两种，记忆窍门：名字里带“嘌呤”的就是双环、个头大。
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. 嘧啶是具有单环结构的含氮碱基，DNA 中的嘧啶是胸腺嘧啶 (thymine) 和胞嘧啶 (cytosine)；由于总是“大配小”（嘌呤配嘧啶），双螺旋的宽度才处处相等。
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. 碱基互补配对是指 A 一定与 T 配对、C 一定与 G 配对；正因如此，只要知道一条链的碱基顺序，就能推出另一条链——这

		也是 DNA 能精确复制 (replication) 的基础。
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. 氢键是碱基对之间的一种弱作用力：单个很弱（所以复制时容易被拆开），但整条 DNA 上数量极多，合起来足以让双链保持稳定。
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. 磷酸二酯键是连接前一个核苷酸的磷酸与后一个核苷酸脱氧核糖的强共价键 (covalent bond)，它把核苷酸串成长链；请特别注意：它比碱基之间的氢键 (hydrogen bond) 强得多，DNA 解开时断的是氢键，不是它。
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. 磷酸—脱氧核糖骨架是由脱氧核糖和磷酸交替连接形成的长链，位于双螺旋的外侧，像梯子的两根扶手，把碱基按顺序固定住；碱基对则像梯子的横档。
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. 双螺旋是 DNA 的整体形状：两条反向平行 (antiparallel) 的链围绕同一中轴盘旋，像一架拧过的梯子——骨架在外、碱基对在内。
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′. 反向平行指 DNA 两条链的方向相反，一条是 5′→3′，另一条是 3′→5′，就像两条并排但头尾颠倒的链；这一特点决定了复制时酶只能沿一个方向合成。
gene	**基因**	A gene is a section of DNA that codes for a particular protein and therefore for a particular characteristic. 基因是 DNA 分子上的一个片段，携带合成某种蛋白质 (protein) 的信息，从而决定某个性状。
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. 基因组是一个生物体（一个细胞中）全部 DNA、也就是全部基因的总和，相当于整套说明书而不是其中一页。

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. 染色体是一条长长的 DNA 分子缠绕在组蛋白 (histone) 上形成的结构；只有在细胞分裂时它高度螺旋、变粗变短，才能在光学显微镜下看到，平时是细丝状的染色质 (chromatin)。
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. 染色质是间期 (interphase) 中 DNA 与蛋白质呈松散细丝状的形态；此时 DNA 必须松散，才能被复制和用于合成蛋白质。染色质与染色体 (chromosome) 是同一种物质在不同时期的两种形态。
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. 组蛋白是 DNA 缠绕其上的一类蛋白质，作用像绕线轴，使很长的 DNA 能整齐地包装进小小的细胞核 (nucleus) 里。
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. 细胞核是有膜包被的细胞器 (organelle)，内含细胞的全部染色体 (chromosome)，是细胞代谢和遗传的控制中心。

Day 2 · The Cell Cycle · 细胞周期与间期

ENGLISH TERM	中文	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. 细胞周期是细胞生长、复制 DNA、再分裂成两个新细胞的一整套有序过程，主要分为分裂间期 (interphase) 和分裂期 (M phase) 两大阶段。
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. 分裂间期（简称间期）是细胞周期中最长的阶段，包括 G1 期、S 期和 G2 期；细胞在此期间生长、正常工作并完成 DNA 复制。特别注意：间期绝不是“休息期”，代谢反而非常活跃。

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. G1 期（第一间隙期）是分裂之后的生长阶段：细胞长大、合成蛋白质和新的细胞器 (organelle)，为随后的 DNA 复制做准备。
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. S 期（合成期）是间期中进行 DNA 复制 (DNA replication) 的阶段；复制完成后，每条染色体都由两条完全相同的姐妹染色单体 (sister chromatid) 组成。
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. G2 期（第二间隙期）在 DNA 复制之后：细胞继续生长，合成分裂所需的蛋白质（如构成纺锤体的微管蛋白），并检查复制好的 DNA 有无错误。
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). M 期（分裂期）是细胞真正分裂的阶段，包括有丝分裂 (mitosis，细胞核分裂) 和紧随其后的胞质分裂 (cytokinesis，细胞质分裂)。
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. 有丝分裂是细胞核分裂成两个染色体组成完全相同的核的过程，依次经过前期 (prophase)、中期 (metaphase)、后期 (anaphase)、末期 (telophase)。注意：有丝分裂产生的是体细胞，不产生配子。
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. 胞质分裂是有丝分裂之后细胞质一分为二的过程，最终形成两个子细胞 (daughter cell)；动物细胞靠细胞膜从中部向内凹陷，植物细胞则在中央形成细胞板。

