

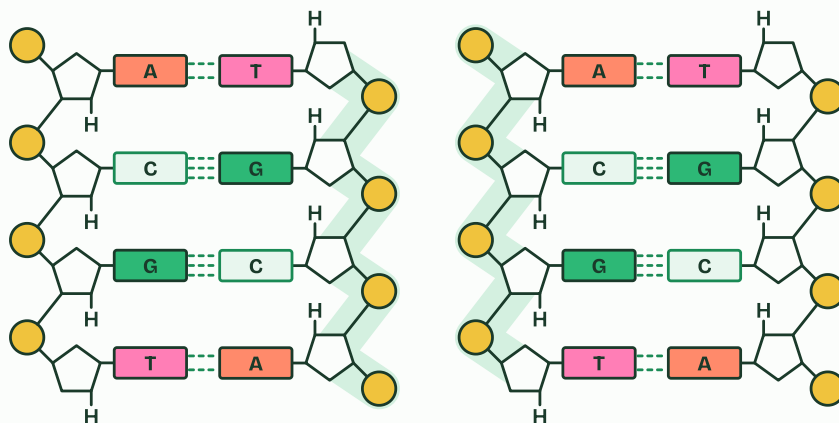
REVISION GUIDE

Four letters, two strands, every *living* thing

Nucleic acids

Every living thing keeps its instructions in the same molecule, written in the same four letters. Here is how a chain of simple parts stores a whole life, copies it almost perfectly and passes it on.

Two copies



Contents

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By the end you can

- ☐ Explain why DNA is the genetic material of every living organism, and why RNA viruses do not break the rule A1.2.1
- ☐ Draw a nucleotide as a circle, a pentagon and a rectangle, each joined in the right place A1.2.2
- ☐ Explain how condensation builds a strand with a strong sugar–phosphate backbone, and draw a short strand of RNA A1.2.3, A1.2.5
- ☐ Name the bases of DNA and RNA, and explain how complementary pairing lets DNA be copied and read A1.2.4, A1.2.8
- ☐ Draw two antiparallel strands joined by hydrogen bonds between A and T, and C and G A1.2.6
- ☐ Give three differences between DNA and RNA, and sketch ribose against deoxyribose A1.2.7
- ☐ Explain why DNA can store limitless information, and why one genetic code in all life points to a common ancestor A1.2.9, A1.2.10
- ☐ Explain what the 5' and 3' ends are, and why nucleotides are only ever added at the 3' end A1.2.11
- ☐ Explain why a purine always pairs with a pyrimidine, and what that does for the helix A1.2.12
- ☐ Describe a nucleosome, and use molecular visualisation software to see how histones hold DNA A1.2.13
- ☐ Explain how Hershey and Chase's results support the conclusion that DNA, not protein, is the genetic material A1.2.14
- ☐ Use Chargaff's data to falsify the tetranucleotide hypothesis, and explain why one result can falsify what many cannot prove A1.2.15

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

01

A1.2.1 DNA AS THE GENETIC MATERIAL

Every living thing keeps its instructions in *DNA*

An organism inherits instructions from its parents: how to build its cells, which proteins to make, when to grow. The molecule that holds those instructions is its **genetic material**.

In every living organism studied, the genetic material is **DNA**, short for deoxyribonucleic acid. That is true of bacteria, archaea, protists, fungi, plants and animals. In a cell with a nucleus, most of the DNA is in the nucleus, with a little in the mitochondria and, in plants, the chloroplasts. In a bacterium it lies loose in the cytoplasm.

DNA belongs to the **nucleic acids**. The other one, **RNA**, does many jobs in the cell (chapter 6), and a few **viruses** use it to carry their genes: influenza, measles and the coronavirus that causes COVID-19 are RNA viruses. Other viruses carry DNA. How anyone found out that DNA, and not protein, carries genes is the story of chapter 11.

Both nucleic acids are polymers built from one kind of monomer (chapter 2), and both contain carbon, hydrogen, oxygen, nitrogen and phosphorus.

One more distinction. DNA is the whole molecule. A **gene** is one stretch of its base sequence, and a single DNA molecule carries many genes.

KEY TERMS

genetic material

The molecule that carries the instructions an organism inherits. It is copied each time a cell divides and passed from parents to offspring.

DNA

Deoxyribonucleic acid: the nucleic acid that is the genetic material of all living organisms.

nucleic acids

Polymers built from nucleotides. DNA and RNA are the two nucleic acids.

RNA

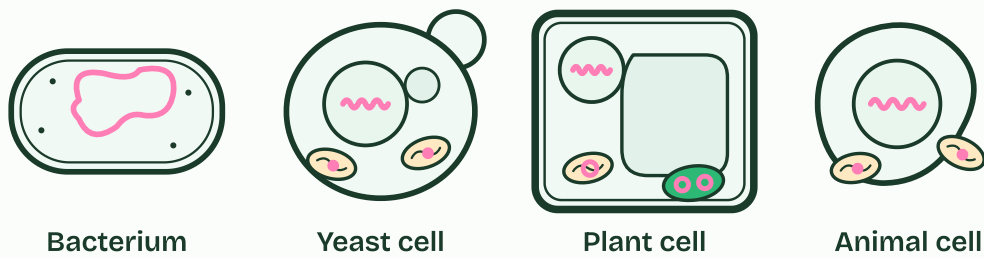
Ribonucleic acid: the other nucleic acid. It has several jobs in cells, and in some viruses it is the genetic material.

viruses

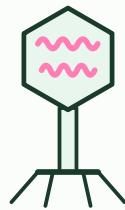
Tiny particles of genetic material inside a protein coat. A virus has no cells and can only be copied inside a host cell.

gene

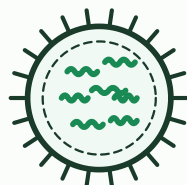
A stretch of a DNA molecule: a particular base sequence that carries one piece of information.

**Viruses** not to scale

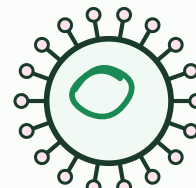
— DNA — RNA



phage



influenza virus



coronavirus

Pink is DNA and green is RNA. Viruses are far smaller than cells, so the strip of viruses is not to scale.

Bacterium DNA, one long loop, loose in the cytoplasm: there is no nucleus.

Plant cell DNA in the nucleus, and small loops in mitochondria and chloroplasts.

Phage A virus that infects bacteria. Its DNA lies inside a protein coat.

Coronavirus RNA inside a protein coat, with a fatty envelope. It has no cells and makes nothing for itself: it can only be copied inside a host cell.

Yeast cell DNA in the nucleus, and a little in each mitochondrion.

Animal cell DNA in the nucleus, and a little in each mitochondrion.

Influenza virus RNA inside a protein coat, with a fatty envelope. It has no cells and makes nothing for itself: it can only be copied inside a host cell.

WATCH OUT

"DNA" and "gene" are not two words for one thing. DNA is the molecule; a gene is one stretch of its base sequence, and one DNA molecule carries many genes.

PREDICT

A virus is found whose genes are made of RNA. Does that break the rule that DNA is the genetic material of all living organisms?

- (A) Yes: the rule must now say DNA or RNA
- (B) No: viruses are not counted as living organisms
- (C) No: the RNA is only a copy, and the virus keeps its real genes as DNA

Decide before you look. Answer on page 41.

02

A1.2.2 COMPONENTS OF A NUCLEOTIDE

Three parts, one *monomer*

Nucleic acids are **polymers**. The small unit, the **monomer**, is the **nucleotide**.

A nucleotide has three parts joined by covalent bonds: a **phosphate group**, a **pentose sugar** and a **nitrogenous base**. The sugar is in the middle. The phosphate is bonded to one corner of it and the base to another, and the base and the phosphate are never bonded to each other.

In DNA the sugar is deoxyribose, and in RNA it is ribose (chapter 6). The bases have names of their own (chapter 4).

Between them the three parts contain carbon, hydrogen, oxygen, nitrogen and phosphorus. Nitrogen comes only from the base and phosphorus only from the phosphate. In the cell the phosphate group carries a negative charge, a fact that matters again later in this guide.

KEY POINTS

- **Draw it the IB way.** A circle for the phosphate, a pentagon for the sugar and a rectangle for the base.
- The sugar is in the middle: the circle is at the upper left of the pentagon, on a short stalk, and the rectangle is at its right-hand corner.
- One ring round all three marks one nucleotide.

KEY TERMS

polymers

Long molecules built from many copies of a small unit, joined in a chain.

monomer

One small unit of a polymer. The monomer of a nucleic acid is the nucleotide.

nucleotide

The monomer of nucleic acids: a phosphate group, a pentose sugar and a nitrogenous base joined together.

phosphate group

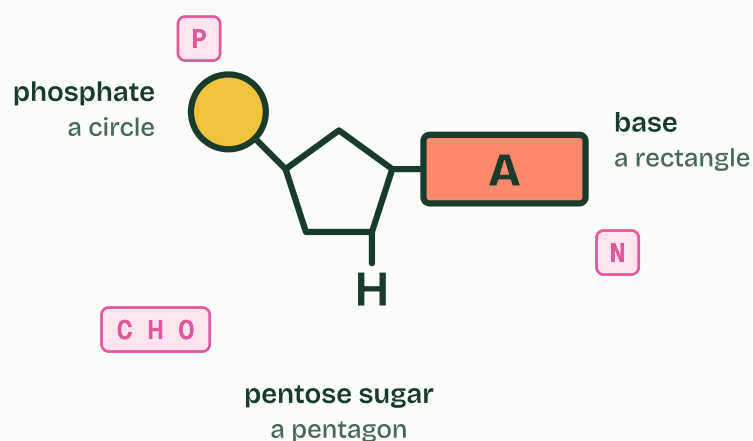
A phosphorus atom with oxygen atoms round it. In a cell it carries a negative charge.

pentose

A sugar with five carbon atoms.

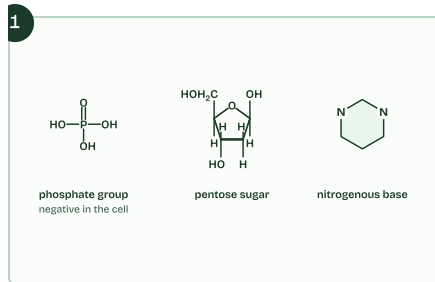
nitrogenous base

A ring of carbon and nitrogen atoms that is the part of a nucleotide that varies. Its order along a strand is the message.

