



## 6.1 Structure of Nucleic Acids & Replication of DNA

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Your notes

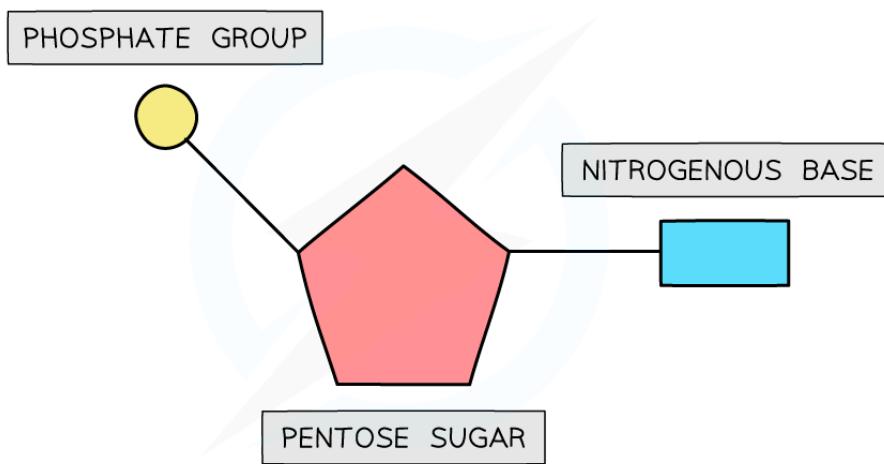
## 6.1.1 Nucleotides

### Nucleotide Structure

- **Nucleic acids** such as **DNA** (deoxyribonucleic acid) and **RNA** (ribonucleic acid) are **macromolecules** (giant molecules)
- Like proteins (polypeptides) and carbohydrates (polysaccharides), these nucleic acids are **polymers** ('poly' meaning 'many')
- This means they are made up of many similar, smaller molecules (known as **subunits** or **monomers**) joined into a long chain
- The subunits that make up DNA and RNA are known as **nucleotides**
- Therefore DNA and RNA can also be known as **polynucleotides**

### Nucleotides

- Nucleotides are made up of three components:
  - A **nitrogen-containing base** (also known as a nitrogenous base)
  - A **pentose sugar** (containing 5 carbon atoms)
  - A **phosphate group**



