



Nucleic acids

Revision notes · IB Biology A1.2 Nucleic acids: nucleotides, DNA and RNA structure, base pairing and the genetic code.

For IB Diploma Biology SL undefined. **HL only** is additional higher level content, for HL students only.

Nucleic acids Spec A1.2

DNA as the genetic material and nucleotides Spec A1.2.1, A1.2.2, A1.2.3, A1.2.4

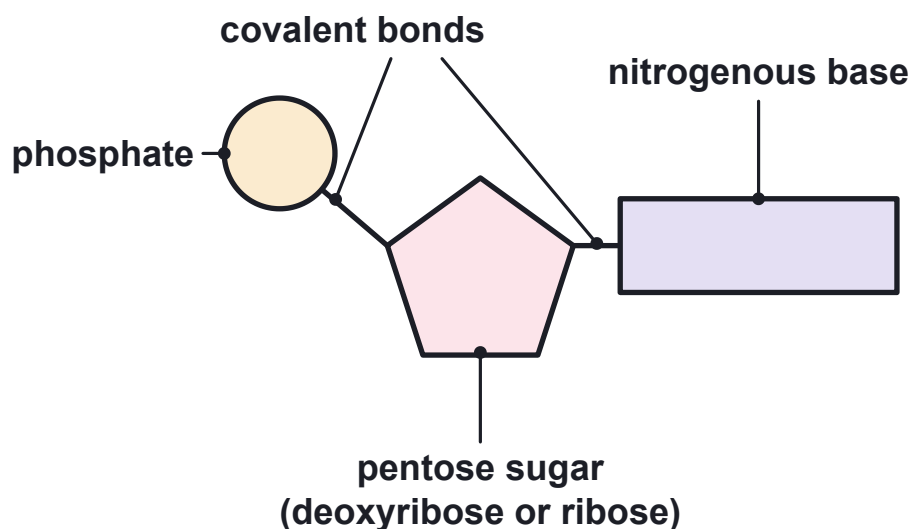
DNA as the genetic material

DNA is the genetic material of all living organisms, from bacteria to plants and animals. Some viruses use RNA as their genetic material, for example influenza virus and HIV, but viruses are not considered to be living.

Components of a nucleotide

Nucleic acids are polymers of **nucleotides**. Every nucleotide has three parts, joined by covalent bonds:

- a **phosphate** group (drawn as a circle)
- a **pentose sugar**, a five-carbon sugar: deoxyribose in DNA, ribose in RNA (drawn as a pentagon)
- a **nitrogenous base** (drawn as a rectangle), attached to the sugar on the opposite side from the phosphate



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A nucleotide: circle = **phosphate**, pentagon = **pentose sugar**, rectangle = **base**.

The sugar-phosphate backbone

In a strand of DNA or RNA, the phosphate of one nucleotide is covalently bonded to the sugar of the next. This **sugar-phosphate bonding** makes a continuous chain of covalently bonded atoms along each strand, which forms a strong **backbone**. The bases stick out from the backbone.

Bases form the basis of a code

Nitrogenous bases in DNA and RNA

Nucleic acid	Bases
DNA	adenine (A), thymine (T), guanine (G), cytosine (C)
RNA	adenine (A), uracil (U), guanine (G), cytosine (C)