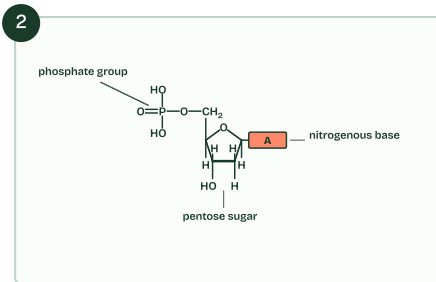


STEP BY STEP

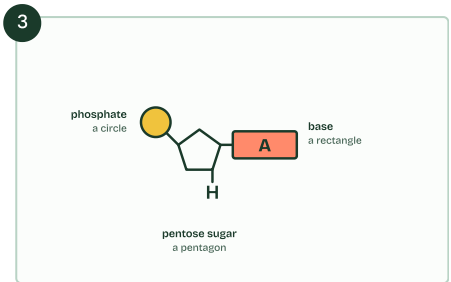
4 STEPS



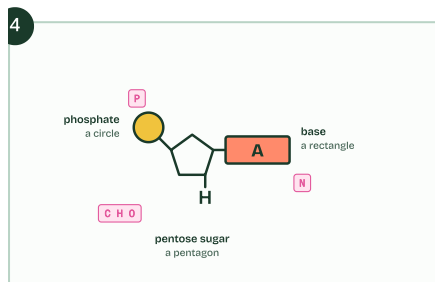
A nucleotide is built from **three parts**.



The **sugar** sits in the middle, bonded to both of the others.



The IB draws them as a **circle**, a **pentagon** and a **rectangle**, in these positions.



Nitrogen comes from the base and **phosphorus** from the phosphate.

WATCH OUT

A nucleotide is not a base. Each nucleotide contains one base, along with a sugar and a phosphate. And the base is bonded to the sugar, never to the phosphate.

PREDICT

How many different nucleotides does a cell use to build DNA?

- (A) One: every nucleotide in DNA is exactly the same as every other
- (B) Twelve: four kinds of base, four kinds of sugar and four kinds of phosphate
- (C) Four: the sugar and phosphate are the same, only the base differs

Decide before you look. Answer on page 41.

03

A1.2.3 A1.2.5 SUGAR-PHOSPHATE BONDING AND RNA

Building a strand with a strong *backbone*

Nucleotides join by **condensation**, as in the sugars and lipids of B1.1. The phosphate of each new nucleotide bonds to the sugar of the last nucleotide in the chain, and a molecule of water is released. The reverse is **hydrolysis**: water is added back and the bond breaks, which is how your digestion takes the nucleic acids in food apart.

Repeat the join and you build a **strand**: sugar, phosphate, sugar, phosphate. Every link is a **covalent bond**, so the strand is one continuous chain of covalently bonded atoms. That is the **sugar-phosphate backbone**: strong, and it fixes the order of the nucleotides along it. (Chemists call the link a phosphodiester bond; the IB does not ask for the name.)

The bases are not part of the backbone. Each sticks out sideways from its sugar, all on the same side, free to pair with another base (chapter 4). The backbone is the same all along, whatever the bases are, and any base can follow any other. Chapter 7 builds on that.

RNA is one such strand, a polymer of ribonucleotides made by condensation. DNA strands are built the same way; the enzymes that do it come in D1.1.

To draw an RNA strand, stack the nucleotides, join the lower left corner of each pentagon to the circle of the next, and point every base the same way. To mark one nucleotide, ring a circle, a pentagon and a rectangle together, not a pentagon, a rectangle and the circle below it.

One nucleotide has no order. A strand does. Order is a property of the polymer that its monomers do not have.

KEY TERMS

condensation

A reaction that joins two molecules and releases a molecule of water.

hydrolysis

A reaction in which a bond is broken by adding a molecule of water.

strand

One chain of nucleotides, also called a polynucleotide.

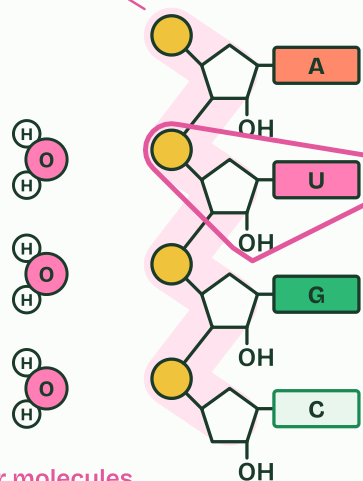
covalent bond

A bond in which two atoms share a pair of electrons. Covalent bonds are strong.

sugar-phosphate backbone

The chain of alternating sugars and phosphates, joined by covalent bonds, that runs along a nucleic acid strand.

sugar-phosphate backbone

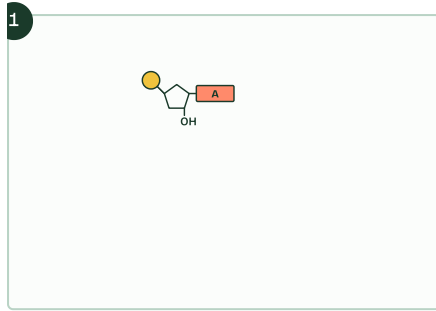
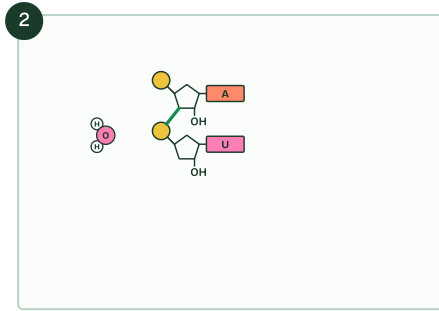
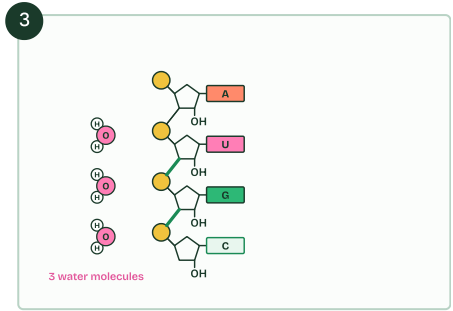
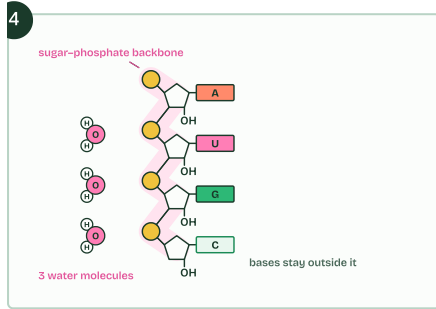
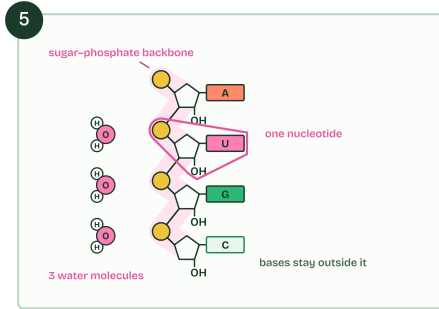
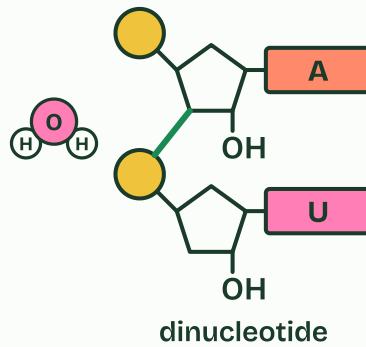
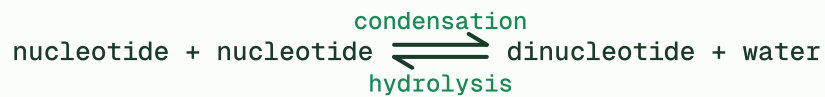


one nucleotide

bases stay outside it

STEP BY STEP

5 STEPS

One **nucleotide**.**Condensation:** the phosphate bonds to the sugar above, and water leaves.Each new bond releases one **water** molecule.Sugar, phosphate, sugar, phosphate: a covalently bonded **backbone**.One nucleotide is a circle, a pentagon and a rectangle **together**.

Join nucleotides into a strand and count the water that leaves. Try a join that does not work and read why, then add water to split the strand again.

STEP BY STEP

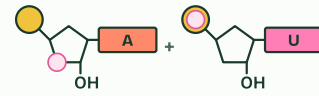
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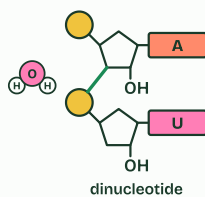
Two **nucleotides**, each a phosphate, a sugar and a base.

2



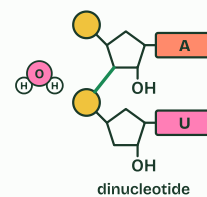
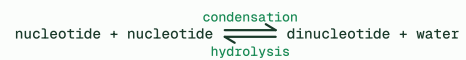
The phosphate of one and the sugar of the other face each other.

3



They leave as **water**, and a **sugar-phosphate bond** joins the sugar of one to the phosphate of the next: **condensation**, making a **dinucleotide**.

4



Add water and the bond splits again, the H to one nucleotide and the OH to the other: **hydrolysis**.

WATCH OUT

Hydrogen bonds do not hold a strand together. Inside a strand every link is covalent. Hydrogen bonds only come in between two strands (chapter 4), which is why the two strands of DNA can be parted without breaking either.

PREDICT

How many water molecules are released when 10 nucleotides join into one strand?

- (A) 9
(B) 10
(C) 20

Decide before you look. Answer on page 41.

04

A1.2.4

A1.2.8

BASES AND COMPLEMENTARY PAIRING

Four letters that *pair*

DNA uses four bases: **adenine** (A), **cytosine** (C), **guanine** (G) and **thymine** (T). RNA has A, C and G too, but **uracil** (U) takes the place of thymine. You need the names as well as the letters.

The order of the bases along a strand is the message, like letters spelling words: the **base sequence**. A gene is a stretch of that sequence, read three bases at a time to choose amino acids (D1.2).

Bases pair across between two strands by **complementary base pairing**: A with T (or with U when RNA is involved), and C with G. Complementarity rests on **hydrogen bonds**. Each base has a pattern of atoms that can give or take a hydrogen bond, and only in these two pairs do the patterns line up across the gap. A–T forms two bonds and C–G three; you do not need to memorise those numbers.