**The basic structure of a nucleotide**

### Nucleotide structure table



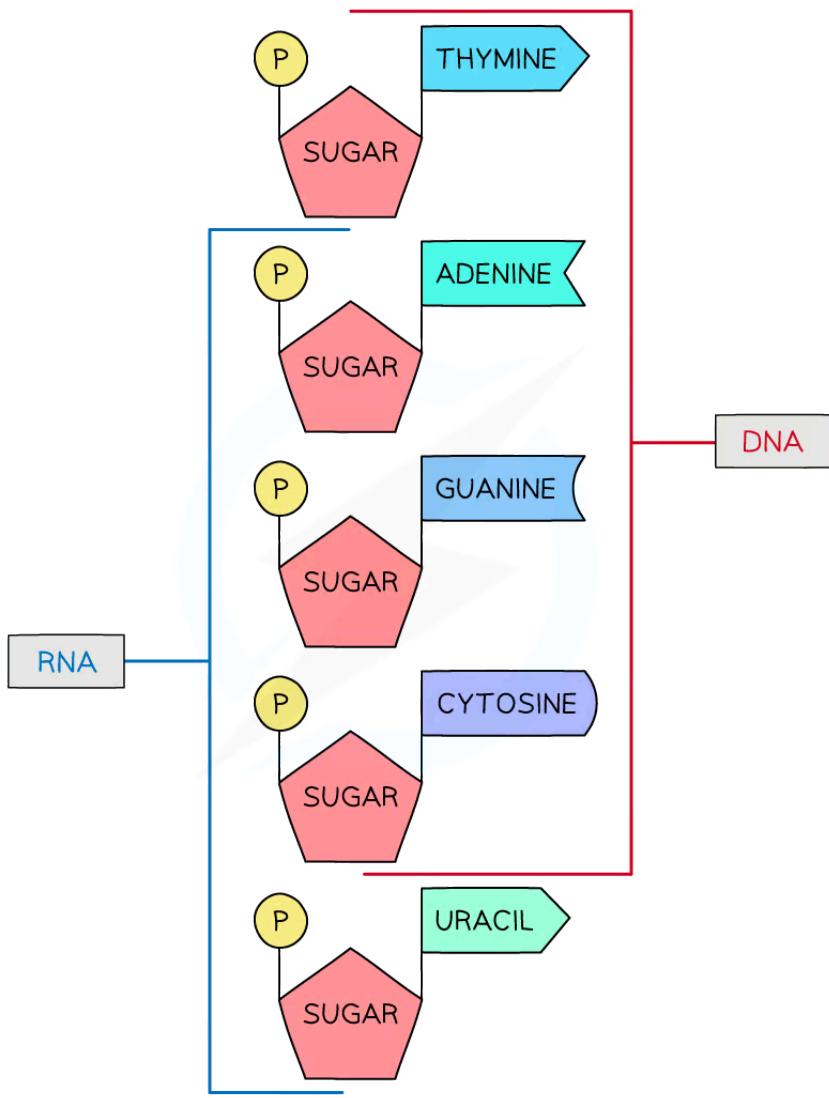
Your notes

Properties	DNA	RNA
Pentose sugar	Deoxyribose	Ribose
Bases	Adenine (A) Thymine (T) Cytosine (C) Guanine (G)	Adenine (A) Uracil (U) Cytosine (C) Guanine (G)
Number of strands	Double-stranded (double helix)	single-stranded

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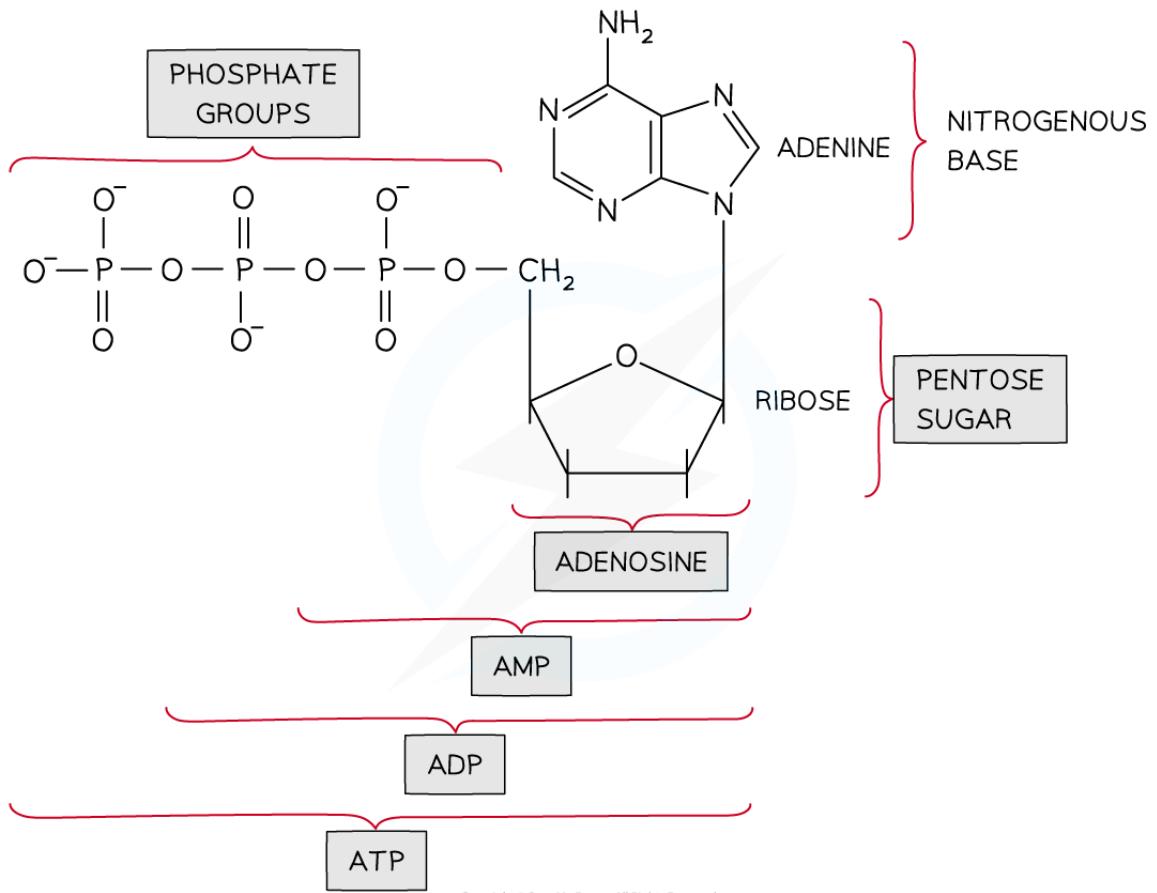


