SL IB Biology

Your notes

Nucleic Acids

Contents

DNA & RNA Structure

Your notes

Genetic Material of Life

DNA as the genetic material of living organisms

- **Deoxyribose nucleic acid** (DNA) carries the **genetic code** in all living organisms
- This is the reason why the genetic code is said to be **universal**, it applies to all forms of life
- DNA is **mainly found in the nucleus** where it forms chromosomes
  - It is also found in **chloroplasts** and **mitochondria** of eukaryotic cells
- **Ribonucleic acid** (RNA) is another type of nucleic acid which is the **main component of ribosomes**, which play an important role in protein synthesis
  - Some RNA is also found in the **nucleus** and **cytoplasm**
- Certain viruses (such as SARS-CoV-2) contain **RNA** as their genetic material instead of DNA
- These viruses cause a variety of different diseases, such as COVID-19, Ebola, mumps and influenza
- Viruses are **not considered to be living organisms**, since they are unable to replicate by themselves
- They are **dependent on other living cells** for replication and survival
- Viruses also **lack a cellular structure**, which is another reason they are not considered to be living

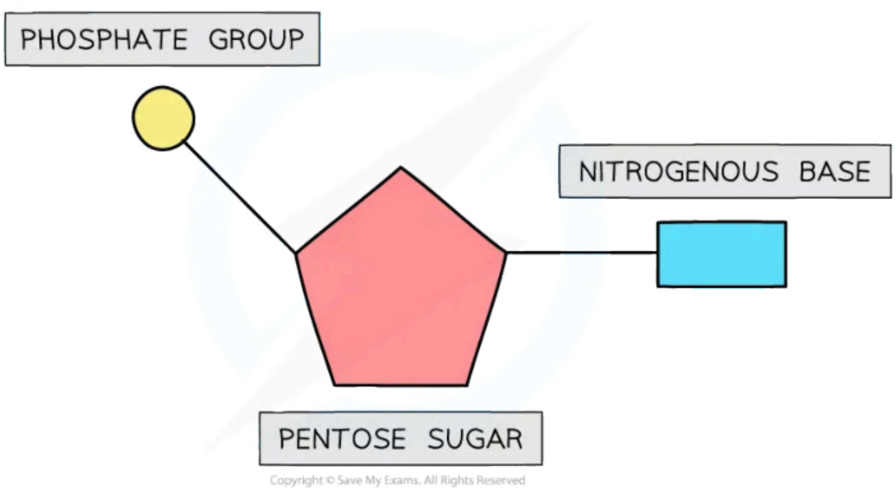
Nucleotide Components

Your notes

Components of a nucleotide

- Both DNA and RNA are **polymers** that are made up of **many repeating units** called **nucleotides**
- Each nucleotide is formed from:
  - A **pentose sugar** (a sugar with 5 carbon atoms)
  - A nitrogen-containing **organic base** (with either 1 or 2 rings of atoms)
  - A **phosphate group** (this is acidic and negatively charged)
- The base and phosphate group are both **covalently bonded** to the sugar
- The **nitrogenous bases** in DNA are:
  - Adenine (A)
  - Guanine (G)
  - Cytosine (C)
  - Thymine (T)
- RNA share the same nitrogenous bases as DNA except thymine, which is replaced by **uracil (U) in RNA**
- The nitrogenous bases can be grouped as either **purine** or **pyrimidine** bases:
  - **Adenine** and **guanine** are purine bases
  - **Cytosine**, **thymine** (in DNA) and **uracil** (in RNA) are pyrimidine bases

Nucleotide structure diagram



The basic structure of a nucleotide

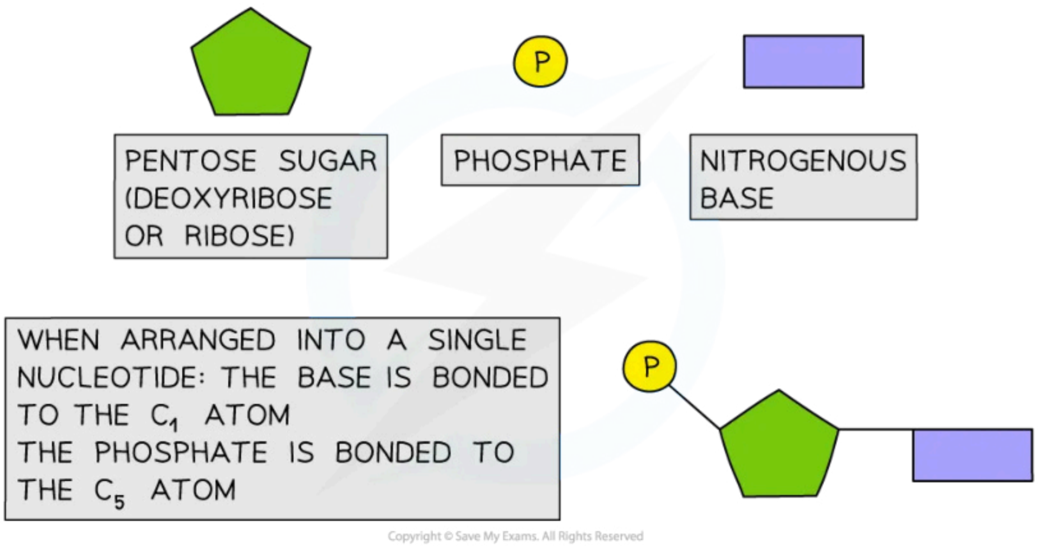
Drawing simple diagrams of the structure of single nucleotides of DNA and RNA

- **Simple shapes** can be used to draw the **main building blocks of nucleotides** and the DNA double helix
  - Advanced drawing skills are not required!
- **Pentagons** can represent **pentose sugars**
- **Circles** can represent **phosphates**
  - Often shown as a circle with the letter P inside: ⓟ

Your notes

- **Rectangles** can represent **bases**
- **Covalent bonds** can be shown with **solid lines**
- **Hydrogen bonds** can be shown with **dashed lines**
  - Or with complementary shapes that fit together (see diagrams)