That pairing is what makes accurate copying possible. In **replication** the hydrogen bonds break and the strands separate, while the covalent backbones stay whole. Each strand is a **template**: free nucleotides pair with its exposed bases, and each new strand is complementary to its template. Each new molecule therefore has exactly the base sequence of the original. That answers the second guiding question: each strand carries what is needed to rebuild the other.

The same rule lets cells read DNA. In **transcription**, one strand of a gene is the template for an RNA copy, with an RNA base opposite each DNA base and U opposite A. In **translation**, three bases of messenger RNA pair with three bases of a transfer RNA, which brings the matching amino acid. Here both are outlined; D1.2 teaches them.

KEY TERMS

adenine

One of the four bases of DNA, written A. It pairs with thymine (uracil in RNA).

cytosine

One of the four bases of DNA, written C. It pairs with guanine.

guanine

One of the four bases of DNA, written G. It pairs with cytosine.

thymine

A base found in DNA, written T. It pairs with adenine.

uracil

A base found in RNA, written U, in the place of thymine. It pairs with adenine.

base sequence

The order of the bases along a strand of DNA or RNA.

complementary base pairing

The rule that each base pairs with one particular other base: A with T (or U), and C with G.

hydrogen bonds

Weak attractions between a slightly positive hydrogen atom on one molecule and a slightly negative atom on another.

replication

Copying a DNA molecule to make two molecules with the same base sequence.

template

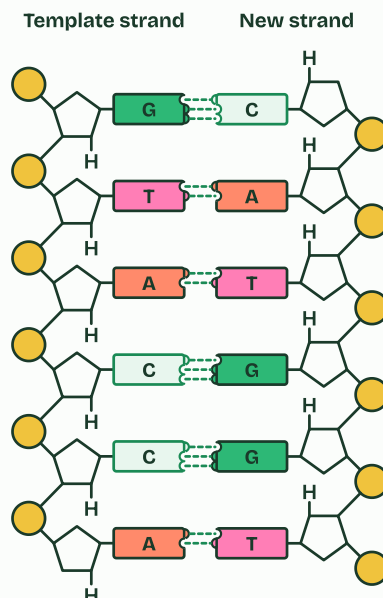
A strand that new nucleotides pair with, so the new strand has the complementary sequence.

transcription

Making an RNA copy of a gene, using one DNA strand as the template.

translation

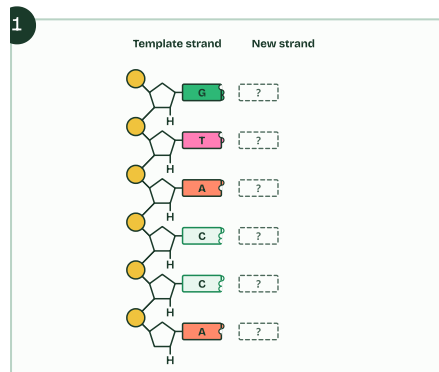
Making a chain of amino acids by reading the codons of messenger RNA.



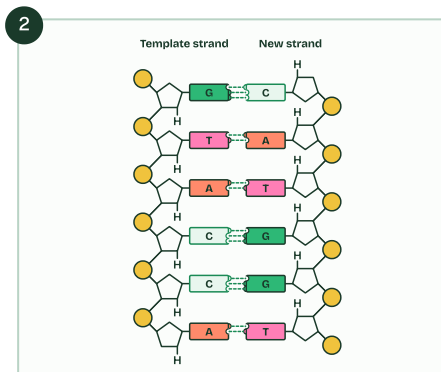
The knobs and notches stand for the atoms that form hydrogen bonds: a knob is a hydrogen that can be shared, a notch an atom that can take it. Real bases are flat rings.

SWITCH IT

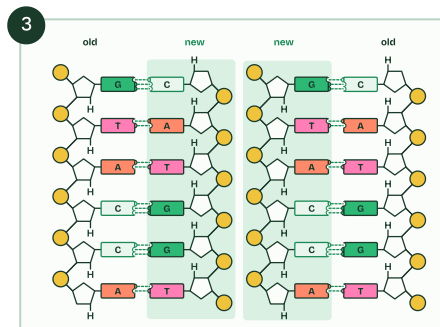
4 SETTINGS



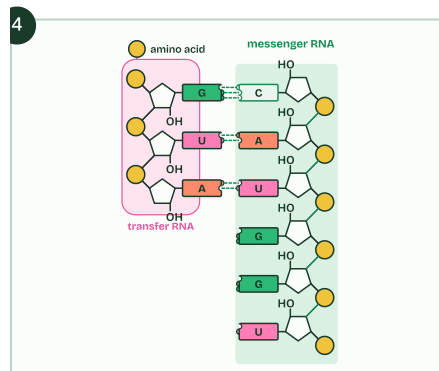
Which base fits each slot?



Paired: only A with T and G with C form hydrogen bonds



Copy it: two molecules with the same sequence



Read it: messenger RNA, read by a transfer RNA

REMEMBER IT

Which base pairs with which

A Apples	T Tree	C Cars	G Garage
A denine pairs with thymine (uracil in RNA)	T hymine in DNA only	C ytosine pairs with guanine	G uanine pairs with cytosine

WATCH OUT

Complementary does not mean identical. The two strands of one molecule have different sequences; it is the two molecules made by copying that are identical. And in RNA, uracil takes the place of thymine, not of adenine.

PREDICT

One strand of a DNA molecule reads A A T G C. The strands separate and each is copied. What does the strand built against it read, and the strand built against that one?

- (A) T T A C G, then T T A C G
- (B) T T A C G, then A A T G C
- (C) U U A C G, then A A T G C

Decide before you look. Answer on page 41.

05

A1.2.6 THE DOUBLE HELIX

Two strands, one *helix*

DNA is two strands held together by hydrogen bonds between complementary bases: A with T and G with C. The bases are on the inside and the two sugar-phosphate backbones are on the outside. A pair of bases facing each other is a **base pair**.

The strands are **antiparallel**: they run in opposite directions, like the two lanes of a road. In a drawing, the second strand's nucleotides are upside down, with the pentagons inverted and the phosphates on the other side. What direction means chemically is chapter 8.

The pair of strands winds into a **double helix**. In an exam you draw the two strands antiparallel and paired, with A opposite T and G opposite C. You do not have to draw the twist.

One hydrogen bond is weak, but millions of them hold the two strands firmly together. How that squares with copying and reading DNA, which need the strands parted, is the prediction below.

KEY TERMS

base pair

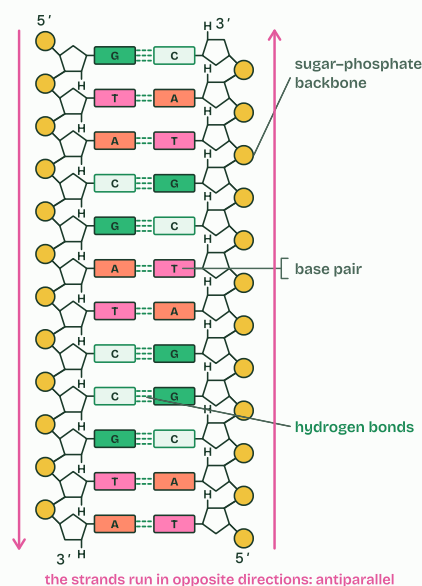
Two bases, one from each strand, held together by hydrogen bonds: A with T or G with C.

antiparallel

Running in opposite directions, like the two lanes of a road.

double helix

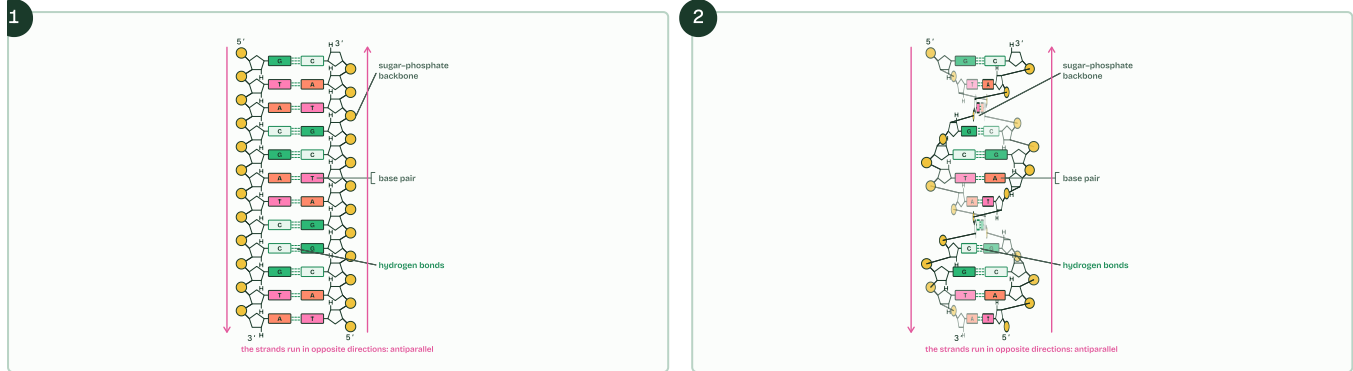
The shape of DNA: two strands wound round each other in a spiral.



Twelve base pairs. Slide Twist to wind the ladder into a double helix, about ten base pairs a turn, then Turn it, or drag it sideways. Real DNA is about 2 nm across, with 0.34 nm between base pairs.

SWITCH IT

2 SETTINGS



Flat: the ladder the exam asks for

Twisted into a double helix

WORKED EXAMPLE

In a double-stranded DNA molecule, 20% of the bases are adenine. Thymine pairs with adenine, so 20% are thymine. That leaves 60%, shared equally between guanine and cytosine: 30% each. Every nucleotide carries one phosphate, so the number of phosphates equals the number of bases.

BUILT AS A MODEL

In 1953 James Watson and Francis Crick worked out this structure by building scale models of the parts and fitting them to the evidence: X-ray diffraction images of DNA made by Rosalind Franklin and Raymond Gosling, which showed a regular helix with the backbones outside, and chemical analyses showing equal amounts of A and T, and of G and C (Chargaff, chapter 12). A model is a simplification that can be tested against data. This guide's own figures leave out every atom.

WATCH OUT

Antiparallel does not mean twisted, or that the bases are opposite each other. It means the two strands run in opposite directions.

PREDICT

To be copied, the two strands of DNA must come apart. Why does pulling them apart not break the strands themselves?