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. 检查点是细胞周期中的调控关卡：只有当细胞大小、DNA 是否复制完整、有无损伤等条件都合格时，细胞才被允许进入下一阶段；检查点失灵可能导致细胞失控分裂（与癌症 cancer 有关）。
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. 生长是多细胞生物细胞数目增多、个体变大的过程，靠一轮又一轮以有丝分裂 (mitosis) 结束的细胞周期来实现。
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. 细胞分化是未特化的细胞发育成具有特定结构和功能的细胞（如神经细胞、肌肉细胞）的过程；分化改变的是基因的表达情况，而不是细胞里的 DNA 序列。
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. 细胞器是细胞内承担特定功能的结构，如细胞核 (nucleus)、线粒体 (mitochondrion)；细胞在 G1、G2 期会合成新的细胞器，保证分裂后两个子细胞都够用。

Day 3 · DNA Replication · DNA 复制

ENGLISH TERM	中文	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. DNA 复制是把一个 DNA 分子复制成两个完全相同分子的过程，发生在间期的 S 期，也就是有丝分裂 (mitosis) 开始之前——不是在分裂过程中进行的，这是常见易错点。
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. 半保留复制指每个新形成的 DNA 分子中，一条链来自原来的母链（模板链 template strand），另一条是新合成的子链 (daughter strand)；保留一半旧链能最大限度保证遗传信息准确。

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. 模板链是被当作蓝图使用的那条原有 DNA 链，新链严格按照碱基互补配对 (complementary base pairing) 的规则依着它合成。
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. 解旋酶是使双螺旋解开的酶：它打断碱基对之间的氢键 (hydrogen bond)，把两条链分开——被打断的只是氢键，磷酸—脱氧核糖骨架并没有断裂。
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. DNA 聚合酶是按照碱基互补配对规则把游离的核苷酸 (nucleotide) 加到模板链上、并用磷酸二酯键 (phosphodiester bond) 把它们连成新链的酶。
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. 复制叉是 DNA 双链被解开处形成的 Y 形结构，新链正是在这里边解旋、边合成的。
daughter strand	**子链**	A daughter strand is the newly made DNA strand that is complementary to the template strand it was built on. 子链是新合成的那条 DNA 链，它与自己所依据的模板链 (template strand) 互补配对。
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. 姐妹染色单体是一条染色体复制后形成的两条完全相同的拷贝，在着丝粒 (centromere) 处相连；只要还连在一起，它们仍算作 1 条染色体，直到后期 (anaphase) 分开后才各自成为独立的染色体。
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. 着丝粒是把两条姐妹染色单体 (sister chromatid) 连在一起的区域，有丝分裂时纺锤丝 (spindle fibre) 就附着在这里牵引染色体。

Day 4 · Mitosis · 有丝分裂

ENGLISH TERM	中文	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. 前期是有丝分裂的第一个时期：染色质 (chromatin) 高度螺旋化成为可见的染色体（每条已含两条姐妹染色单体），纺锤体 (spindle) 开始形成，核膜 (nuclear envelope) 和核仁逐渐解体消失。
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. 中期是所有染色体的着丝粒 (centromere) 整齐排列在细胞赤道板 (equator) 上、并被纺锤丝牵住的时期；这是观察染色体形态和数目的最佳时期。
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. 后期是着丝粒分裂、纺锤丝把姐妹染色单体拉向细胞两极的时期；一旦分开，每条染色单体就成为一条独立的染色体，两极各得到完全相同的一套。
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. 末期是有丝分裂的最后一个时期：染色体到达两极后解螺旋、重新变回染色质 (chromatin)，两套染色体外面各自形成新的核膜 (nuclear envelope)，纺锤体消失。
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. 纺锤丝是由微管蛋白构成的纤维，整体合称纺锤体 (spindle)；它附着在着丝粒上，在有丝分裂中牵引染色体移动。注意澳洲考试用英式拼写 fibre，不是 fiber。
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. 中心粒是动物细胞中的一对小圆柱结构，分裂时移向细胞两极，参与组织纺锤体 (spindle) 的形成；高等植物细胞没有中心粒，同样能形成纺锤体。
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. 赤道板是位于细胞两极正中间的一个假想平面，中期 (metaphase) 时染色体就排列在这里；它不是真实存在的结