Components of a nucleotide diagram



Simple shapes can be used to represent parts of nucleotide molecules

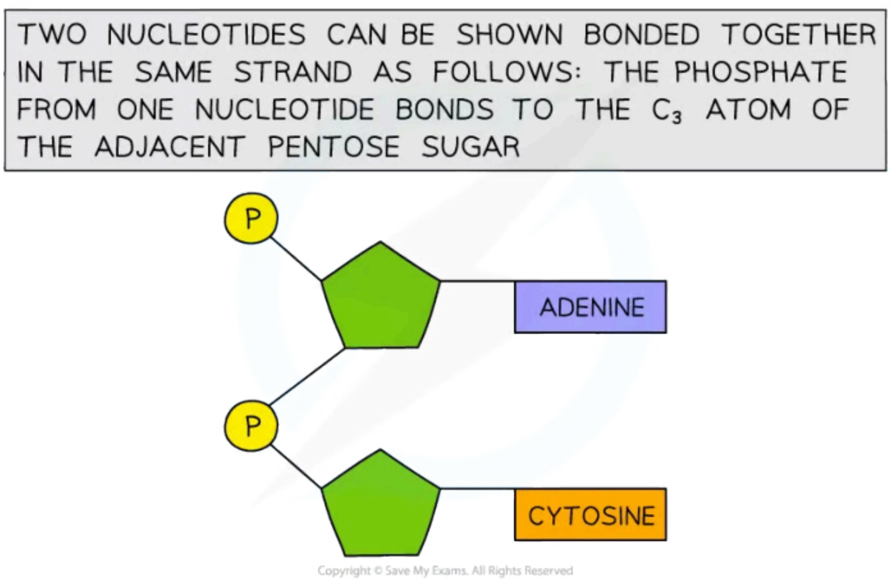
Your notes

Linking Nucleotides

Forming the sugar-phosphate backbone

- Nucleotides join together in chains to form DNA or RNA strands
- The **phosphate group of one nucleotide** forms a covalent bond to the **pentose sugar of the next one**
  - This carries on to form a **large polymer**
  - These polymers form **nucleic acids,** which are also known as **polynucleotides**
- The phosphate group of one nucleotide is linked to the pentose sugar of the next one by **condensation reactions**
  - This means a **molecule of water is released** during the formation of each covalent bond
- This forms a '**sugar-phosphate backbone**' with a base linked to each sugar
- The polymer of nucleotides is known as a **strand**
- DNA is double-stranded, RNA is usually single-stranded
- There are just **4 separate bases** that can be joined in **any combination/sequence**
  - Because the **sugar and phosphate are the same** in every nucleotide

Linking nucleotides together diagram



Two nucleotides shown bonded together covalently within a strand

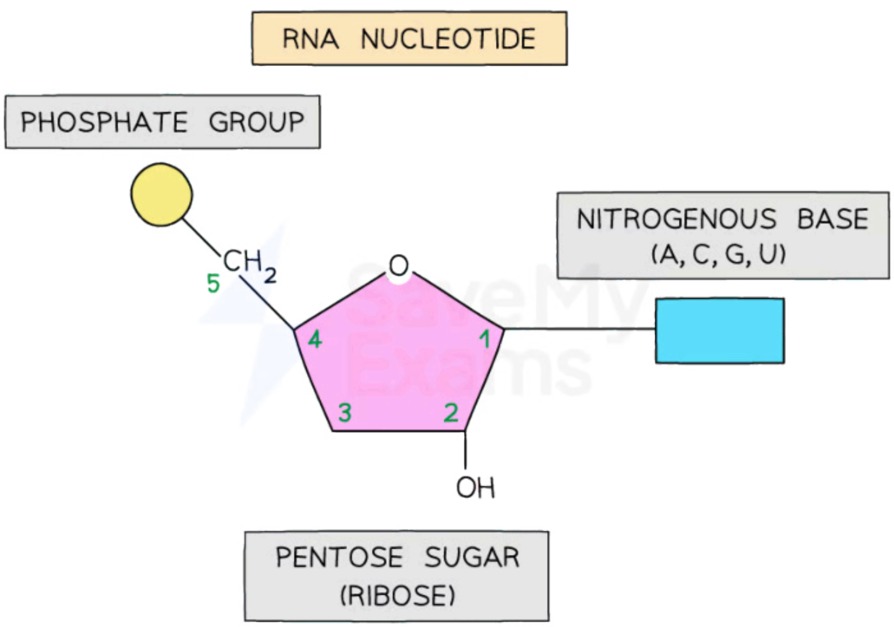
RNA Structure

Your notes

RNA structure

- Unlike DNA, RNA molecules are **relatively short** with lengths of between a hundred to a few thousand nucleotides
- It usually forms a **single-stranded polynucleotide** with **ribose** as the pentose sugar in each nucleotide
- RNA nucleotides contain the following **nitrogenous bases**:
  - Adenine
  - Guanine
  - Cytosine
  - Uracil (instead of thymine in DNA)
- The carbon atoms in nucleotides are numbered **from the right in a clockwise direction**
  - This makes it easier to **identify the bonds** in the sugar-phosphate backbone of polynucleotides
  - It also indicates the **orientation of the polynucleotide**