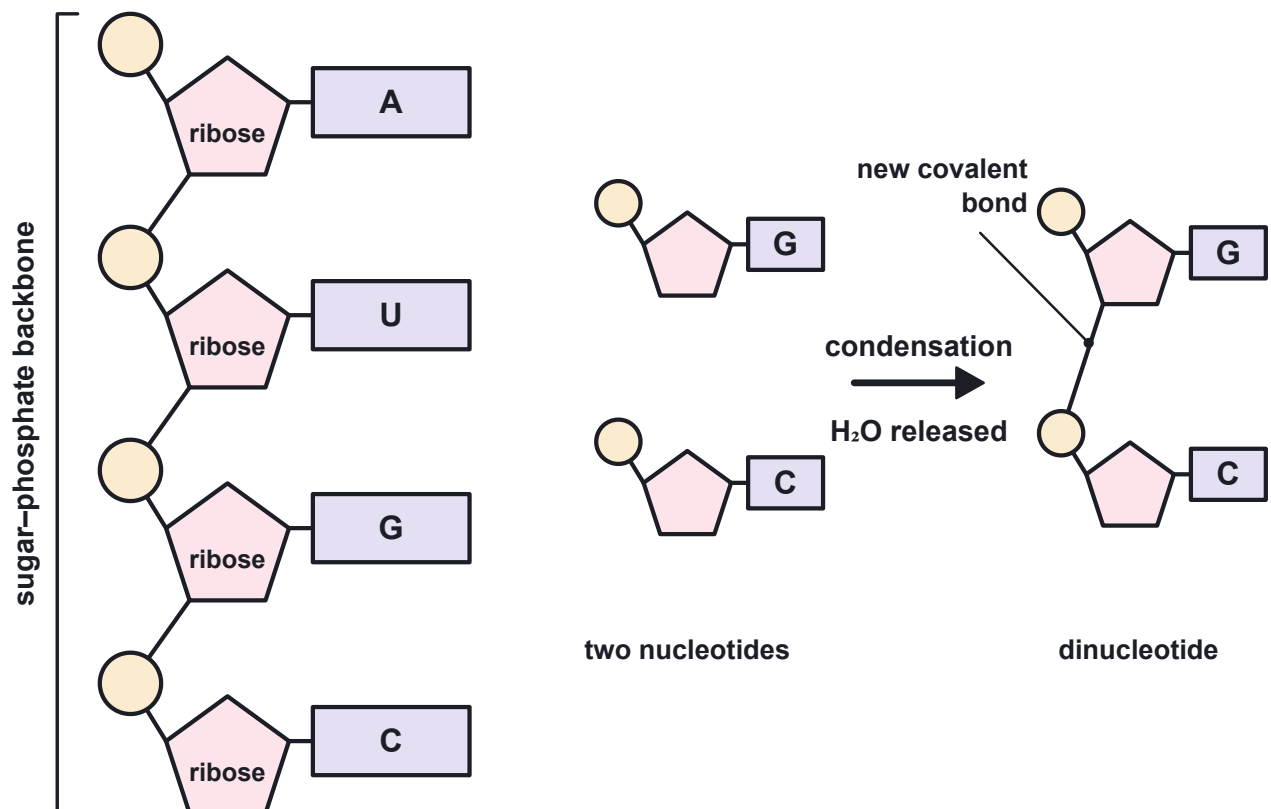
The backbone is the same in every molecule. What varies is the **sequence of bases**, and it is this sequence that stores genetic information, in the way a sequence of letters stores the meaning of a sentence.

Exam tip: You need the full names of the five bases: adenine, thymine, guanine, cytosine and uracil. Spelling matters in written answers.

RNA polymers and the DNA double helix Spec A1.2.5, A1.2.6

RNA as a polymer

RNA is a **polymer formed by condensation of nucleotide monomers**. When two nucleotides are joined, the phosphate of one bonds covalently to the sugar (ribose) of the other and a molecule of water is released. Repeating this builds a single strand of any length, with a sugar-phosphate backbone and one base on each nucleotide.