		构，只是一个位置概念，答题时别说它是一层膜。
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. 核膜是包被细胞核的双层膜，在前期 (prophase) 解体消失，在末期 (telophase) 于两套染色体外重新形成，这样才有两个新的细胞核。
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. 子细胞是一个细胞周期结束时产生的两个新细胞；经过有丝分裂和胞质分裂后，它们彼此之间以及与母细胞 (parent cell) 的遗传物质完全相同。
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. 遗传物质完全相同指 DNA 碱基序列和染色体数目都一模一样；这是先在 S 期进行半保留复制 (semi-conservative replication)、再由有丝分裂把姐妹染色单体精确均分到两极的结果——这两步是答“为什么子细胞相同”的标准得分点。
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. 二倍体 (2n) 指细胞中含有两套完整的染色体，分别来自父母双方；人的体细胞是二倍体，共 46 条（23 对）。有丝分裂产生的子细胞仍然是二倍体。
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. 单倍体 (n) 指只含一套染色体的细胞，例如配子（精子、卵细胞）；单倍体细胞由减数分裂 (meiosis) 产生，有丝分裂 (mitosis) 不会产生单倍体细胞。
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. 无性生殖是只由一个亲本、通过有丝分裂 (mitosis) 产生后代的方式，后代与亲本遗传物质完全相同，例如水螅出芽、草莓匍匐茎、植物扦插。
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. 组织修复是通过有丝分裂产生新的、遗传物质完全相同的细胞来替换受损或衰老的细胞，例如皮肤伤口愈合；正因为新细胞与原细胞相同，修复后的组织功能才一样。
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. 干细胞是一类未特化的细胞，既能通过有丝分裂 (mitosis) 不断自我增殖，又能分化 (differentiation) 成一种或多种特化细胞，是生长和组织修复的细胞来源。
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. 癌症是细胞周期的检查点 (checkpoint) 调控失灵、细胞不受控制地持续分裂而引起的疾病；这些细胞堆积形成的团块叫肿瘤（英式拼写 tumour，带 u）。
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. 减数分裂是另一种核分裂方式：一个二倍体 (diploid) 细胞产生 4 个遗传上有差异的单倍体 (haploid) 配子；而有丝分裂 (mitosis) 产生 2 个与母细胞完全相同的二倍体细胞。本单元只需能把两者区分开。

Sources

内容来源 · 每一条都实际打开核对过

这份手册依据澳大利亚高中生物大纲编写，之后经过三轮独立审校：科学准确性、中文翻译准确度、11 年级难度匹配。下列来源全部由独立核查环节逐条重新抓取，确认链接可打开且页面内容确实支持手册里的说法；没通过核查的一律不列。学术写作时请引用原始来源，而不是这份手册。

Syllabus & curriculum · 官方大纲与课程标准

1 **Biology Stage 6 Syllabus (2017)**

syllabus · NSW Education Standards Authority (NESA) · used in the syllabus · Day 1 · Day 2 · Day 3 · Day 4

https://www.nsw.gov.au/education-and-training/nesa/curriculum/science/biology-stage-6-2017

确认 NSW 11 年级四个模块（细胞是生命的基础、生物体的组织、生物多样性、生态系统动态）与 12 年级模块（遗传、基因改变）的官方名称与顺序，说明 DNA 结构、DNA 复制、细胞周期与有丝分裂在课程中的位置。

2 **Biology – Victorian Curriculum and Assessment Authority**

syllabus · Victorian Curriculum and Assessment Authority (VCAA) · used in the syllabus

https://www.vcaa.vic.edu.au/curriculum/vce-curriculum/vce-study-designs/biology/biology

VCE 生物学「学习设计」（Study Design）官方发布页，载明 2022 年起 Units 1–4 的学习领域、成果与评估要求，并附 Units 1–2 的教师配套材料。

3 **Structure of Biology | The Australian Curriculum (Version 8.4)**

syllabus · Australian Curriculum, Assessment and Reporting Authority (ACARA) · used in the syllabus · Day 2

https://v8.australiancurriculum.edu.au/senior-secondary-curriculum/science/biology/structure-of-biology/

给出国家高中生物学的单元结构：Unit 1 生物多样性与生命的关联，Unit 2 细胞与多细胞生物。注意：国家课程 Units 1–2 只涵盖细胞结构与功能，DNA 复制与有丝分裂在后续单元。

4 **Heredity and genetic change — Module 5 and 6 guides**

government · NSW Department of Education · used in the syllabus · Day 1 · Day 3

https://education.nsw.gov.au/teaching-and-learning/curriculum/science/science-curriculum-resources-k-12/science-11-12-curriculum-resources/s6-biology-module-5-6