### ***The nucleotides found in DNA and RNA***

## **ATP**

- **Adenosine triphosphate** (ATP) is the energy-carrying molecule that provides the energy to drive many processes inside living cells
- ATP is **another type of nucleic acid** and hence it is structurally very similar to the nucleotides that make up DNA and RNA
- It is a phosphorylated nucleotide
- Adenosine (a nucleoside) can be combined with one, two or three phosphate groups
  - One phosphate group = **adenosine monophosphate** (AMP)

- Two phosphate groups = **adenosine diphosphate** (ADP)
- Three phosphate groups = **adenosine triphosphate** (ATP)


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### The structure of AMP, ADP and ATP

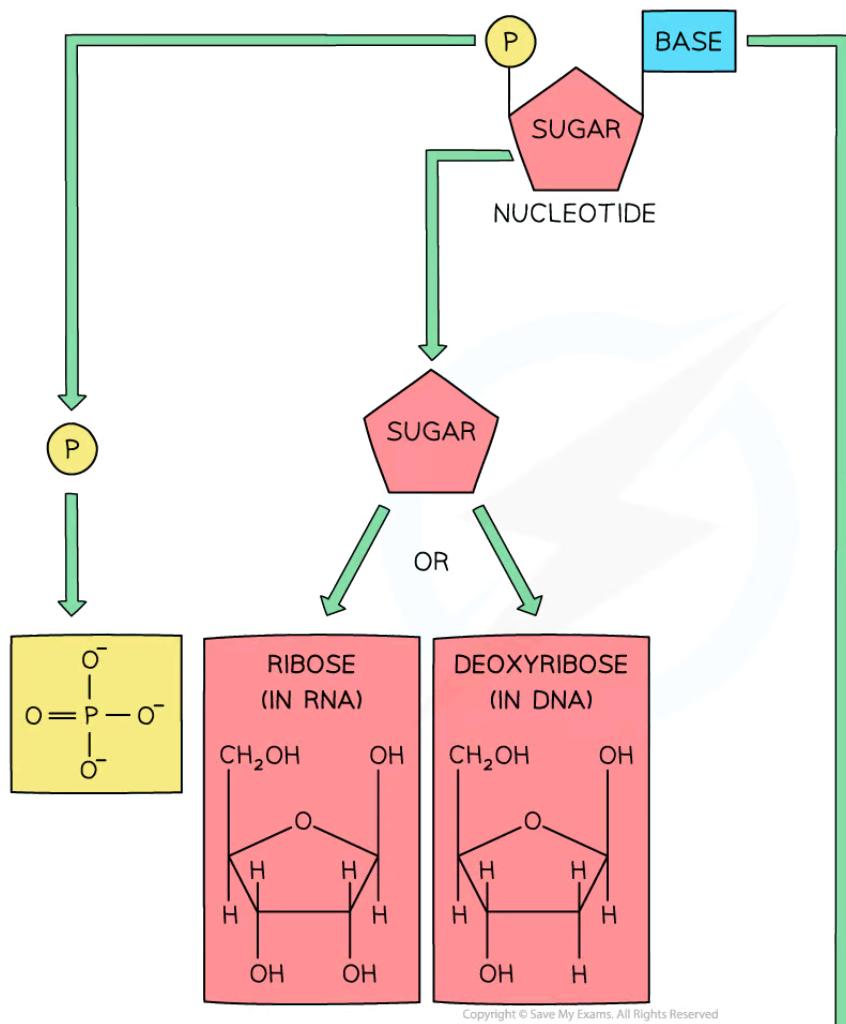
#### Examiner Tip

Don't worry – you are not expected to know the structural formulae for the nucleotides that make up DNA and RNA or AMP, ADP and ATP (as in the diagram above)! You just need to learn the different groups that they are made up of (phosphate groups, pentose sugars and nitrogenous bases). Remember that **adenine** is a **nitrogenous base** whereas **adenosine** is a **nucleoside** (a base – adenine, attached to a pentose sugar).