RNA nucleotide diagram

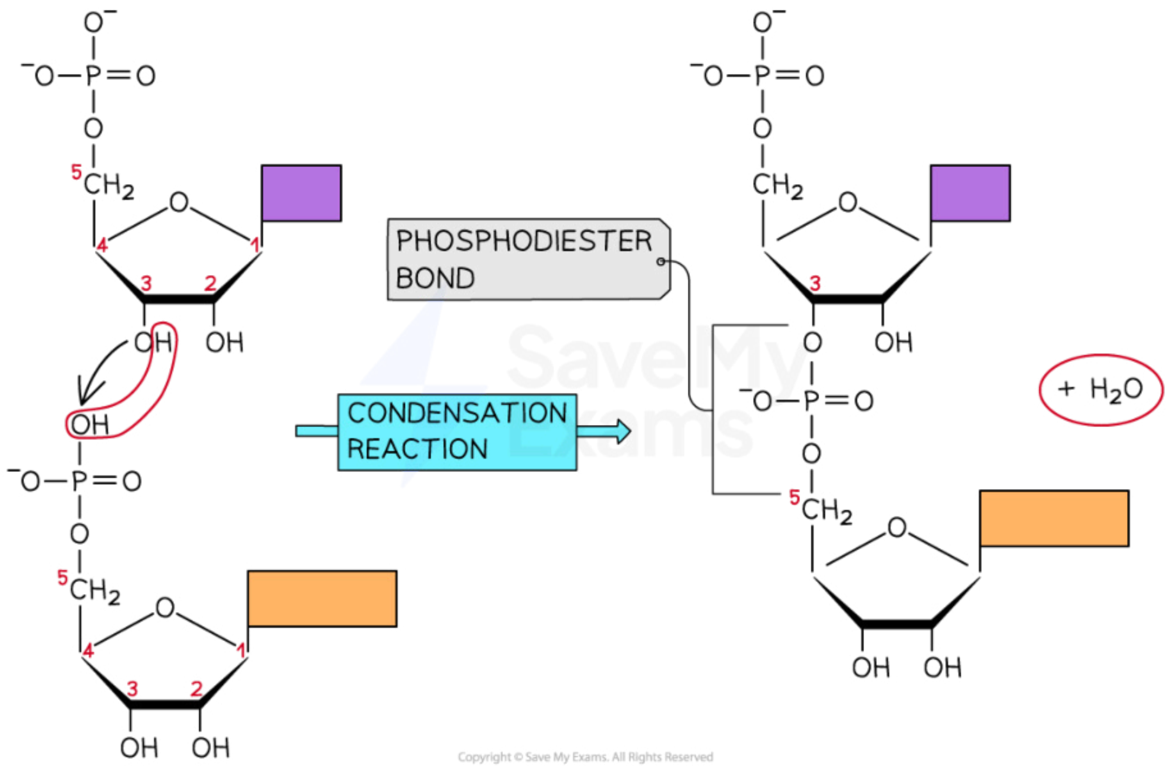


The structure of an RNA nucleotide

- Different types of RNA are found in the cells of living organisms:
  - **messenger RNA** (mRNA), which is formed in the nucleus and transported to the ribosomes in the cytoplasm
  - **transfer RNA** (tRNA), which is responsible for transporting amino acids to ribosomes during protein synthesis
  - **ribosomal RNA** (rRNA), which forms part of ribosomes

- Adjacent RNA nucleotides are linked together by **condensation reactions**, during which a molecule of water is released
- This forms a **phosphodiester bond** between the pentose sugar of one nucleotide and the phosphate group of the next nucleotide

The formation of an RNA polymer diagram



Linking RNA nucleotides together by condensation reactions will result in the formation of phosphodiester bonds

Examiner Tip

Ensure that you are able to draw and recognise diagrams of a single RNA nucleotide, as well as RNA polymers

Your notes

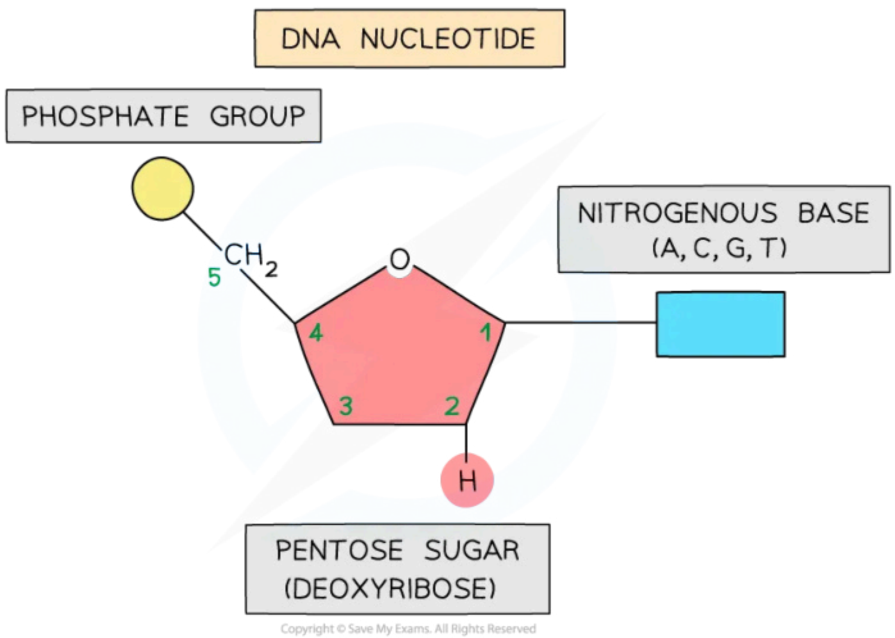
Your notes

DNA Structure

DNA structure

- DNA is a **double helix** made of two antiparallel strands of nucleotides linked by hydrogen bonding between complementary base pairs
- The nucleic acid DNA is a **polynucleotide** – it is made up of **many nucleotides** bonded together in a **long chain**