- (A) Strong covalent bonds join the two strands, while each strand is held together by weak hydrogen bonds
- (B) The bases leave the strands while they are copied, then the strands are put back together afterwards
- (C) Weak hydrogen bonds join the two strands, while each strand is a chain of strong covalent bonds

Decide before you look. Answer on page 41.

06

A1.2.7 DIFFERENCES BETWEEN DNA AND RNA

DNA and RNA *compared*

DNA and RNA differ in three ways you need to be able to give: the number of strands, the bases, and the sugar.

KEY POINTS

- **Strands.** DNA has two, wound into a double helix. RNA usually has one, which can fold back and pair with itself in places: transfer RNA does.
- **Bases.** DNA has A, C, G and T. RNA has A, C, G and U.
- **Sugar.** DNA has **deoxyribose**. RNA has **ribose**.

Deoxyribose has one oxygen fewer than ribose: on carbon 2 it carries an H where ribose carries an OH, and "deoxy" means "without an oxygen". The ring oxygen is still there. Sketch both rings and mark the difference.

Cells use several kinds of nucleic acid. DNA makes up the chromosomes, with more in mitochondria and chloroplasts. **Messenger RNA** is a copy of a gene, taken to a ribosome. **Transfer RNA** brings amino acids to the ribosome. **Ribosomal RNA** is part of every ribosome. And some viruses have RNA as their genes.

KEY TERMS

deoxyribose

The pentose sugar in DNA. It has an H on carbon 2 where ribose has an OH.

ribose

The pentose sugar in RNA. It has an OH on carbon 2.

Messenger RNA

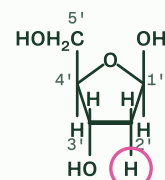
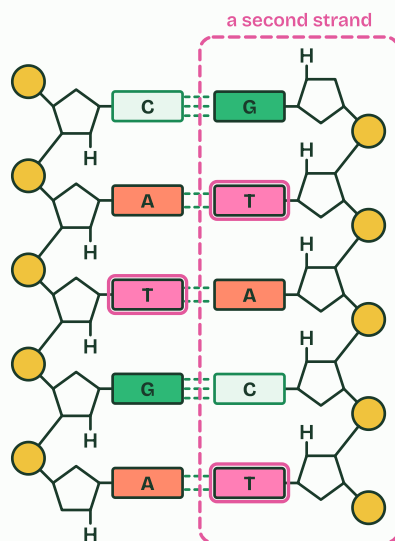
RNA that is a copy of a gene and is taken to a ribosome to be translated.

Transfer RNA

RNA that brings an amino acid to the ribosome. It folds back on itself and pairs with itself in places.

Ribosomal RNA

RNA that is part of every ribosome.



deoxyribose
H on carbon 2'

Switch between them. What differs from the other nucleic acid is outlined in pink.

SWITCH IT

2 SETTINGS

1

DNA

2

RNA

REMEMBER IT

The three differences between DNA and RNA

S Some	B Bananas	S Split
Sugar deoxyribose in DNA, ribose in RNA	Bases thymine in DNA, uracil in RNA	Strands two in DNA, usually one in RNA

LINKS

What makes RNA more likely than DNA to have been the first genetic material? A start: RNA can carry a base sequence and also act as a catalyst (some RNA molecules speed up reactions, as in the ribosome), so one molecule could have done both jobs. DNA is double-stranded and has no reactive OH on carbon 2, which makes it the steadier store, and that may be why it took over storage later. (A2.1, higher level.)

WATCH OUT

Deoxyribose still has its ring oxygen: the missing oxygen is the one on carbon 2. And RNA is not always a straight single strand: transfer RNA folds and pairs with itself.

PREDICT

A sample of nucleic acid is single-stranded and contains thymine but no uracil. What is it most likely to be?

- (A) DNA, from one of the few viruses with single-stranded DNA
- (B) RNA, because RNA is the nucleic acid that has only a single strand
- (C) A mixture of DNA and RNA, from a sample that has been contaminated

Decide before you look. Answer on page 41.

07

A1.2.9

A1.2.10

INFORMATION STORAGE AND THE GENETIC CODE

Endless sequences, *one* code

Along a strand any base can follow any other: the backbone sets no rule. And a DNA molecule can be any length. So any sequence, of any length, is possible. With four choices at every position the possibilities multiply very fast, as the slider shows. The capacity is, for every practical purpose, limitless.

That information is kept at the scale of molecules. Each human cell with a nucleus holds about 6 billion base pairs, two sets of about 3 billion, which would stretch to about 2 m if laid end to end. They are packed into a nucleus a few micrometres across. Chapter 10 shows how. (Red blood cells have no nucleus, so no DNA.) In one 2017 study, researchers stored computer files in DNA at about 215 petabytes per gram, in the laboratory.

Within a species, DNA sequences are almost the same, with small differences that are the source of different alleles. Between species they differ more. Same molecule, endless messages.

The **genetic code** is the set of rules by which a sequence of bases in messenger RNA is translated into a sequence of amino acids, three bases at a time. Each group of three is a **codon**. Almost every organism uses the same code: a codon means the same amino acid in a bacterium, a fungus, a plant and a human, with a few small variations, for example in mitochondria.

The code is arbitrary: no chemical law makes a given codon stand for a given amino acid. If life had begun separately several times, the codes would most likely differ. The best explanation for one shared code is that all life inherited it from a **universal common ancestor**. A code shared like that is **conserved** across life, and it is evidence of that shared ancestry. A gene moved from one species into another is read correctly because of it. You do not need to memorise examples: the one in the second figure is only an illustration.

That answers the first guiding question. A chain of simple units can store hereditary information because any order is possible, so the order can carry the message.

KEY TERMS

genetic code

The rules by which a sequence of bases in messenger RNA is translated into a sequence of amino acids, three bases at a time.

codon

A group of three bases in messenger RNA that stands for one amino acid.

universal common ancestor

The single ancestral population from which all living organisms are thought to be descended.

conserved

Kept the same through long periods of evolution.

$4 \times 4 \times 4 \dots (n \text{ times})$

$n = 1$ base

4

4 sequences



Slide to add bases. Each one multiplies the number of sequences by four.

SLIDE IT

8 SETTINGS

1

$4 \times 4 \times 4 \dots$ (n times)

n = 1 base

4

4 sequences



Bases in the sequence 0

2

$4 \times 4 \times 4 \dots$ (n times)

n = 2 bases

$4 \times 4 = 16$

16 sequences



Bases in the sequence 1

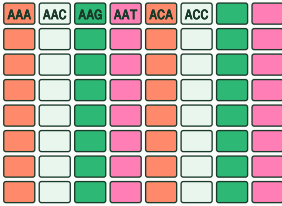
3

$4 \times 4 \times 4 \dots$ (n times)

n = 3 bases

$4 \times 4 \times 4 = 64$

64 sequences



Bases in the sequence 2

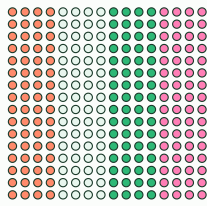
4

$4 \times 4 \times 4 \dots$ (n times)

n = 4 bases

$4 \times 4 \times 4 \times 4 = 256$

256 sequences



Bases in the sequence 3

5

$4 \times 4 \times 4 \dots$ (n times)

n = 10 bases

$4 \times 4 \times \dots \times 4$ (10 times)

1,048,576

about a million different sequences

Bases in the sequence 4

6

$4 \times 4 \times 4 \dots$ (n times)

n = 20 bases

$4 \times 4 \times \dots \times 4$ (20 times)

1,099,511,627,776

over a trillion different sequences

Bases in the sequence 5

7

$4 \times 4 \times 4 \dots$ (n times)

n = 100 bases

$4 \times 4 \times \dots \times 4$ (100 times)

about 1.6×10^{60}

a 1 followed by 60 zeros is not even close to the end of it

Bases in the sequence 6

8

$4 \times 4 \times 4 \dots$ (n times)

n = 1000 bases

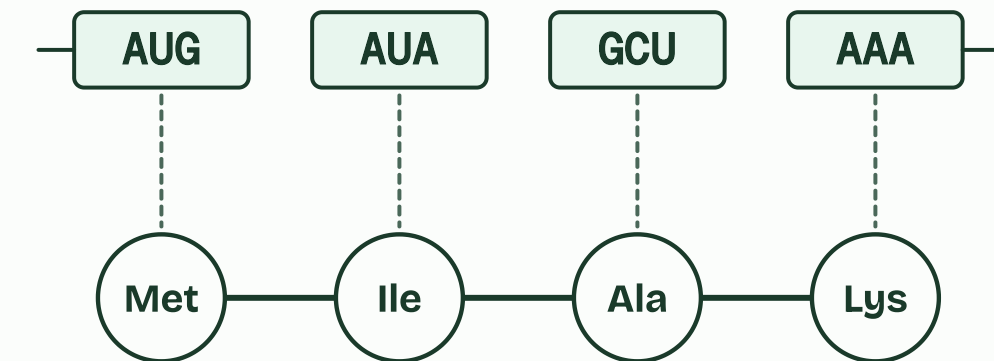
$4 \times 4 \times \dots \times 4$ (1,000 times)

a number with
603 digits

one DNA molecule can be this long and far longer

Bases in the sequence 7

Messenger RNA, read three bases at a time



Amino acids, joined into a chain

Read in a bacterium: Met, Ile, Ala, Lys

amino acid names need not be learned

The same messenger RNA read by five different ribosomes. One reader, the mitochondrion, differs in one codon.

SWITCH IT

5 SETTINGS

1

Messenger RNA, read three bases at a time

Amino acids, joined into a chain
Read in a bacterium: Met, Ile, Ala, Lys
amino acid names need not be learned

Bacterium

2

Messenger RNA, read three bases at a time

Amino acids, joined into a chain
Read in a yeast cell: Met, Ile, Ala, Lys
amino acid names need not be learned

Yeast

3

Messenger RNA, read three bases at a time

Amino acids, joined into a chain
Read in a wheat cell: Met, Ile, Ala, Lys
amino acid names need not be learned

Wheat

4

Messenger RNA, read three bases at a time

Amino acids, joined into a chain
Read in a human cell: Met, Ile, Ala, Lys
amino acid names need not be learned

Human cell

5

Messenger RNA, read three bases at a time

Amino acids, joined into a chain
Read in a human mitochondrion: Met, Met, Ala, Lys
One of the rare variations: the code is almost, not quite, universal.

Human mitochondrion

LINKS

One nucleotide holds no message. Join many and the strand has a sequence; pair two strands and the molecule can be copied. Storage and copying are properties of the polymer that its monomers do not have.