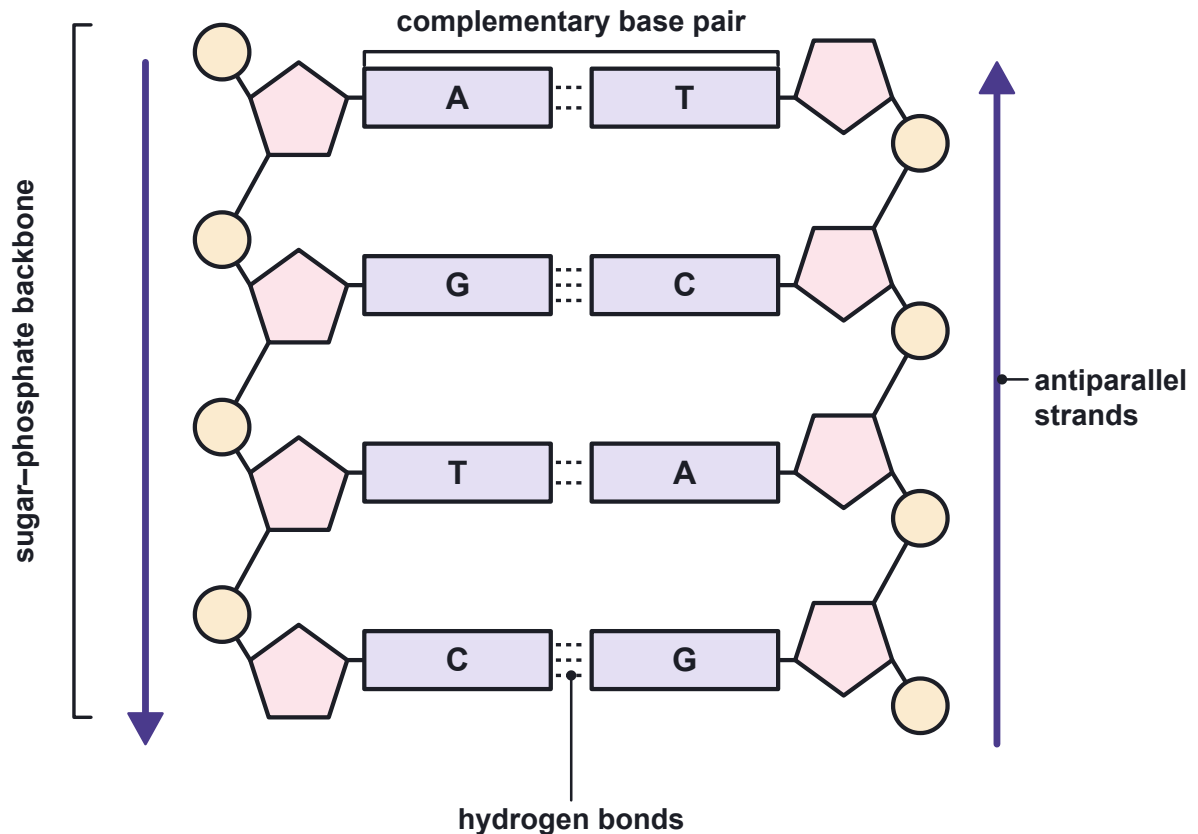
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RNA is a polymer of nucleotides. Each new sugar-phosphate bond forms by **condensation**, releasing a molecule of water.

DNA as a double helix

- DNA has **two strands** of nucleotides, wound into a **double helix**.
- The two strands are **antiparallel**: they run in opposite directions.
- The bases face inwards and the two strands are linked by **hydrogen bonds** between bases.

- Pairing is complementary: adenine (A) pairs with thymine (T) and guanine (G) pairs with cytosine (C).



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DNA: two antiparallel strands (one drawn upside down), linked by hydrogen bonds between complementary base pairs, A with T and G with C.

Exam tip: In DNA diagrams draw the two strands antiparallel (one strand upside down) and pair A with T and G with C. You do not need to draw the helix, the relative sizes of the bases or the number of hydrogen bonds.