DNA nucleotide diagram

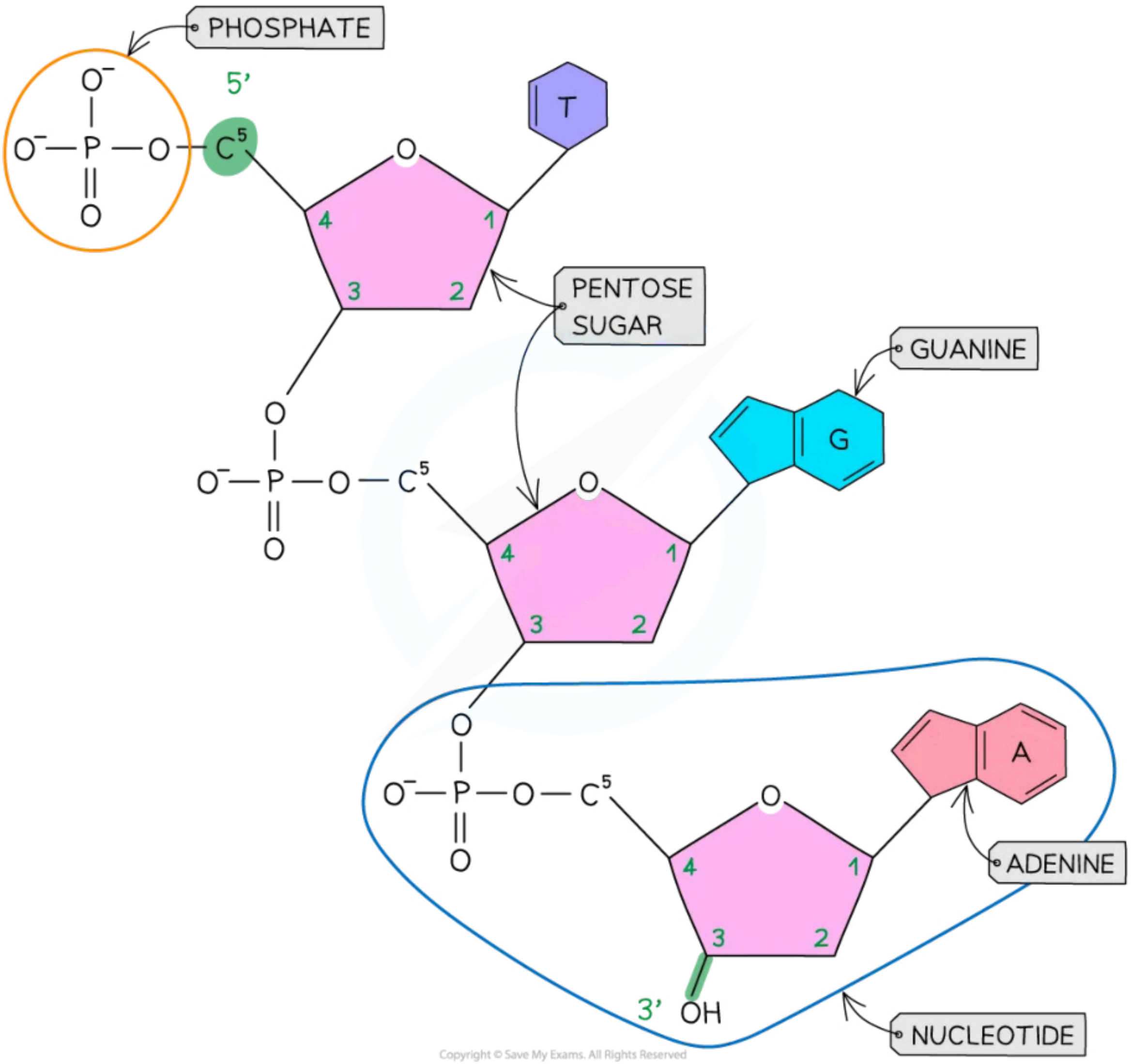


A DNA nucleotide

- DNA molecules are made up of **two polynucleotide strands** lying side by side, running in opposite directions – the strands are said to be **antiparallel**
- Each DNA polynucleotide strand is made up of **alternating deoxyribose sugars and phosphate groups bonded together** to form the **sugar-phosphate backbone**
- Each DNA polynucleotide strand is said to have a **3' end and a 5' end** (these numbers relate to which carbon atom on the pentose sugar could be bonded with another nucleotide)
- Because the strands run in opposite directions (they are **antiparallel**), one is known as the **5' to 3' strand** and the other is known as the **3' to 5' strand**
- The nitrogenous bases of each nucleotide project out from the backbone **towards the interior** of the double-stranded DNA molecule

A single DNA polynucleotide strand diagram

Your notes



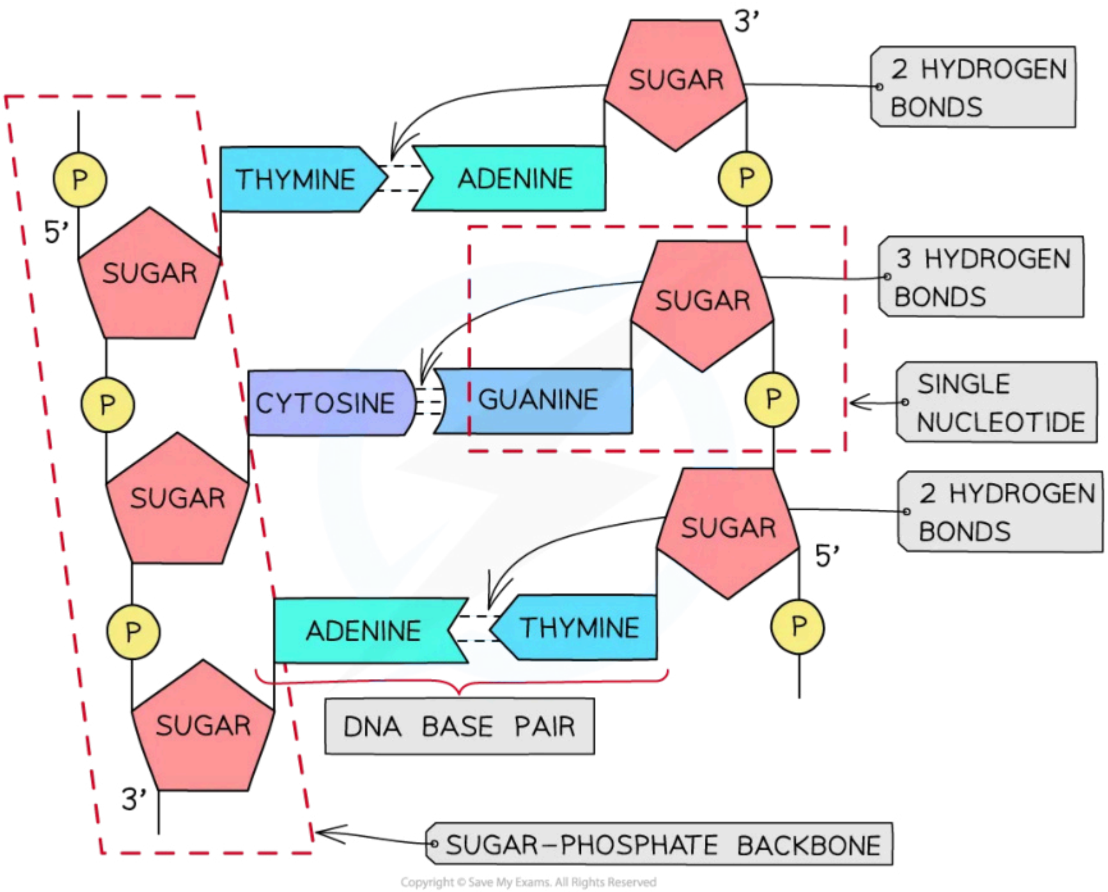
A single DNA polynucleotide strand showing 3 nucleotides in a sequence

Hydrogen bonding

- The two antiparallel DNA polynucleotide strands that make up the DNA molecule are **held together by hydrogen bonds** between the nitrogenous bases
- These hydrogen bonds always occur between the **same pairs of bases**:
  - The purine **adenine** (A) always pairs with the pyrimidine **thymine** (T) – two hydrogen bonds are formed between these bases
  - The purine **guanine** (G) always pairs with the pyrimidine **cytosine** (C) – three hydrogen bonds are formed between these bases
  - This is known as **complementary base pairing**
  - These pairs are known as **DNA base pairs**