WATCH OUT

A universal code does not mean every organism has the same DNA. The dictionary is shared; the books written with it are different.

PREDICT

How many different sequences of three bases can DNA's four bases make?

- (A) 12
(B) 64
(C) 81

Decide before you look. Answer on page 41.

08

A1.2.11 HL DIRECTIONALITY

Every strand has a *direction*

The carbons of the pentose are numbered 1' to 5', said "one prime" to "five prime". The prime shows it is a carbon of the sugar and not an atom of the base. The base is on 1'. Carbon 2' carries the OH of ribose or the H of deoxyribose, 3' carries an OH, and 5', outside the ring, carries the phosphate.

In a strand, the phosphate on the 5' carbon of each nucleotide is bonded to the 3' carbon of the one before. So every link in the backbone runs the same way, and the strand has **directionality**. One end has a free phosphate on a 5' carbon, the **5' end**. The other has a free OH on a 3' carbon, the **3' end**. New nucleotides are only ever added at the 3' end, to its OH, so strands grow 5' to 3'.

Antiparallel can now be said exactly: one strand runs 5' to 3' and its partner runs 3' to 5' alongside it. A sequence is written 5' to 3', left to right, unless it is marked otherwise.

KEY POINTS

- **Replication.** Each new strand is built 5' to 3', so the two antiparallel templates are copied in opposite directions. (How that works at a replication fork is D1.1.)
- **Transcription.** RNA is built 5' to 3', so the enzyme moves along the template strand in that strand's 3' to 5' direction.
- **Translation.** A ribosome moves along messenger RNA from its 5' end towards its 3' end, so the codons are read in that order.

KEY TERMS

directionality

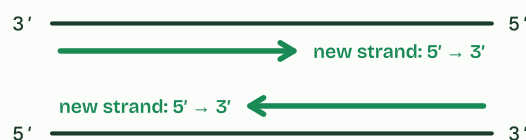
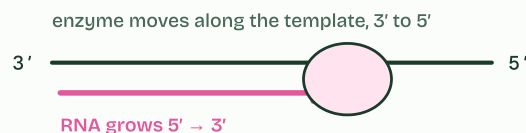
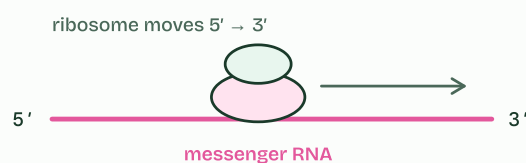
A strand has two different ends, so it runs one way: from its 5' end to its 3' end.

5' end

The end of a strand with a free phosphate on a 5' carbon.

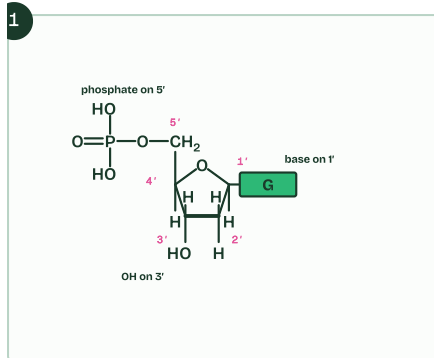
3' end

The end of a strand with a free OH on a 3' carbon. New nucleotides are added here.

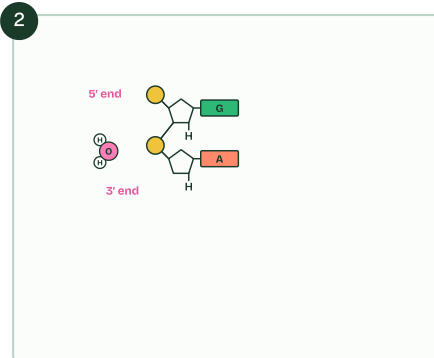
Replication
two templates**Transcription**
DNA to RNA**Translation**
RNA to protein

STEP BY STEP

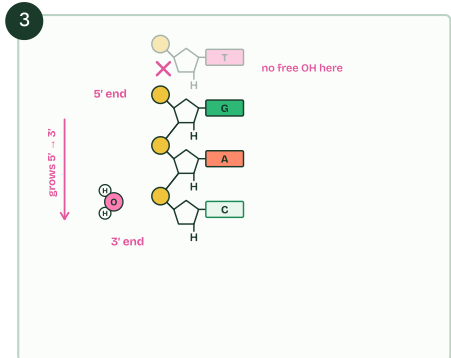
5 STEPS



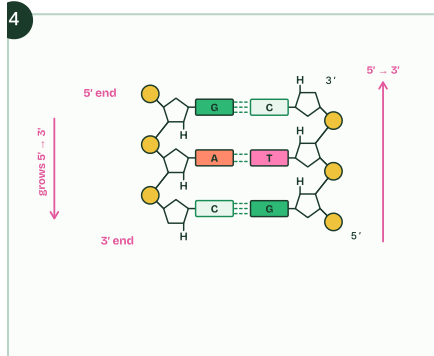
Carbons **1' to 5'**.



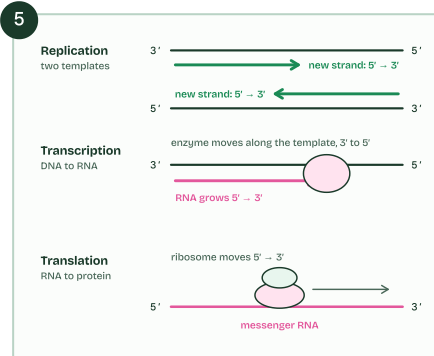
Each phosphate links a **5'** carbon to the **3'** carbon before it.



New nucleotides join only at the **3' end**.



The strands are **antiparallel**: one runs 5' to 3', the other 3' to 5'.



So DNA is copied, transcribed and read in **one direction**.

WATCH OUT

5' and 3' name carbon atoms in the sugar. They are not positions along a gene. And new strands are built 5' to 3', which means their templates are read 3' to 5'.

PREDICT

One DNA strand reads 5'-ATGC-3'. Written 5' to 3', what is its partner?

- (A) 5'-TACG-3'
- (B) 5'-CGTA-3'
- (C) 5'-GCAT-3'

Decide before you look. Answer on page 42.

09

A1.2.12 HL PURINE-TO-PYRIMIDINE BONDING

A big base with a small *one*

Bases come in two shapes. **Purines** (adenine and guanine) have two rings fused together, one of six atoms and one of five. **Pyrimidines** (cytosine, thymine and uracil) have one ring of six.

Every base pair in DNA is one purine and one pyrimidine: A with T, G with C. So every pair is the same length. The two backbones stay the same distance apart all along, and the helix has the same width and the same three-dimensional shape whatever the sequence.

That matters. The helix is regular and stable along its whole length, and any sequence fits the same structure, so the sequence is free to carry information (chapter 7). Proteins that work along DNA, such as the histones of chapter 10 and the enzymes that copy and read it, meet the same shape everywhere.

Two purines would be too wide for the gap, and two pyrimidines too narrow to reach across with hydrogen bonds. A purine with the wrong pyrimidine (A with C, or G with T) is the right length, but its hydrogen bonds do not line up (chapter 4). Try each pairing in the figure.

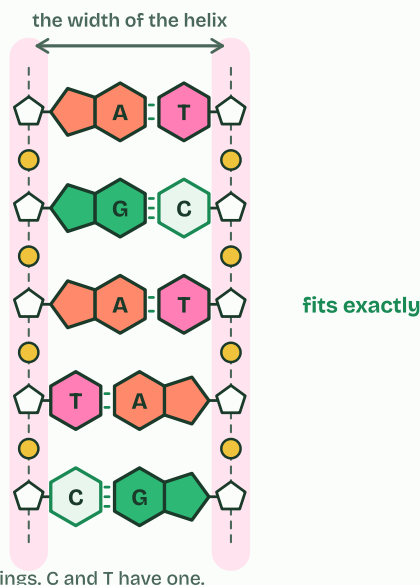
KEY TERMS

purines

Bases with two rings fused together, one of six atoms and one of five. Adenine and guanine are purines.

pyrimidines

Bases with a single ring of six atoms. Cytosine, thymine and uracil are pyrimidines.



Change the middle pair. The ring shapes are drawn only here: at standard level every base is a plain rectangle.

SWITCH IT

5 SETTINGS

1

A with T

2

G with C

3

A with G

4

C with T

5

A with C

REMEMBER IT

Which bases are purines

P Pure Purines two rings	A As Adenine a purine	G Gold Guanine a purine	C CUT Pyrimidines cytosine, uracil, thymine: one ring
--	---	---	---

WATCH OUT

There is no "big pair" and "small pair". Every pair is one big base and one small one, so every pair is the same size.

PREDICT

30% of the bases in a sample of double-stranded DNA are adenine. What percentage are purines?

- (A) 30%
- (B) 50%
- (C) 60%

Decide before you look. Answer on page 42.

10

A1.2.13 HL STRUCTURE OF A NUCLEOSOME

Wound on a *spool*

In eukaryotes, the DNA in the nucleus is wound around proteins called **histones**. A **nucleosome** is a core of eight histone proteins with DNA wrapped round it, just under two turns, and one more histone attached to the **linker DNA** where the DNA enters and leaves, holding the wrapped DNA in place. The linker DNA runs on to the next nucleosome: beads on a string.

Wound this way, about 2 m of DNA fits into a nucleus. The cell can also control which stretches can be read: tags on histones are D2.2. How do the histones hold the DNA on? That is the prediction below.

KEY TERMS

histones

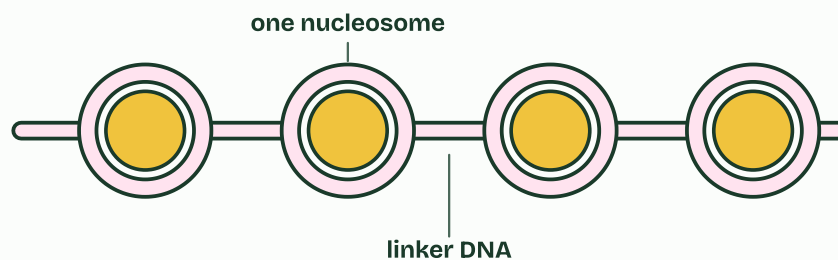
Proteins that DNA is wound around in the nuclei of eukaryotic cells.

nucleosome

A core of eight histone proteins with DNA wrapped round it, and one more histone attached to the linker DNA to hold it in place.