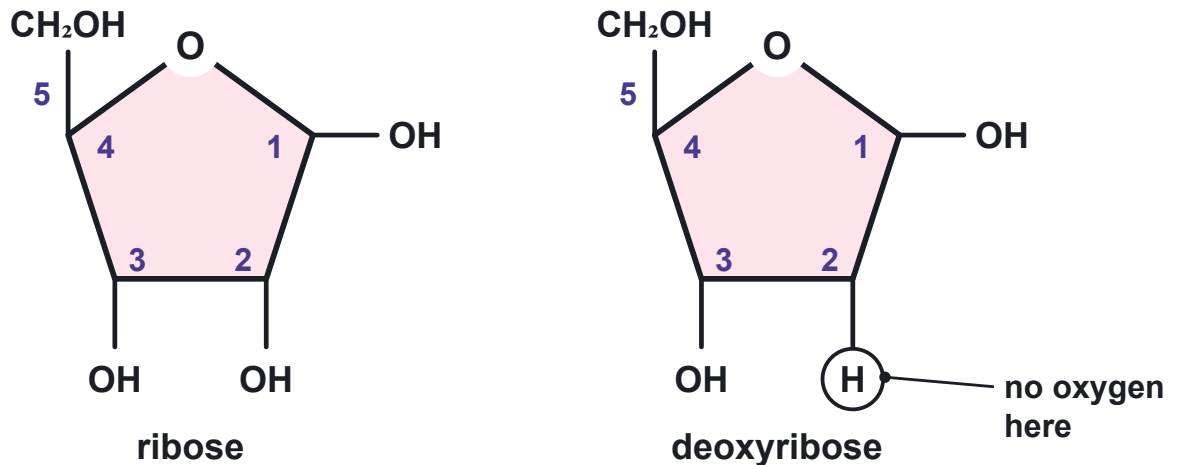
Exam tip: Linking question: how can polymerization result in emergent properties? A single nucleotide stores no information, but a polymer of thousands of them stores a whole gene.

Differences between DNA and RNA Spec A1.2.7

Differences between DNA and RNA		
Feature	DNA	RNA
Number of strands	Two (double helix)	One
Nitrogenous bases	A, T, G, C	A, U, G, C (uracil instead of thymine)
Pentose sugar	Deoxyribose	Ribose

Ribose and deoxyribose

Both sugars are pentoses with a five-membered ring containing an oxygen atom. The difference is on carbon 2: ribose has an OH group there, while deoxyribose has only H, so it has one oxygen atom fewer ('deoxy' means without oxygen).



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Ribose has an **OH** on carbon 2; deoxyribose has only **H** there, so it has one oxygen fewer.

Examples of nucleic acids

- **DNA:** the genetic material, found in chromosomes in the nucleus, and in mitochondria, chloroplasts and the cytoplasm of prokaryotes.
- **Messenger RNA (mRNA):** a copy of a gene, carried to ribosomes.
- **Transfer RNA (tRNA):** carries amino acids to the ribosome during translation.
- **Ribosomal RNA (rRNA):** part of the structure of ribosomes.

Common mistake: In a compare question, write each difference as a matched pair, such as 'DNA contains deoxyribose but RNA contains ribose'. Stating only one side rarely scores.

Base pairing, information storage and the genetic code Spec A1.2.8, A1.2.9, A1.2.10

Complementary base pairing

Complementarity is based on hydrogen bonding: A and T (or A and U in RNA) form hydrogen bonds with each other, and so do G and C. Other combinations do not fit and do not bond properly. So the sequence on one strand fixes the sequence on the other.

- **Replication:** the two strands separate and each acts as a template. Free nucleotides pair with complementary bases, so two identical DNA molecules are produced.
- **Transcription** (expression): an mRNA molecule is built with bases complementary to one strand of a gene, with U pairing with A.
- **Translation** (expression): each tRNA anticodon pairs with a complementary mRNA codon, so amino acids are added in the order the code specifies.

Limitless capacity for storing information

There is no restriction on the order of bases along a strand, and a DNA molecule can be any length. So **any base sequence is possible** and the diversity of possible sequences is effectively limitless. With 4 bases, the number of possible sequences of length n is 4^n . DNA also stores data with great economy: the human genome of about 3 billion base pairs fits inside a nucleus only a few micrometres across.

Number of possible base sequences

How many different base sequences are possible for a DNA strand 10 nucleotides long?