Your notes

DNA molecule with hydrogen bonding diagram

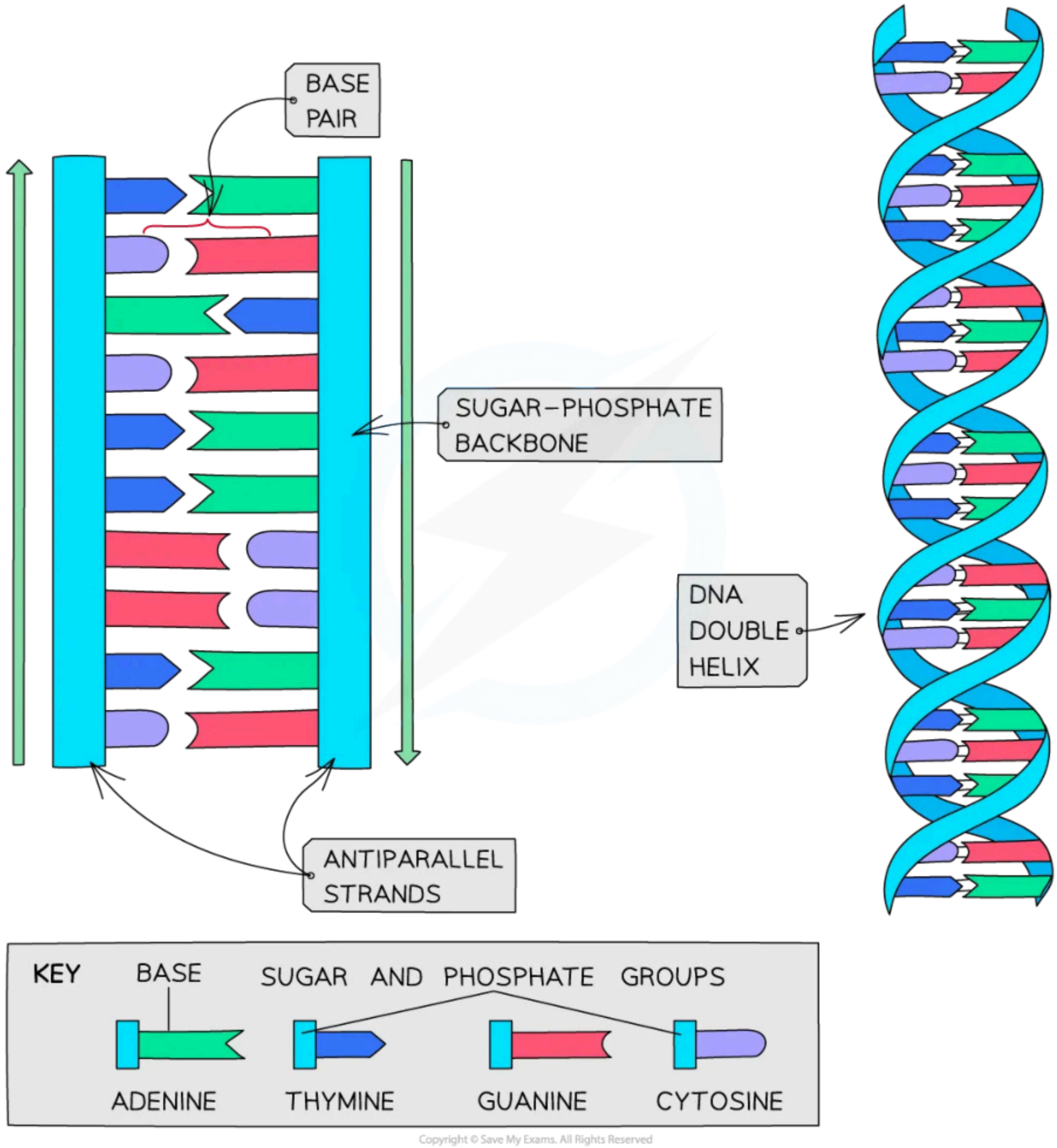


A section of DNA – two antiparallel DNA polynucleotide strands held together by hydrogen bonds

Double helix

- DNA is not two-dimensional as shown in the diagram above
- DNA is described as a double helix
- This refers to the **three-dimensional shape** that DNA molecules form

DNA double helix formation diagram



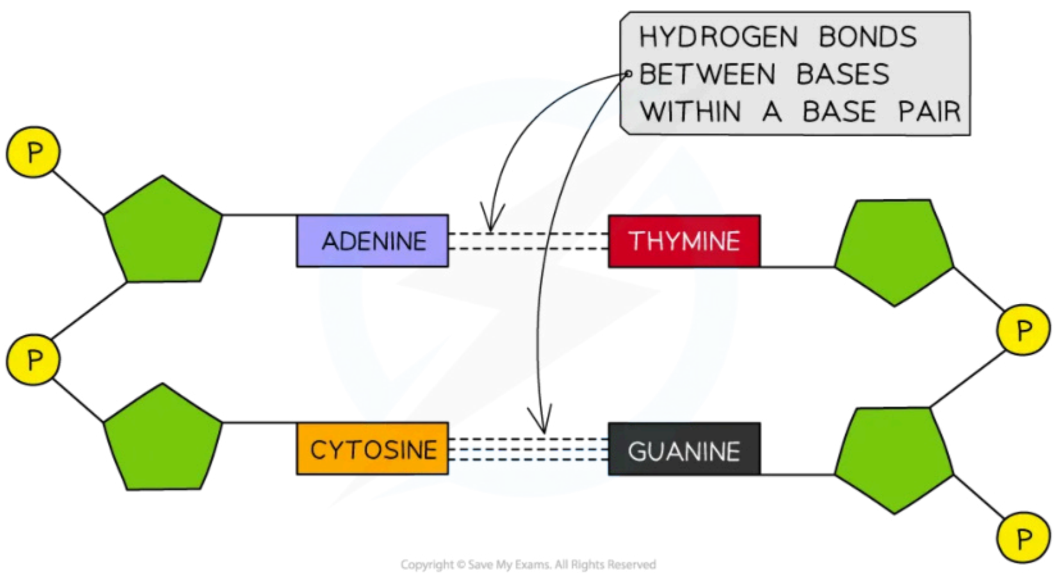
DNA molecules form a three-dimensional structure known as a DNA double helix

Your notes

Examiner Tip

Make sure you can name the different components of a DNA molecule (sugar-phosphate backbone, nucleotide, complementary base pairs, hydrogen bonds) and make sure you are able to locate these on a diagram. Remember that covalent bonds join the nucleotides in the sugar-phosphate backbone, and hydrogen bonds join the bases of the two complementary strands together. Remember that the bases are complementary, so the number of A = T and C = G. You could be asked to determine how many bases are present in a DNA molecule if given the number of just one of the bases.