「遗传」（Module 5）与「基因改变」（Module 6）的官方模块教学指南，附 DNA 复制、多肽合成等可下载配套文件，用于教授 NESA 课程。

DNA structure · DNA 的结构

5 **DNA Replication**

education site · TeachMePhysiology (TeachMe Series) · used in Day 1 · Day 3

https://teachmephysiology.com/biochemistry/cell-growth-death/dna-replication/

老师指定的 DNA 复制总览：半保留复制、复制的三个阶段（起始、延伸、终止）、DNA 聚合酶只能在 3' 端添加核苷酸延长引物，以及后随链上的冈崎片段。

6 DNA Replication Mechanisms

textbook National Center for Biotechnology Information (NCBI Bookshelf) — Molecular Biology of the Cell, 4th edition, Alberts et al., Garland Science 2002 used in Day 1 · Day 3

https://www.ncbi.nlm.nih.gov/books/NBK26850/

权威教科书对复制机制的讲解：DNA 模板配对、DNA 聚合酶实现的半保留复制、复制叉，以及极高的复制保真度（每复制约 10^9 个核苷酸才出 1 个错误）。

7 DNA Replication

government National Human Genome Research Institute (NHGRI), National Institutes of Health used in Day 1 · Day 3

https://www.genome.gov/genetics-glossary/DNA-Replication

官方给出的 DNA 复制简短定义——细胞中基因组 DNA 被复制的过程，适合学生作为标准定义背诵和引用。

8 DNA replication — Module 5

government NSW Department of Education used in Day 1 · Day 3

https://education.nsw.gov.au/teaching-and-learning/curriculum/science/science-curriculum-resources-k-12/science-11-12-curriculum-resources/dna-replication

NSW 教育部官方课例资源，讲解 DNA 结构以及 DNA 复制过程与所涉及的酶，对应 NESA Biology Stage 6 Syllabus (2017) 第 5 模块。

9 The Structure and Function of DNA

textbook Molecular Biology of the Cell, 4th edition (Alberts B, Johnson A, Lewis J, et al.), Garland Science — hosted on NCBI Bookshelf, National Center for Biotechnology Information used in Day 1 · Day 3

https://www.ncbi.nlm.nih.gov/books/NBK26821/

支撑DNA结构的核心论点：DNA由四种核苷酸共价连接成多核苷酸链；两条糖–磷酸骨架相互缠绕形成双螺旋；A与T配对、G与C配对；碱基之间的氢键把两条链连在一起。

10 Deoxyribonucleic Acid (DNA) Fact Sheet

government National Human Genome Research Institute (NHGRI), National Institutes of Health used in Day 1

https://www.genome.gov/about-genomics/fact-sheets/Deoxyribonucleic-Acid-Fact-Sheet

支撑四种含氮碱基(A、T、G、C)、互补配对规则(A—T、C—G)、双螺旋像“扭曲的梯子”的形状，以及DNA必须被紧密包装、这种包装形式被称为染色体这一要点。

11 Chromosomal DNA and Its Packaging in the Chromatin Fiber

textbook Molecular Biology of the Cell, 4th edition (Alberts B, Johnson A, Lewis J, et al.), Garland Science — hosted on NCBI Bookshelf, National Center for Biotechnology Information used in Day 1 · Day 4

https://www.ncbi.nlm.nih.gov/books/NBK26834/

支撑DNA包装部分：核小体核心颗粒是DNA缠绕在由八个组蛋白(H2A、H2B、H3、H4各两个)构成的核心上；核小体层层堆叠形成更高度压缩的排列；核小体的形成把DNA缩短到原长度的约三分之一。

12 Chromosomes Fact Sheet

government National Human Genome Research Institute (NHGRI), National Institutes of Health used in Day 1 · Day 4

https://www.genome.gov/about-genomics/fact-sheets/Chromosomes-Fact-Sheet

以学生能懂的层次支撑染色体包装的论点：染色体是位于动植物细胞核内的线状结构；DNA紧紧缠绕在称为组蛋白的线轴状蛋白质上，使极长的DNA分子能装进细胞里。

13 Biochemistry, DNA Structure

reference StatPearls [Internet], StatPearls Publishing — hosted on NCBI Bookshelf, National Center for Biotechnology Information used in Day 1