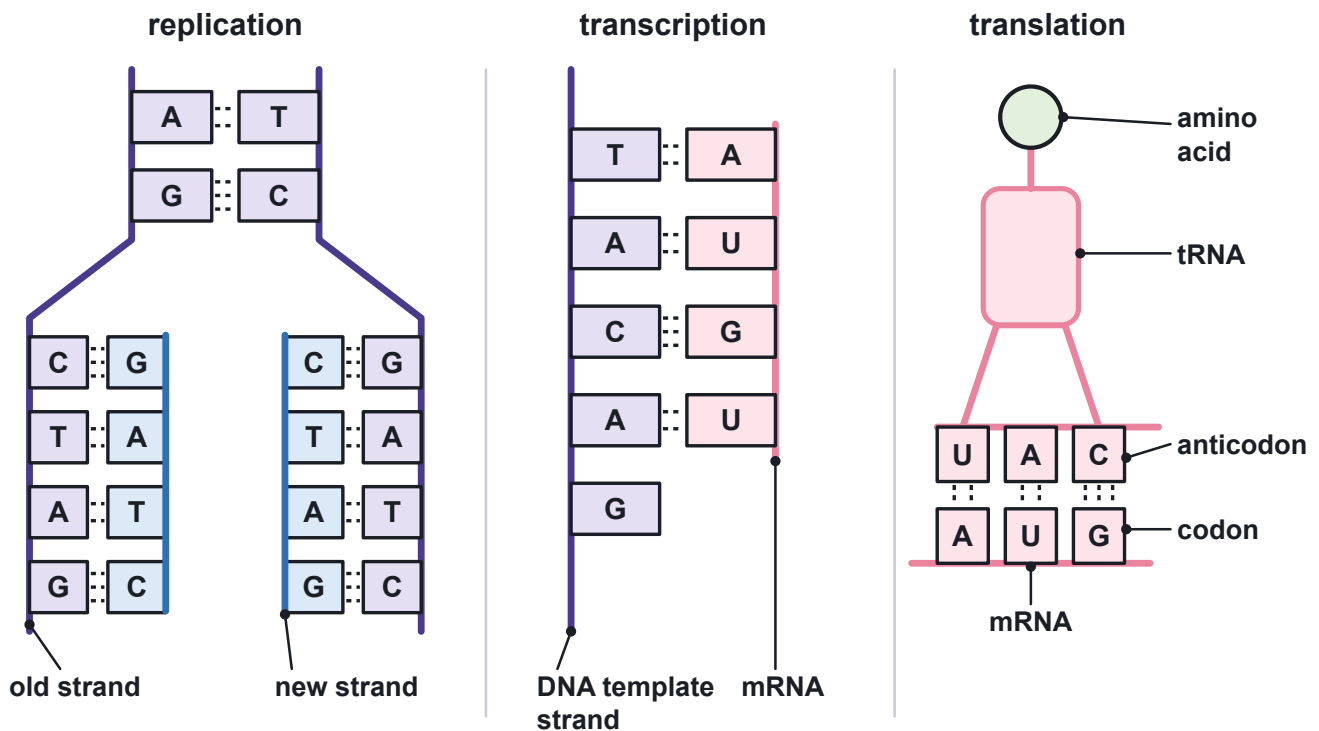
1. Each position can hold any one of 4 bases.
2. Number of sequences = $4 \times 4 \times \dots$ (10 times) = 4^{10} .
3. $4^{10} = 1\,048\,576$.

Answer: About one million (1 048 576) sequences, from just 10 nucleotides.

Maths skill: Possible sequences = 4^n for DNA of length n nucleotides. Each extra nucleotide multiplies the number of possibilities by 4.

A universal genetic code

The genetic code, the way base triplets (codons) correspond to amino acids, is **conserved across all life forms**, with only a few minor variations. It is very unlikely that so many organisms would arrive at the same arbitrary code independently. The best explanation is that all living organisms inherited it from a **universal common ancestor**. This is also why a gene from one species can be expressed in another.



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Complementary base pairing by **hydrogen bonds** in replication, transcription and translation.

Quick check

1. What are the three components of a nucleotide?
2. State three differences between DNA and RNA.
3. What does antiparallel mean in DNA?

Quick check answers

Nucleic acids

1. A phosphate group, a pentose sugar and a nitrogenous base.
2. DNA has two strands, RNA one; DNA has thymine, RNA uracil; DNA has deoxyribose, RNA ribose.
3. The two strands run in opposite directions.