Drawing base-pairing in a DNA molecule



When drawing the base pairing, the opposite strand should be antiparallel to the first. The presence of hydrogen bonding is shown, but the numbers/lengths of bonds is not required

Examiner Tip

Simple, hand-drawn shapes will suffice in an exam. Expert tip - a **large** drawing is always easier for an examiner to read (and award marks for) than a small one! Read the question carefully; examiners often want a **whole nucleotide** to be identified in your diagram and to ensure your diagram includes **all 4 complementary bases.** You don't have to remember the number of hydrogen bonds between the bases. Also, remember to draw DNA strands as **antiparallel** (one upside-down versus the other) but you don't have to be able to draw a helix shape!

Basis of Genetic Code

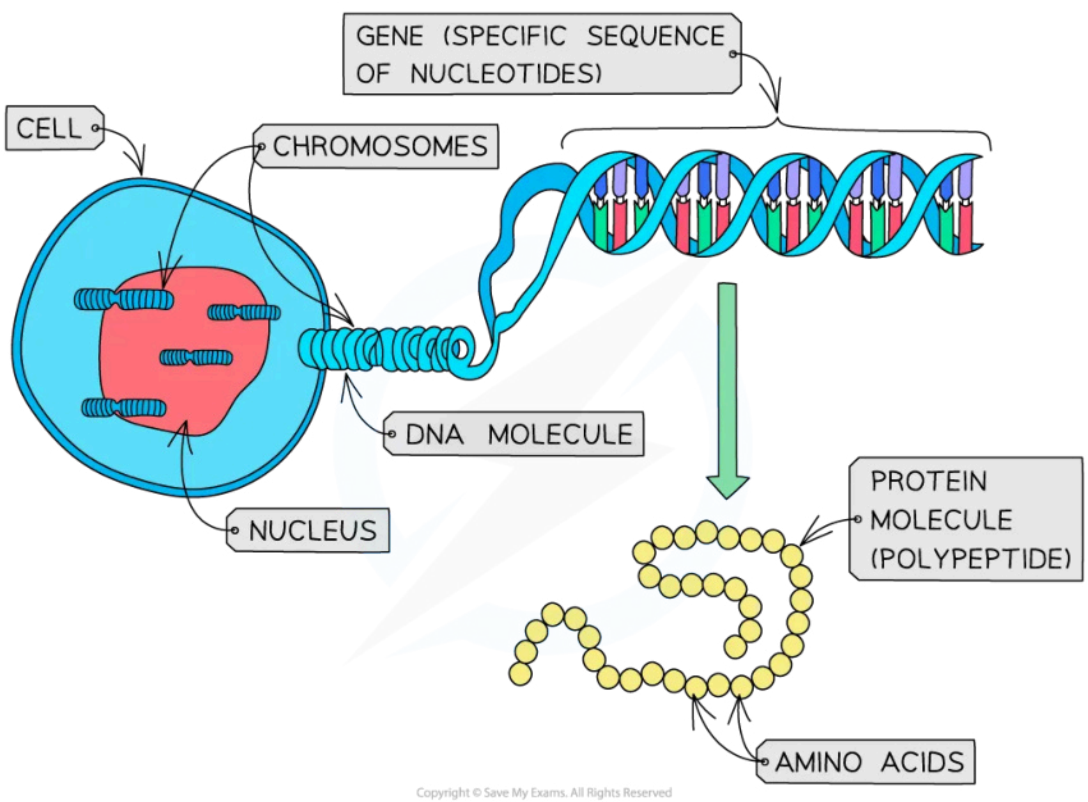
Your notes

The Genetic Code

Genetic code

- DNA molecules carry the genetic code as a **sequence of nitrogenous bases** in the nucleotides
  - These bases are adenine, guanine, cytosine and thymine
- One of the strands of a DNA molecule will **carry the base sequence** that will be read by enzymes
  - This strand is known as the **coding strand**
- The **sequence of bases** that form genes on the coding strand will determine the **order of amino acids** in the proteins that are synthesised
- The code is read as a **triplet of bases**, called a **codon**, with each sequence of three bases coding for **one amino acid**
  - Remember that there are 20 different amino acids that could be coded for
- The sequence of amino acids will **determine the shape and function of the protein** that is synthesised from the code

From gene to protein diagram



The sequence of DNA bases in the genes codes for the production of a specific protein molecule

Conservation of The Genetic Code

Your notes

The genetic code is universal

- The genetic code is **universal**, meaning that almost every organism uses the **same code** (there are a few rare and minor exceptions)
- The **same triplet codes code for the same amino acids in all living things** (meaning that genetic information is transferable between species)
  - The universal nature of the genetic code is why genetic engineering is possible
- This provides evidence for a **universal common ancestor** from which all living organisms on Earth evolved
- Over time, mutations have led to **changes in some of the base sequences** of organisms
  - These base sequences form the genome of an organism
  - Some base sequences form part of regions that code for proteins, called **coding sequences**, while others are located in regions that do not code for proteins (**non-coding sequences**)
- Many of these coding and non-coding sequences have remained unchanged in all organisms and are known as **conserved sequences**
- Highly conserved sequences are usually found in the genes that code for **proteins involved with** transcription **and** translation, as well as **histone proteins** which help to package DNA tightly into the nucleus
- The similarity in these sequences indicate that living organisms share a **universal ancestry**