## Purines & Pyrimidines

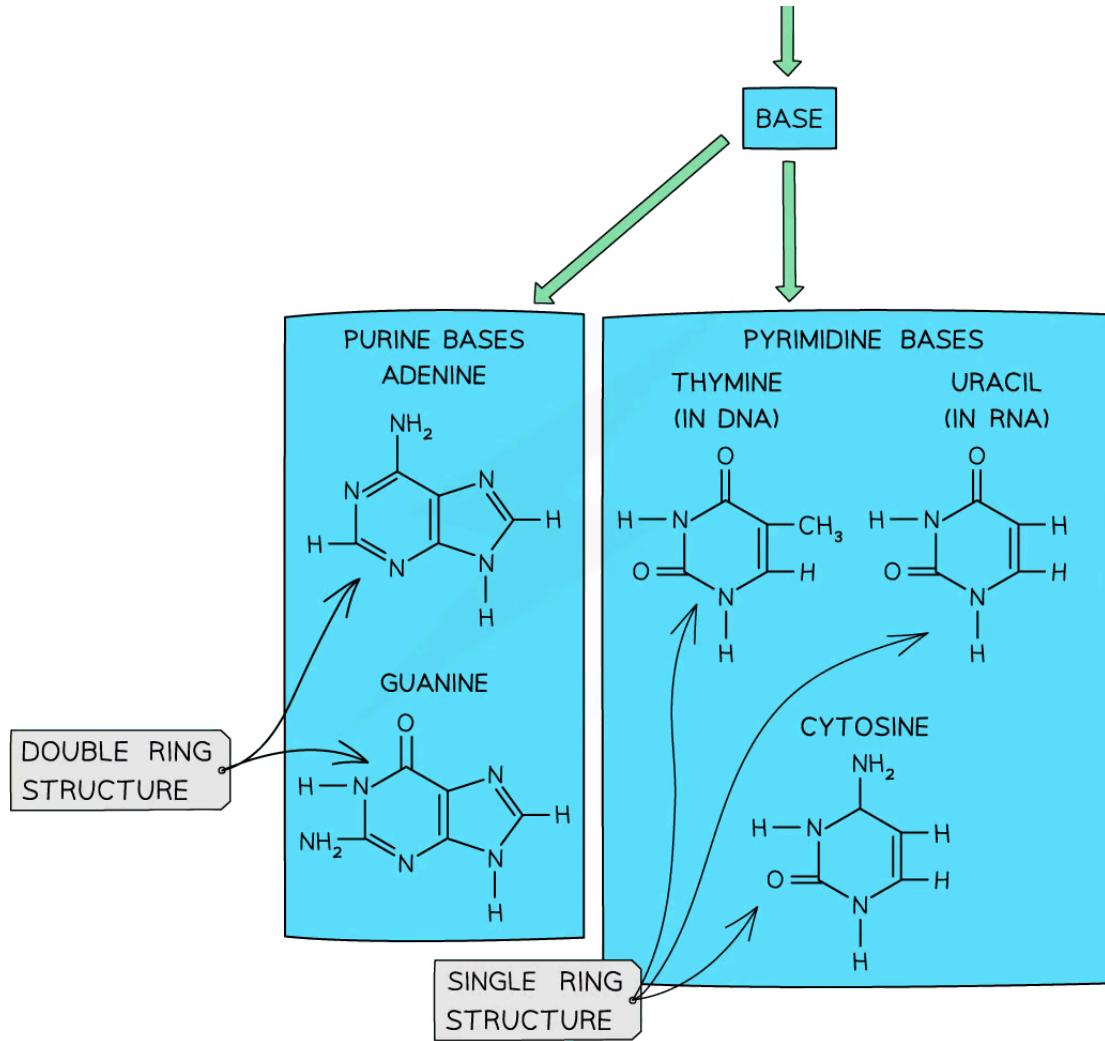

**Your notes**

- The **nitrogenous base** molecules that are found in the nucleotides of DNA (A, T, C, G) and RNA (A, U, C, G) occur in **two structural forms**: purines and **pyrimidines**
- The bases **adenine** and **guanine** are **purines** – they have a **double ring structure**
- The bases **cytosine**, **thymine** and **uracil** are **pyrimidines** – they have a **single ring structure**


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***The molecular structures of purines and pyrimidines are slightly different***

### Examiner Tip

You don't need to know the structural formulae of these bases, just which are purines and which are pyrimidines.