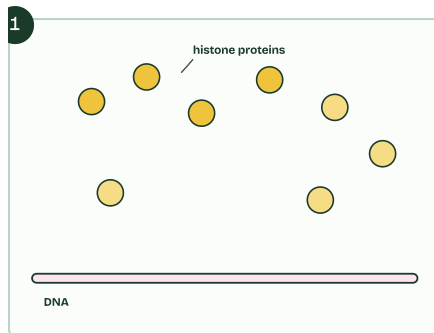
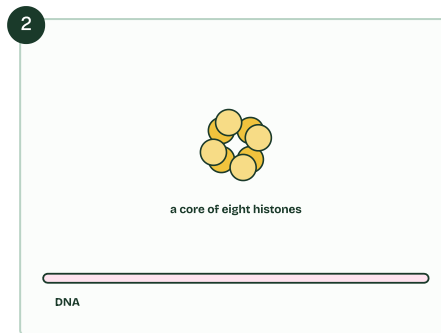
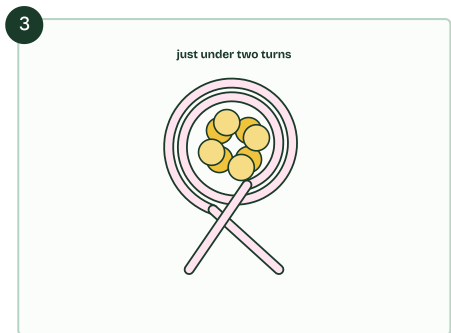
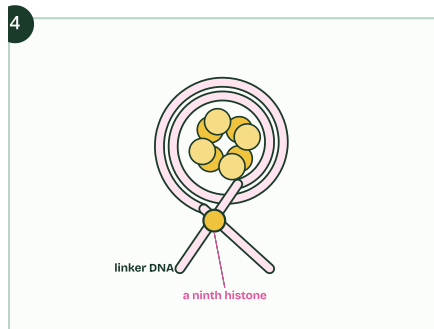
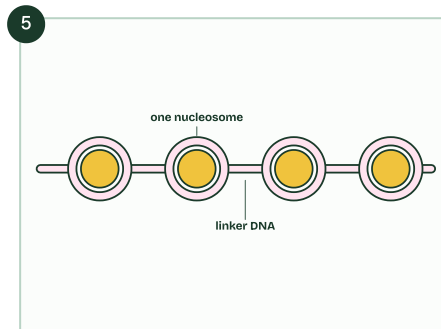
linker DNA

The stretch of DNA that leads into and out of a nucleosome and runs on to the next one.



STEP BY STEP

5 STEPS

DNA and **histone** proteins.**Eight** histones form a core.The DNA wraps round the core, just under **two turns**.A **ninth** histone, on the linker DNA, holds it in place.**Nucleosomes** along the DNA, like beads on a string.

TRY IT

Best on a laptop. The links open in a new tab.

1. Open the nucleosome core particle entry 1KX5 on the RCSB Protein Data Bank and open its 3D view.
2. Colour by chain. Count the protein chains in the core and the strands of DNA.
3. The eight proteins come as two copies each of four kinds: find each pair.
4. Where does the DNA touch the proteins: at its bases, or at its backbone?
5. Select the lysine and arginine residues and show them as sticks. Where do they point? Find the histone tails reaching out between the turns of DNA.
6. Count the turns of DNA round the core.
7. Is there a ninth histone in this structure? (In a core particle, no: the linker DNA was trimmed off before it was crystallised.) Open an entry that includes a linker histone, such as 4QLC, and find it.
On a phone the 3D viewer needs a bigger screen. Answer these from the figure instead: how many histones are in the core, how many turns of DNA wrap round it, and where does the ninth histone sit?

PREDICT

A chemical is added that cancels the negative charges on DNA's phosphate groups. What would you expect to happen to the nucleosomes?

- (A) The DNA would grip the histones even more tightly than before
- (B) Nothing would change, because histones hold the bases and not the phosphates
- (C) The DNA would come away from the histones more easily

Decide before you look. Answer on page 42.

WATCH OUT

The DNA is not wrapped round one histone, and the ninth histone is not in the core: eight in the core, one on the linker DNA. Histones hold DNA by charge, not by base pairing.

11

A1.2.14 HL EVIDENCE FROM THE HERSHEY-CHASE EXPERIMENT

Hershey and Chase: which one carries the genes?

In 1952 nobody knew whether genes were made of protein or of DNA. Many expected protein: proteins are built from 20 different amino acids and vary hugely, while DNA, with only four bases, looked too simple (chapter 12 tells that story).

Alfred Hershey and Martha Chase used a **bacteriophage** called T2, a virus that infects the bacterium *E. coli*. T2 is made of only two things: a protein coat, and DNA inside it. It attaches to a bacterium and injects its genetic material, and the bacterium then makes new phages. So whatever goes into the cell is what carries the genetic information.

They needed a way to tell the two apart. Protein contains **sulfur**, in the amino acids cysteine and methionine, but almost no phosphorus. DNA contains **phosphorus**, in its phosphate groups, but no sulfur. So phages grown with radioactive sulfur-35 had labelled protein coats, and phages grown with radioactive phosphorus-32 had labelled DNA. A **radioisotope** gives itself away by its radiation.

Each batch of labelled phages infected unlabelled bacteria. After a few minutes a blender shook the phage coats off the bacteria. A centrifuge then spun the mixture: the heavier bacteria formed a **pellet** at the bottom, and the light phage coats stayed in the liquid above, the **supernatant**. The radioactivity in each was measured. Predict what they found before you read on.

KEY TERMS

bacteriophage

A virus that infects bacteria. T2, the one used here, is a protein coat with DNA inside.

radioisotope

A form of an element whose atoms give out radiation, so they can be detected and followed.

pellet

The solid that collects at the bottom of a tube after centrifuging. Here it was the bacteria.

supernatant

The liquid above the pellet after centrifuging.

ANIMATION · HERSHEY AND CHASE: THE FILM

5 MOMENTS

1 THE LABELS

Sulfur-35 batch
labels the protein coat

Phosphorus-32 batch
labels the DNA

2 INFECTION

Sulfur-35 batch
labels the protein coat

Phosphorus-32 batch
labels the DNA

Sulfur is in protein, not DNA, so it labels the **protein coat**. Phosphorus is in DNA, so it labels the **DNA**.

It **injects** its DNA into the bacterium. The empty protein coat stays outside.

3 THE BLENDER

Sulfur-35 batch
labels the protein coat

Phosphorus-32 batch
labels the DNA

4 THE CENTRIFUGE

Sulfur-35 batch
labels the protein coat

Phosphorus-32 batch
labels the DNA

A few minutes later, a **blender** shakes the coats off the bacteria.

The heavy bacteria sink into a **pellet**. The light coats stay in the liquid above, the **supernatant**.

5 YOUR PREDICTION

Sulfur-35 batch
labels the protein coat

Phosphorus-32 batch
labels the DNA

Where is the radioactivity?

In each batch: the pellet or the supernatant?

PREDICT, THEN SEE THE RESULTS

Where is the radioactivity? Predict before the results.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-a1-2-nucleic-acids#hershey-chase

PREDICT

After blending and spinning, where will most of the radioactivity be in each batch?

- (A) Both in the pellet: the whole phage goes into the bacterium
- (B) Sulfur-35 in the pellet, phosphorus-32 in the liquid
- (C) Sulfur-35 in the liquid, phosphorus-32 in the pellet

Decide before you look. Answer on page 42.

WHY 1952?

Technology opens up new experiments. This one needed a way to tag protein and DNA separately, and radioisotopes only became widely available to biologists after the Second World War, made in nuclear reactors.

EVIDENCE, NOT PROOF

Some sulfur-35 stayed with the bacteria, and not all the phosphorus-32 went in, so the result was not perfectly clean. It persuaded most biologists, alongside other evidence and, a year later, the double helix.

WATCH OUT

Sulfur labels the protein, phosphorus the DNA: swapping them is the commonest slip. The pellet is the bacteria, not the viruses. And the results supported the conclusion that DNA is the genetic material of T2; saying the same of all life is a generalisation, which is chapter 12's subject.

12

A1.2.15 HL CHARGAFF'S DATA

Chargaff's numbers: one result can *falsify*

From the late 1940s Erwin Chargaff took DNA from many organisms, broke it into its bases, separated them and measured how much of each there was.

He found two things. First, in every species the amount of A is about equal to the amount of T, and the amount of G about equals C, so purines (A + G) equal pyrimidines (C + T). Second, the proportions differ from species to species: some DNA is rich in A and T, some in G and C, while different tissues of one species give the same proportions.

The leading idea until then was the **tetranucleotide hypothesis**, from the early 1900s: that DNA is a monotonous repeat of the four nucleotides in equal amounts. It predicts 25% of each base in every species, and a molecule too simple to carry information.

Chargaff's equalities had no explanation until the double helix, in which A pairs with T and G with C. A virus with single-stranded DNA, such as phiX174, does not show A = T: as expected, if the rule comes from pairing. Try the figure's switches, then predict.