Nucleic Acid Structure & Function

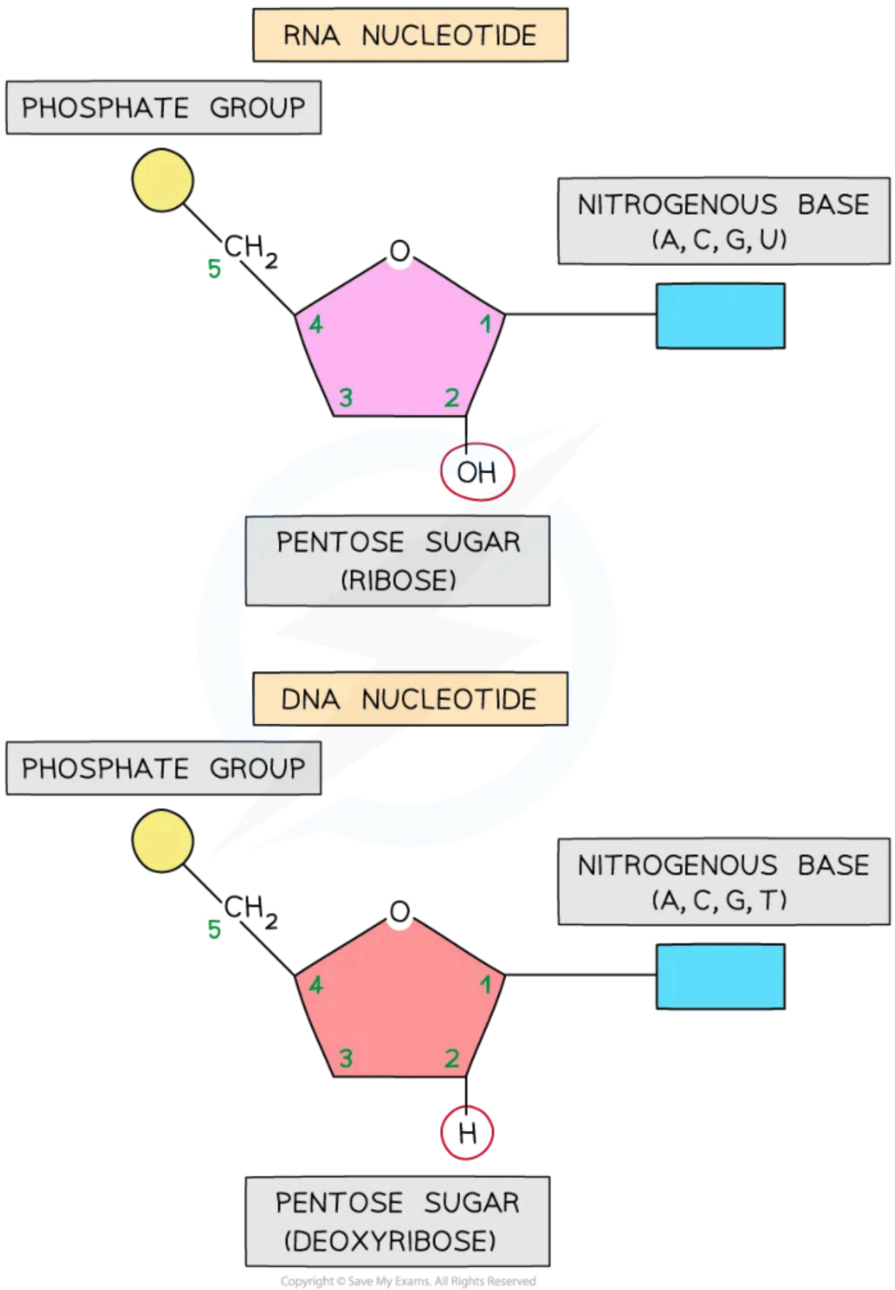
Your notes

DNA & RNA: Comparison

Differences between DNA and RNA

- **Unlike DNA**, RNA nucleotides **never contain** the nitrogenous base **thymine** (T) – in place of this they contain the nitrogenous base **uracil** (U)
- **Unlike DNA**, RNA nucleotides contain the **pentose** sugar **ribose** (instead of deoxyribose)

Comparing DNA and RNA nucleotides diagram

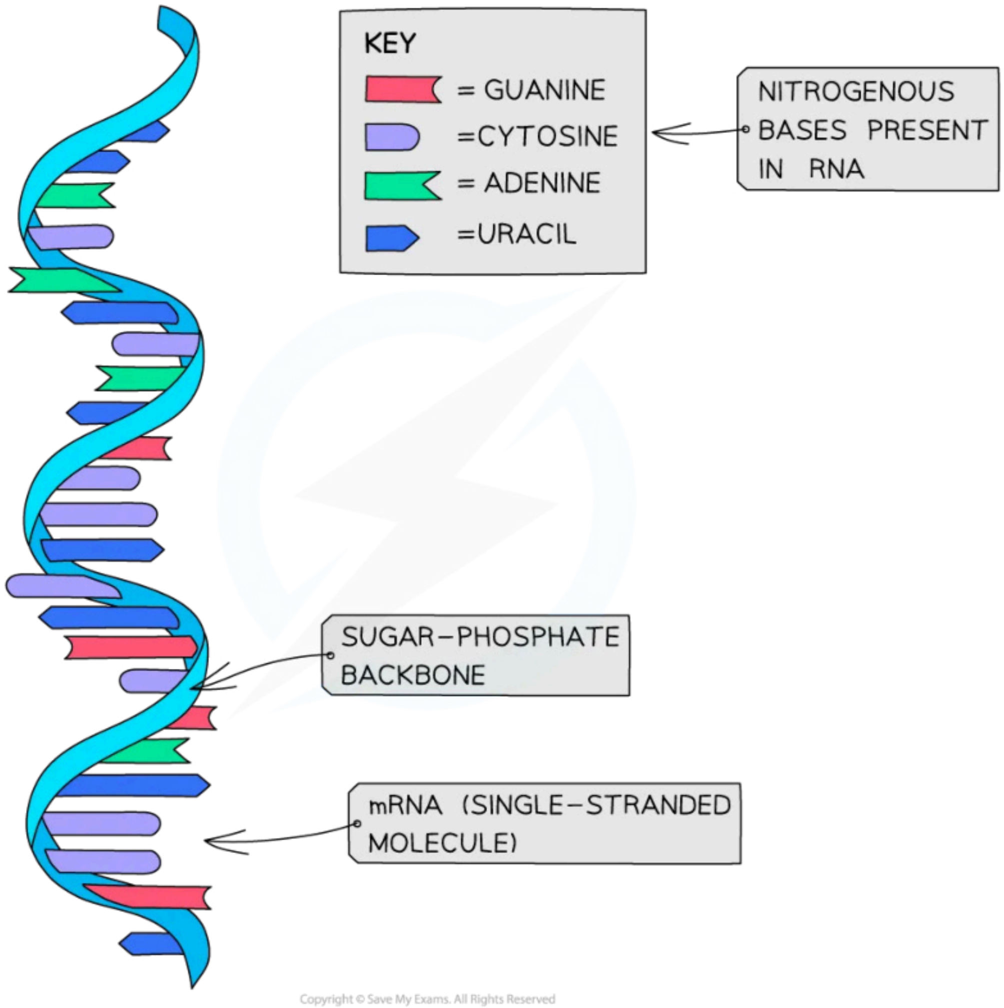


An RNA nucleotide compared with a DNA nucleotide

- **Unlike DNA**, RNA molecules are only made up of **one polynucleotide strand** (they are **single-stranded**)
- **Unlike DNA,** RNA polynucleotide chains are relatively **short compared to DNA**