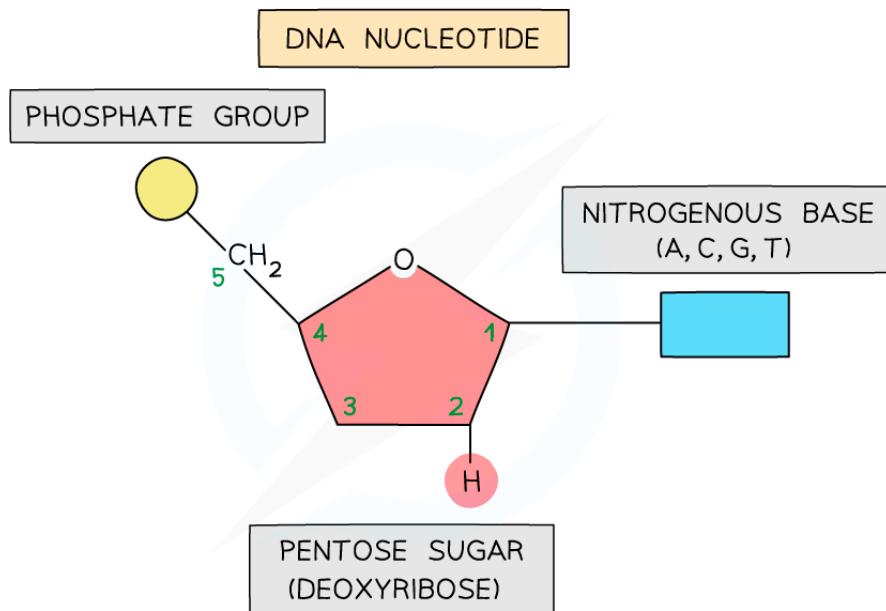


Your notes

## 6.1.2 The Structure of DNA

### DNA Structure

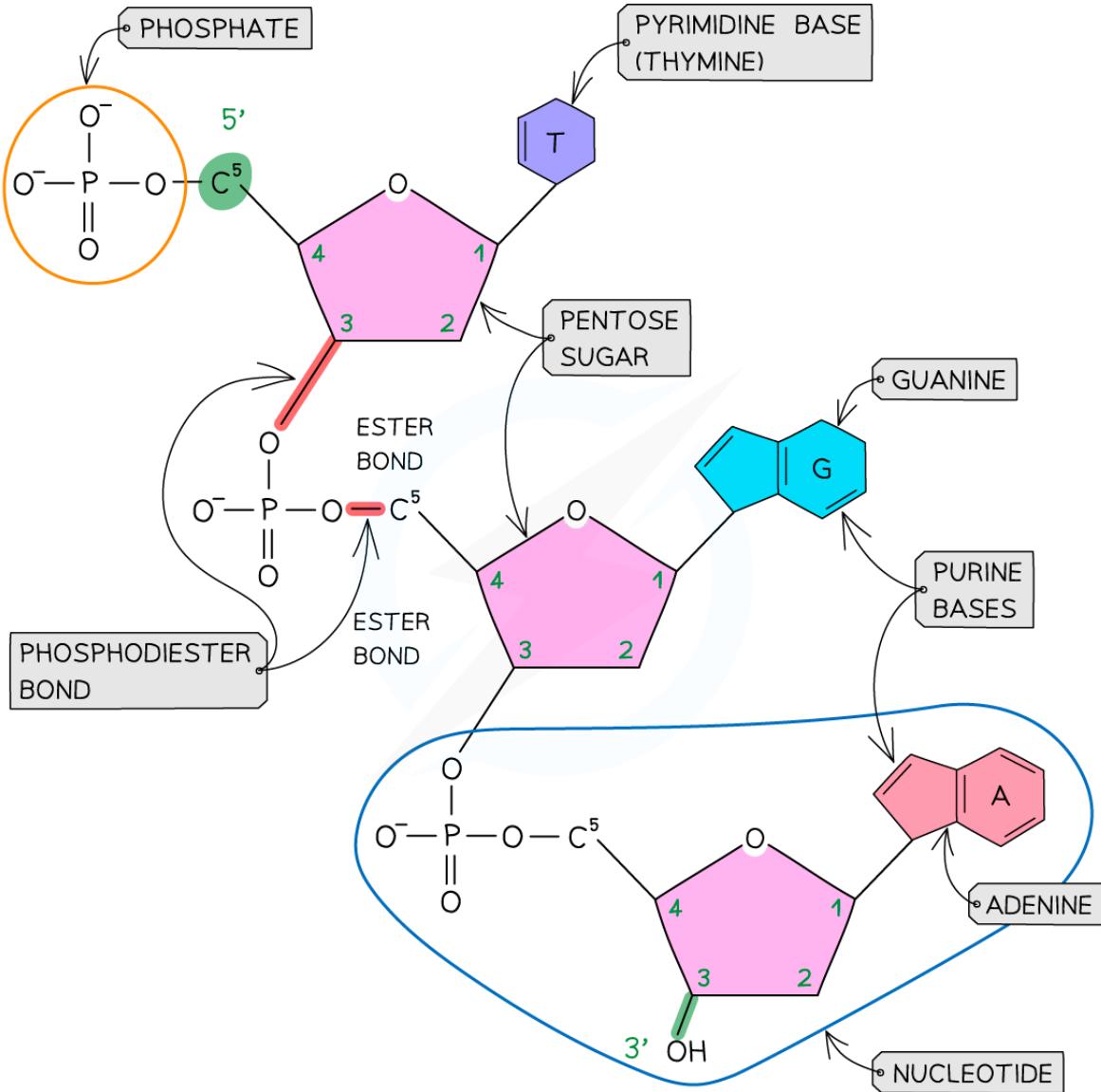
- The nucleic acid DNA is a **polynucleotide** – it is made up of **many nucleotides** bonded together in a **long chain**



**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**. These bonds are **covalent bonds** known as **phosphodiester bonds**
  - The phosphodiester bonds link the **5-carbon of one deoxyribose sugar** molecule to the phosphate group from the same nucleotide, which is itself linked by another phosphodiester bond to the **3-carbon of the deoxyribose sugar molecule of the next nucleotide** in the strand
  - Each DNA polynucleotide strand is said to have a **3' end and a 5' end** (these numbers relate to which carbon on the pentose sugar could be bonded with another nucleotide)
  - As 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