https://www.ncbi.nlm.nih.gov/books/NBK538241/

支撑细节层面的内容：一个核苷酸由含氮碱基、五碳糖和至少一个磷酸基团组成；DNA的三维形状是右手双螺旋；A–T之间由两个氢键连接、G–C之间为三个氢键。

14 Mitosis

government National Human Genome Research Institute (NHGRI), National Institutes of Health — Talking Glossary of Genomic and Genetic Terms used in Day 1 · Day 4

https://www.genome.gov/genetics-glossary/Mitosis

对有丝分裂的简明、适合学生的定义:细胞复制其染色体并将其分离,产生两个完全相同的细胞核以准备细胞分裂,随后细胞内容物通常均等分配到两个基因组相同的子细胞中;以及拷贝必须精确、复制或分配染色体时偶发的错误会对细胞和人体带来不良后果这一要点。

The cell cycle · 细胞周期

15 The Eukaryotic Cell Cycle – The Cell – NCBI Bookshelf

textbook National Center for Biotechnology Information (NCBI Bookshelf) — Cooper GM, The Cell: A Molecular Approach, 2nd edition, Sinauer Associates, 2000 used in Day 2 · Day 4

https://www.ncbi.nlm.nih.gov/books/NBK9876/

细胞周期分为 G1、S、G2 与 M 四期;间期(interphase)为两次有丝分裂之间的时期、约占整个周期 95%;DNA 复制发生在 S 期;以及细胞周期检查点——G2 检查点在 S 期完成前阻止进入 M 期,G1 检查点由 p53 在 DNA 受损时介导阻滞,中期检查点监测染色体在有丝分裂纺锤体上的排列。

16 The Events of M Phase – The Cell – NCBI Bookshelf

textbook National Center for Biotechnology Information (NCBI Bookshelf) — Cooper GM, The Cell: A Molecular Approach, 2nd edition, Sinauer Associates, 2000 used in Day 2 · Day 4

https://www.ncbi.nlm.nih.gov/books/NBK9958/

有丝分裂各阶段的顺序与标志性事件:前期以染色体凝缩出现、中心体向两侧移动为标志;前中期为纺锤体微管附着到着丝点的过渡期;中期染色体排列在赤道板上;后期姐妹染色单体分离并向两极移动;末期细胞核重新形成、染色体解凝;以及通常伴随有丝分裂结束发生、产生两个子细胞的胞质分裂。

17 Genetics, Mitosis – StatPearls

reference StatPearls Publishing, hosted by the National Center for Biotechnology Information (NCBI Bookshelf); authors Ibraheem Rehman, Mustafa Farooq, Brittany Simpson used in Day 2 · Day 4

https://www.ncbi.nlm.nih.gov/books/NBK482449/

有丝分裂各阶段:前期、前中期、中期(染色体排列在赤道板,即与纺锤体两极等距的假想线上)、后期为最短阶段且姐妹染色单体分开、末期与胞质分裂;有丝分裂在多细胞真核生物中主要用于生长与受损细胞的替换或修复,而原核细胞分裂本身即等于繁殖;以及三个主要检查点 G1/S、G2/M 与中期/后期检查点。

18 Cancer cells | Cancer Research UK

education site Cancer Research UK used in Day 2 · Day 4

https://www.cancerresearchuk.org/about-cancer/what-is-cancer/how-cancer-starts/cancer-cells

以学生易懂的语言说明细胞周期调控失效与癌症的联系:正常细胞只在需要的时间和地点增殖;而癌细胞在数量足够时不会停止生长和分裂,因而不断加倍并形成不断增大的肿块(肿瘤);癌细胞体内的某种因素使正常信号系统失灵,癌细胞还能忽略令其自毁的信号,因而在本该凋亡时不发生凋亡。

DNA replication · DNA 复制

19 DNA Replication

textbook National Center for Biotechnology Information (NCBI Bookshelf) — The Cell: A Molecular Approach, 2nd edition, Geoffrey M. Cooper used in Day 3

https://www.ncbi.nlm.nih.gov/books/NBK9940/

清晰的大学入门级讲解：复制是半保留的，每条亲本链充当模板；聚合酶只能沿 5'→3' 方向合成 DNA——这正是前导链与后随链存在的原因。

20 14.4 DNA Replication in Prokaryotes

textbook OpenStax, Rice University — Biology 2e used in Day 3

https://openstax.org/books/biology-2e/pages/14-4-dna-replication-in-prokaryotes

逐步讲解复制叉上的各种酶：为什么反向平行的双螺旋迫使合成只能 5'→3' 进行（前导链与后随链的由来），以及 DNA 连接酶如何通过形成磷酸二酯键封闭缺口。