KEY TERMS

tetranucleotide hypothesis

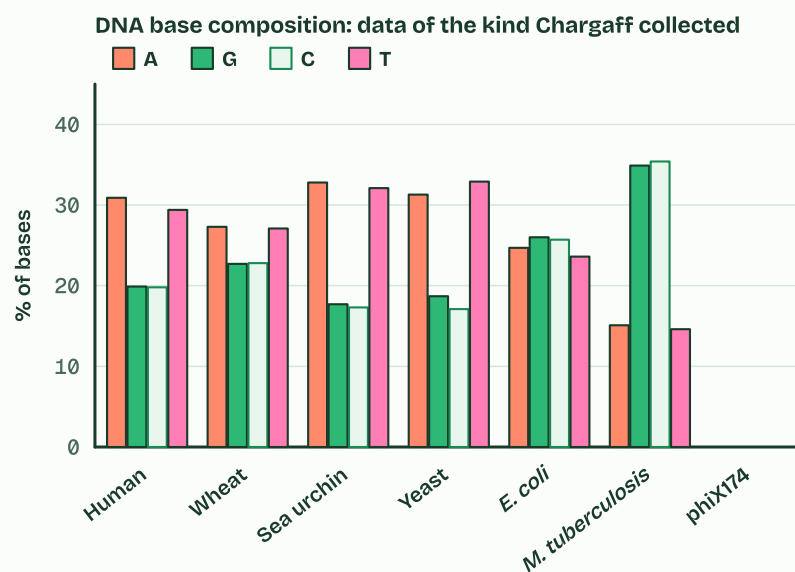
The early idea that DNA is a dull repeat of the four nucleotides in equal amounts, so 25% of each base in every species.

problem of induction

The problem that no number of observations can make a general claim certain, because the next one might differ.

certainty of falsification

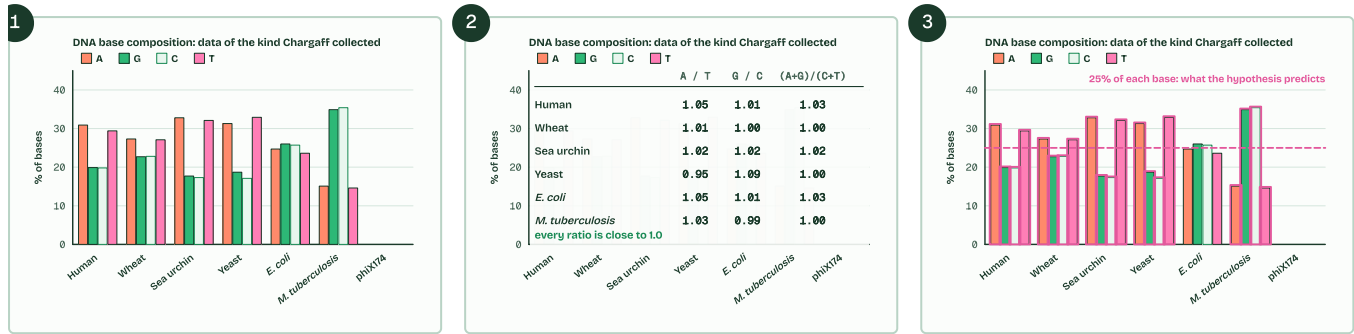
A single reliable result that contradicts a hypothesis shows with certainty that the hypothesis is wrong.



Percent of each base in the DNA of seven species, the kind of analysis Chargaff began. The values are as tabulated in biochemistry textbooks, rounded to one decimal place.

SWITCH IT

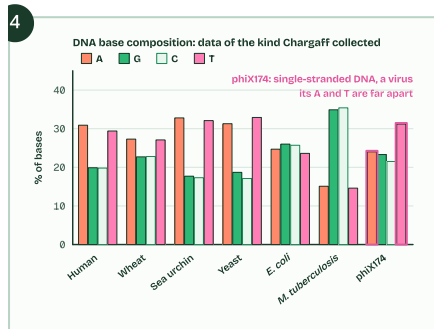
4 SETTINGS



Bases

Ratios

The hypothesis



Add a virus

PREDICT

The tetranucleotide hypothesis says every DNA molecule is 25% of each base. Which result would be enough, on its own, to falsify it?

- (A) A thousand different species, in every one of which the amount of A equals the amount of T
- (B) One species whose DNA is reliably measured as 30% adenine
- (C) One species whose DNA is measured as exactly 25% of each of the four bases

Decide before you look. Answer on page 42.

WATCH OUT

Chargaff's rule is $A = T$ and $G = C$. It is not $A = G$, and not $A + T = G + C$. It holds for double-stranded DNA, not for one strand on its own.

INDUCTION AND FALSIFICATION

However many species show A equal to T, you cannot be certain the next one will: a generalisation from observations is never certain. That is the **problem of induction**. But one reliable result that contradicts a claim is enough to reject it. A claim can be falsified with certainty in a way it can never be proved: that is the **certainty of falsification**. It is how Chargaff's data settled the tetranucleotide question without anyone testing every species.

Key terms

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

3' end 08

The end of a strand with a free OH on a 3' carbon. New nucleotides are added here.

5' end 08

The end of a strand with a free phosphate on a 5' carbon.

adenine 04

One of the four bases of DNA, written A. It pairs with thymine (uracil in RNA).

antiparallel 05

Running in opposite directions, like the two lanes of a road.

bacteriophage 11

A virus that infects bacteria. T2, the one used here, is a protein coat with DNA inside.

base pair 05

Two bases, one from each strand, held together by hydrogen bonds: A with T or G with C.

base sequence 04

The order of the bases along a strand of DNA or RNA.

certainty of falsification 12

A single reliable result that contradicts a hypothesis shows with certainty that the hypothesis is wrong.

codon 07

A group of three bases in messenger RNA that stands for one amino acid.

complementary base pairing 04

The rule that each base pairs with one particular other base: A with T (or U), and C with G.

condensation 03

A reaction that joins two molecules and releases a molecule of water.

conserved 07

Kept the same through long periods of evolution.

covalent bond 03

A bond in which two atoms share a pair of electrons. Covalent bonds are strong.

cytosine 04

One of the four bases of DNA, written C. It pairs with guanine.

deoxyribose 06

The pentose sugar in DNA. It has an H on carbon 2 where ribose has an OH.

directionality 08

A strand has two different ends, so it runs one way: from its 5' end to its 3' end.

DNA 01

Deoxyribonucleic acid: the nucleic acid that is the genetic material of all living organisms.

double helix 05

The shape of DNA: two strands wound round each other in a spiral.

gene 01

A stretch of a DNA molecule: a particular base sequence that carries one piece of information.

genetic code 07

The rules by which a sequence of bases in messenger RNA is translated into a sequence of amino acids, three bases at a time.

genetic material 01

The molecule that carries the instructions an organism inherits. It is copied each time a cell divides and passed from parents to offspring.

guanine 04

One of the four bases of DNA, written G. It pairs with cytosine.

histones 10

Proteins that DNA is wound around in the nuclei of eukaryotic cells.

hydrogen bonds 04

Weak attractions between a slightly positive hydrogen atom on one molecule and a slightly negative atom on another.

hydrolysis 03

A reaction in which a bond is broken by adding a molecule of water.

linker DNA 10

The stretch of DNA that leads into and out of a nucleosome and runs on to the next one.

Messenger RNA 06

RNA that is a copy of a gene and is taken to a ribosome to be translated.

monomer 02

One small unit of a polymer. The monomer of a nucleic acid is the nucleotide.

nitrogenous base 02

A ring of carbon and nitrogen atoms that is the part of a nucleotide that varies. Its order along a strand is the message.

nucleic acids 01

Polymers built from nucleotides. DNA and RNA are the two nucleic acids.

nucleosome 10

A core of eight histone proteins with DNA wrapped round it, and one more histone attached to the linker DNA to hold it in place.

nucleotide 02

The monomer of nucleic acids: a phosphate group, a pentose sugar and a nitrogenous base joined together.

pellet 11

The solid that collects at the bottom of a tube after centrifuging. Here it was the bacteria.

pentose 02

A sugar with five carbon atoms.

phosphate group 02

A phosphorus atom with oxygen atoms round it. In a cell it carries a negative charge.

polymers 02

Long molecules built from many copies of a small unit, joined in a chain.

problem of induction 12

The problem that no number of observations can make a general claim certain, because the next one might differ.

purines 09

Bases with two rings fused together, one of six atoms and one of five. Adenine and guanine are purines.

pyrimidines 09

Bases with a single ring of six atoms. Cytosine, thymine and uracil are pyrimidines.

radioisotope 11

A form of an element whose atoms give out radiation, so they can be detected and followed.

replication 04

Copying a DNA molecule to make two molecules with the same base sequence.

ribose 06

The pentose sugar in RNA. It has an OH on carbon 2.

Ribosomal RNA 06

RNA that is part of every ribosome.

RNA 01

Ribonucleic acid: the other nucleic acid. It has several jobs in cells, and in some viruses it is the genetic material.

strand 03

One chain of nucleotides, also called a polynucleotide.

sugar–phosphate backbone 03

The chain of alternating sugars and phosphates, joined by covalent bonds, that runs along a nucleic acid strand.

supernatant 11

The liquid above the pellet after centrifuging.

template 04

A strand that new nucleotides pair with, so the new strand has the complementary sequence.

tetranucleotide hypothesis 12

The early idea that DNA is a dull repeat of the four nucleotides in equal amounts, so 25% of each base in every species.

thymine 04

A base found in DNA, written T. It pairs with adenine.

transcription 04

Making an RNA copy of a gene, using one DNA strand as the template.

Transfer RNA 06

RNA that brings an amino acid to the ribosome. It folds back on itself and pairs with itself in places.

translation 04

Making a chain of amino acids by reading the codons of messenger RNA.

universal common ancestor 07

The single ancestral population from which all living organisms are thought to be descended.

uracil 04

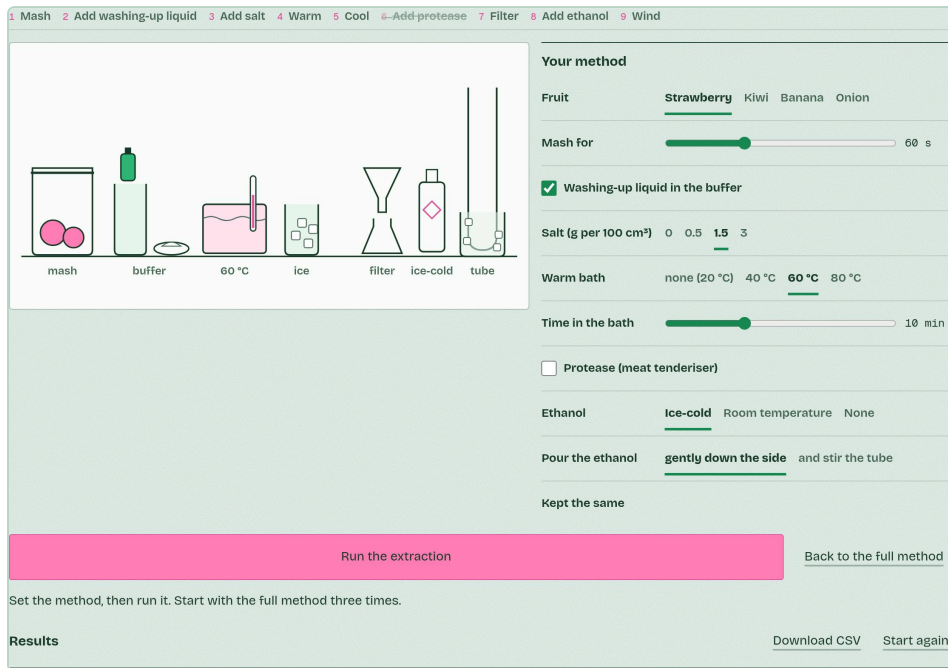
A base found in RNA, written U, in the place of thymine. It pairs with adenine.

viruses 01

Tiny particles of genetic material inside a protein coat. A virus has no cells and can only be copied inside a host cell.