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**A single DNA polynucleotide strand showing the positioning of the ester bonds**

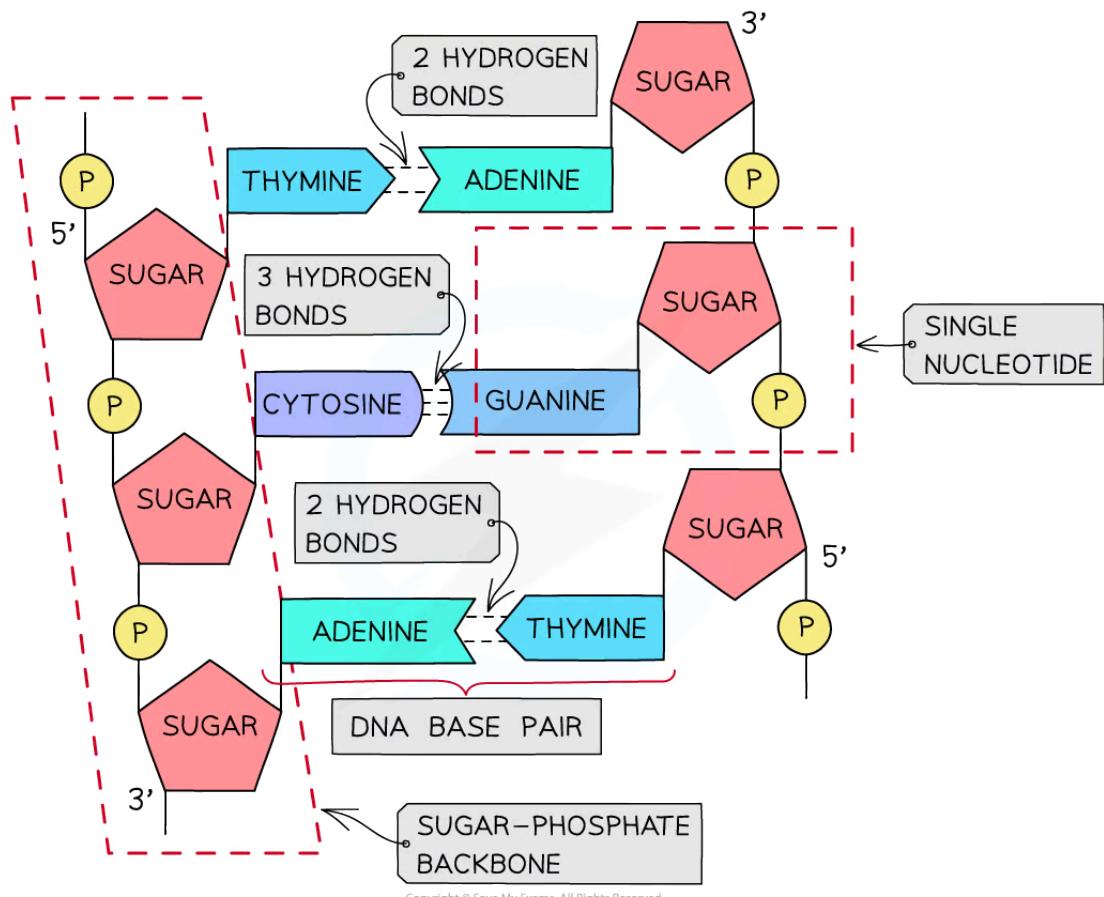
## Hydrogen bonding

- The two antiparallel DNA polynucleotide strands that make up the DNA molecule are **held together by hydrogen bonds** between the nitrogenous bases