RNA structure

Your notes



mRNA as an example of the structure of an RNA molecule

Nucleotide Structure Summary Table

Properties	DNA	RNA
Pentose sugar	Deoxyribose	Ribose
Bases	Adenine (A) Cytosine (C) Guanine (G) **Thymine (T)**	Adenine (A) Cytosine (C) Guanine (G) **Uracil (U)**

Number of strands	Double-stranded (double helix)	Single-stranded

Your notes

Examiner Tip

You need to know the difference between DNA and RNA molecules (base composition, number of strands, pentose sugar present). You also need to be able to sketch the difference between ribose and deoxyribose.

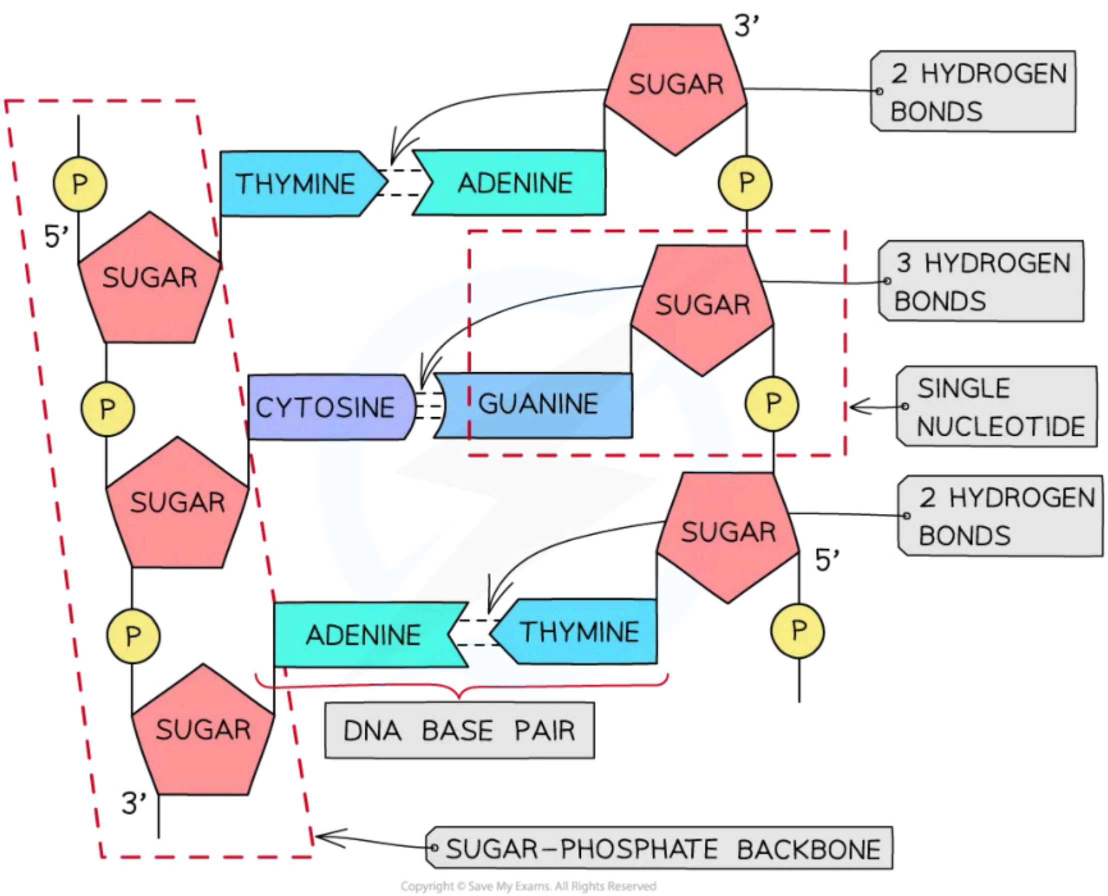
Your notes

Complementary Base Pairing

The role of complementary base pairing

- Complementary base pairing means that the DNA bases on different strands will always pair up in a very specific way:
  - **Adenine** (A) will pair up with **Thymine** (T)
  - **Cytosine** (C) will pair up with **Guanine** (G)
- This is because the hydrogen bonds that hold the two DNA strands together can **only form between these base pairs**:
  - **Two hydrogen bonds** form between A and T
  - **Three hydrogen bonds** form between C and G
- Complementary base pairing means that the **base sequence on one DNA strand** determines the sequence **of the other strand**
  - We say that one strand acts as a template of the other
- This allows DNA to be copied **very precisely during DNA replication** which in turn ensures that the genetic code is accurately copied and expressed in newly formed cells

Complementary base pairs and hydrogen bonding diagram



A section of DNA showing nucleotide bonding and complementary base pair bonding

Your notes

DNA: Information Storage Molecule

Diversity of DNA base sequences

- Despite the genetic code **only containing four bases** (A, T, C, G), they can combine to form a **very diverse range** of **DNA base sequences** in DNA molecules of **different lengths**
- This means that DNA has an almost **limitless capacity for storing genetic information** in living organisms
- One way in which this storage capacity can be measured is by the **number of genes** contained within the DNA of an organism
- Even the most simplistic forms of life may contain several thousand genes within their DNA

Comparing the Number of Genes between Different Organisms Table

Organism	Human	Dog	Water flea	Bacterium (*E. coli*)	Rice plant
Approximate number of genes	20 000	19 000	31 000	4 300	41 500

- The storage capacity of DNA can also be measured in the **number of base pairs** contained within the **genome** of an organism
- The **DNA in the nucleus of a human cell** contains about 3.2 gigabases
  - That is about 10^9 DNA base pairs
- These base pairs are contained in DNA with a **length of about 2 meters**, that fits within the nucleus of each human cell
  - Given the fact that a nucleus is microscopic in size, is an indication of how incredibly well packaged this amount of genetic information is
- This gives DNA an **enormous capacity** for storing genetic 'data' **with great economy**