Dry lab: *Getting DNA out*

Mash, dissolve, warm, filter and pour on cold ethanol. Leave a step out or change it, run it three times, and find out what each step is for.



1 Mash 2 Add washing-up liquid 3 Add salt 4 Warm 5 Cool 6 Add protease 7 Filter 8 Add ethanol 9 Wind

Your method

Fruit: Strawberry Kiwi Banana Onion

Mash for: 60 s

☒ Washing-up liquid in the buffer

Salt (g per 100 cm³): 0 0.5 1.5 3

Warm bath: none (20 °C) 40 °C 60 °C 80 °C

Time in the bath: 10 min

☐ Protease (meat tenderiser)

Ethanol: Ice-cold Room temperature None

Pour the ethanol: gently down the side and stir the tube

Kept the same

[Run the extraction](#) [Back to the full method](#)

Set the method, then run it. Start with the full method three times.

Results [Download CSV](#) [Start again](#)



Run it online: change the variables, run the trials, and the table and graph fill in as you go. biologybybradford.com/guides/ib-biology-a1-2-nucleic-acids#lab

Your question

Which steps of a DNA extraction matter most for how much DNA you get, and why does each one work?

What you can change

The fruit or vegetable, how long you mash it, whether you add washing-up liquid, how much salt, the temperature and time of the warm bath, a protease, and the ethanol: ice-cold, at room temperature, or none. Under Kept the same: the mass of fruit, the buffer, the volume of ethanol and the wait before winding.

What to record

For each run: your settings, the mass of DNA you wind onto the stick (mg) and what the threads look like. Change one thing at a time and repeat each set-up three times: real extractions vary, and so do these.

Find out

- **Which steps matter?** Run the full method three times. Then leave out one step at a time (the washing-up liquid, the salt, the warm bath, the cold ethanol), three runs each. Which loss hurts most?
- **How much salt?** Run 0, 0.5, 1.5 and 3 g per 100 cm³, three runs each, and graph the mean mass against the salt.
- **How long in the bath?** At 60 °C, try 0, 5, 10, 15, 20 and 30 minutes. Where is the best time, and why does the mass fall after it?
- **Higher level: add a protease.** Compare the threads with and without it. What has the protease taken off the DNA?

Record

- For every run: the settings, the mass wound onto the stick and what the threads looked like. The results table fills as you go.
- Change one thing at a time and keep the rest the same, including what is under Kept the same.
- Repeat each set-up three times and take a mean: no two runs give quite the same mass, as in a real lab.
- Use **Graph your results**, or download the CSV and plot it yourself. The white precipitate is mostly DNA, so call it that, not pure DNA.

QUESTIONS ON THE LAB

QUESTION 1

Without salt, almost nothing comes out into the ethanol, even though the cells were broken open. Why?

- (A) Salt breaks down the tough cell walls, so without it the DNA never leaves the cells
- (B) Sodium ions cancel the phosphates' negative charges, so DNA molecules can clump and come out
- (C) Salt reacts with the cold ethanol to make the white solid, which is mostly salt and not DNA

Answer on page 42.

QUESTION 2

Ten minutes at 60 °C gives more, longer threads than no warm bath at all, but thirty minutes gives fewer and shorter ones. Why?

- (A) Warmth makes DNA dissolve in the ethanol, so the longer it is heated the less of it comes out
- (B) Long heating turns the DNA into RNA, which does not form threads when the ethanol is poured on
- (C) A short warm step stops the enzymes that cut DNA, but long heating breaks the DNA itself

Answer on page 42.

QUESTION 3

What are the white threads you wind onto the stick?

- (A) Millions of DNA molecules tangled together, with some RNA and protein caught up in them
- (B) A single DNA molecule from one cell, unwound from its histones so it is long enough to see
- (C) Double helices, each one thick enough to see with the naked eye once it has been uncoiled

Answer on page 43.



Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on A1.2 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

[biologybybradford.com/exam-maker/sit?
topics=A1.2&level=HL&paper=quiz&marks=15&src=ep](https://biologybybradford.com/exam-maker/sit?topics=A1.2&level=HL&paper=quiz&marks=15&src=ep)

Answers

PREDICTIONS IN THE CHAPTERS

- 01** A virus is found whose genes are made of RNA. Does that break the rule that DNA is the genetic material of all living organisms?
- B No: viruses are not counted as living organisms**
- No. A virus has no cells and no metabolism of its own, and it can only be copied inside a host cell, so biologists do not count it as alive. The rule is about living things, and in every one studied so far the genetic material is DNA. In an RNA virus the genes really are RNA: there is no hidden DNA original.
-
- 02** How many different nucleotides does a cell use to build DNA?
- C Four: the sugar and phosphate are the same, only the base differs**
- Four. Every DNA nucleotide has the same phosphate and the same sugar, deoxyribose; only the base differs, and DNA has four bases. RNA has its own four, built on ribose, so a cell's nucleic acids use eight nucleotides in all.
-
- 03** How many water molecules are released when 10 nucleotides join into one strand?
- A 9**
- Nine. Each bond releases one water molecule, and ten nucleotides in a row have nine bonds between them: n nucleotides make $n - 1$ bonds and release $n - 1$ water molecules. Taking the strand apart again by hydrolysis would use nine water molecules.
-
- 04** One strand of a DNA molecule reads A A T G C. The strands separate and each is copied. What does the strand built against it read, and the strand built against that one?
- B T T A C G, then A A T G C**
- Pairing makes a complementary copy, and the complement of the complement is the original. So every molecule made by copying has the same sequence as the one it came from: this is how complementary pairing keeps genetic information exact through replication. (U belongs in RNA, not in a DNA copy.)
-
- 05** To be copied, the two strands of DNA must come apart. Why does pulling them apart not break the strands themselves?
- C Weak hydrogen bonds join the two strands, while each strand is a chain of strong covalent bonds**
- The bonds between the strands are hydrogen bonds: weak one by one, so the strands can be unzipped. The bonds along each strand are covalent, so each strand, and the sequence it carries, stays whole. Both strands then serve as templates (chapter 4).
-
- 06** A sample of nucleic acid is single-stranded and contains thymine but no uracil. What is it most likely to be?
- A DNA, from one of the few viruses with single-stranded DNA**
- Thymine is the clue: it is a DNA base. Most DNA is double-stranded, but a few viruses carry single-stranded DNA, so the number of strands is the least reliable of the three differences. The sugar would settle it: deoxyribose means DNA.
-
- 07** How many different sequences of three bases can DNA's four bases make?
- B 64**
- Four choices for the first base, four for the second and four for the third: $4 \times 4 \times 4 = 64$. (12 adds when it should multiply; 81 is 3 to the power 4, the right numbers the wrong way round.) Each extra base multiplies the possibilities by four again, which is why the capacity of DNA is limitless.
-

- 08 One DNA strand reads 5'-ATGC-3'. Written 5' to 3', what is its partner?

C 5'-GCAT-3'

The partner pairs base by base, T A C G, but runs the other way: 3'-TACG-5'. Read from its own 5' end, that is 5'-GCAT-3'. (5'-CGTA-3' is the first strand backwards, with no pairing at all.)

- 09 30% of the bases in a sample of double-stranded DNA are adenine. What percentage are purines?

B 50%

50%, whatever the sequence. Every base pair is one purine and one pyrimidine, so purines are always half the bases in double-stranded DNA: here 30% adenine and 20% guanine. In symbols, $A + G = C + T$. Chapter 12 picks this up.

- 10 A chemical is added that cancels the negative charges on DNA's phosphate groups. What would you expect to happen to the nucleosomes?

C The DNA would come away from the histones more easily

The DNA would loosen. Histones are rich in positively charged amino acids (lysine and arginine), and DNA's phosphate groups are negatively charged, so the two attract. Because the backbone is on the outside and every base pair is the same width (chapter 9), histones can hold any sequence. Take away the negative charges and the attraction goes. Cells do something like this on purpose, tagging histones to loosen or tighten the wrapping (D2.2).

- 11 After blending and spinning, where will most of the radioactivity be in each batch?

C Sulfur-35 in the liquid, phosphorus-32 in the pellet

Almost only the DNA goes in. The protein coats, carrying the sulfur-35, are shaken off and stay in the liquid; the bacteria, now holding the phage DNA with its phosphorus-32, sink to the pellet. The DNA that went in is what made the new phages: phosphorus-32 turned up in the next generation of phages, and sulfur-35 hardly at all. These results are evidence that DNA, not protein, is the genetic material of T2.

- 12 The tetranucleotide hypothesis says every DNA molecule is 25% of each base. Which result would be enough, on its own, to falsify it?

B One species whose DNA is reliably measured as 30% adenine

One reliable contradiction is enough to reject a claim about all DNA. Human DNA is about 30% adenine and 20% guanine, not 25% of each, and the proportions vary between species. A thousand species with A equal to T cannot prove anything about every species, and do not even test the 25% prediction; a species at exactly 25% agrees with the hypothesis, so it cannot falsify it.

QUESTIONS ON THE DRY LAB

- Q1 Without salt, almost nothing comes out into the ethanol, even though the cells were broken open. Why?

B Sodium ions cancel the phosphates' negative charges, so DNA molecules can clump and come out

The phosphate groups in DNA's backbone are negatively charged (chapter 2), so DNA molecules repel one another and stay dissolved in the water. Sodium ions from the salt crowd round the phosphates and cancel the charge; then the molecules can come together and come out of solution where the ethanol meets the filtrate. Mashing and the washing-up liquid are what break the cells open.

- Q2 Ten minutes at 60 °C gives more, longer threads than no warm bath at all, but thirty minutes gives fewer and shorter ones. Why?

C A short warm step stops the enzymes that cut DNA, but long heating breaks the DNA itself

Cells contain enzymes that digest DNA, and once the cells are broken they get to work. A short time at 60 °C denatures them (B1.2), so more of the DNA survives in long pieces. DNA is tougher than those enzymes, but not indestructible: held hot for longer, it breaks into fragments too short to wind onto the stick.

Q3 What are the white threads you wind onto the stick?

A **Millions of DNA molecules tangled together, with some RNA and protein caught up in them**

One DNA molecule is about 2 nm wide, far too thin to see. What you wind up is a tangle of millions of them, with some RNA and protein caught in it. You cannot see a helix, or tell from the threads whether two fruits' DNA is the same.

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

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