Your notes

- 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**



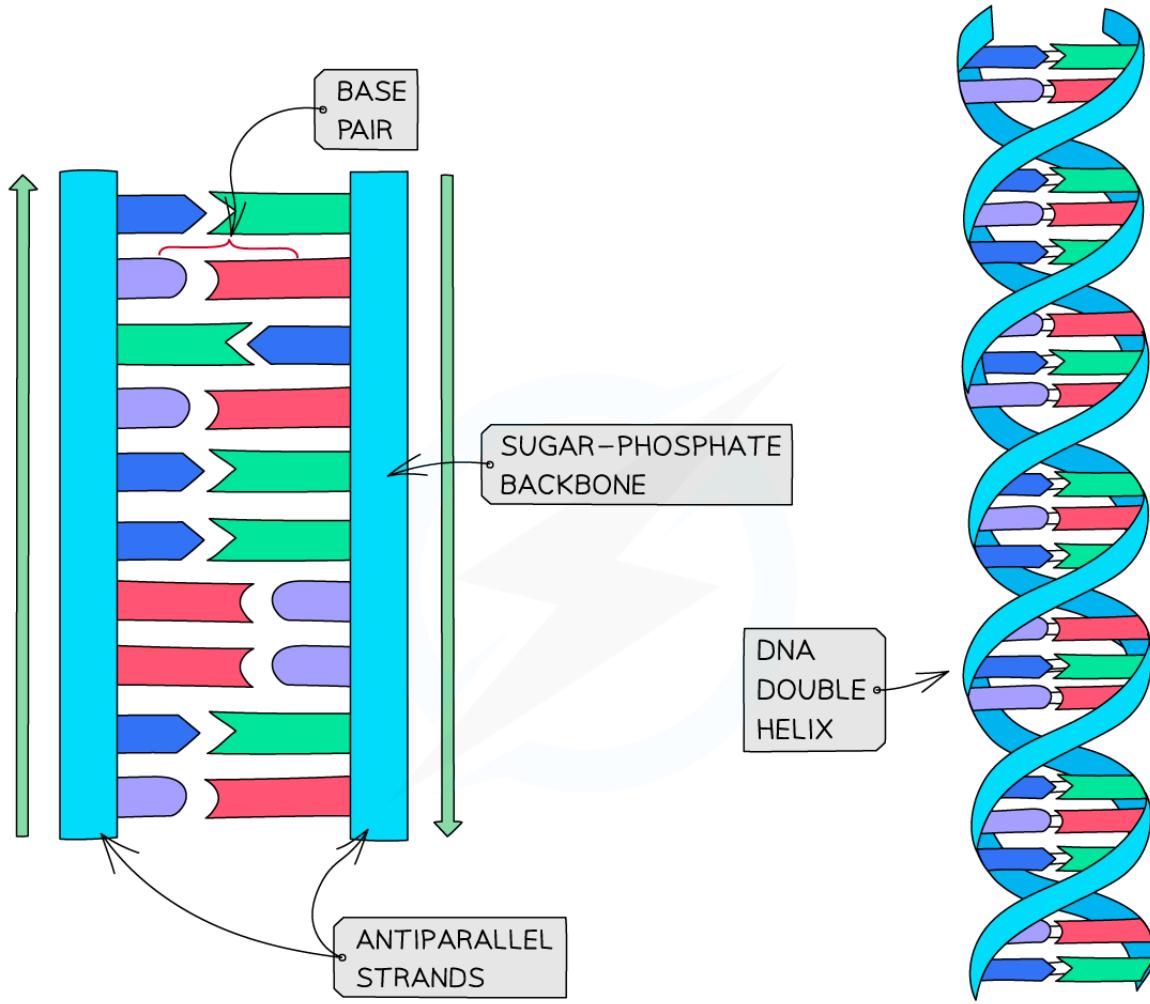
A section of DNA – two antiparallel DNA polynucleotide strands held together by hydrogen bonds

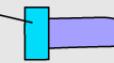
## Double helix

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



Your notes



KEY	BASE	SUGAR AND PHOSPHATE GROUPS		
				
	ADENINE	THYMINE	GUANINE	CYTOSINE

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

 **Examiner Tip**

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

**Your notes**

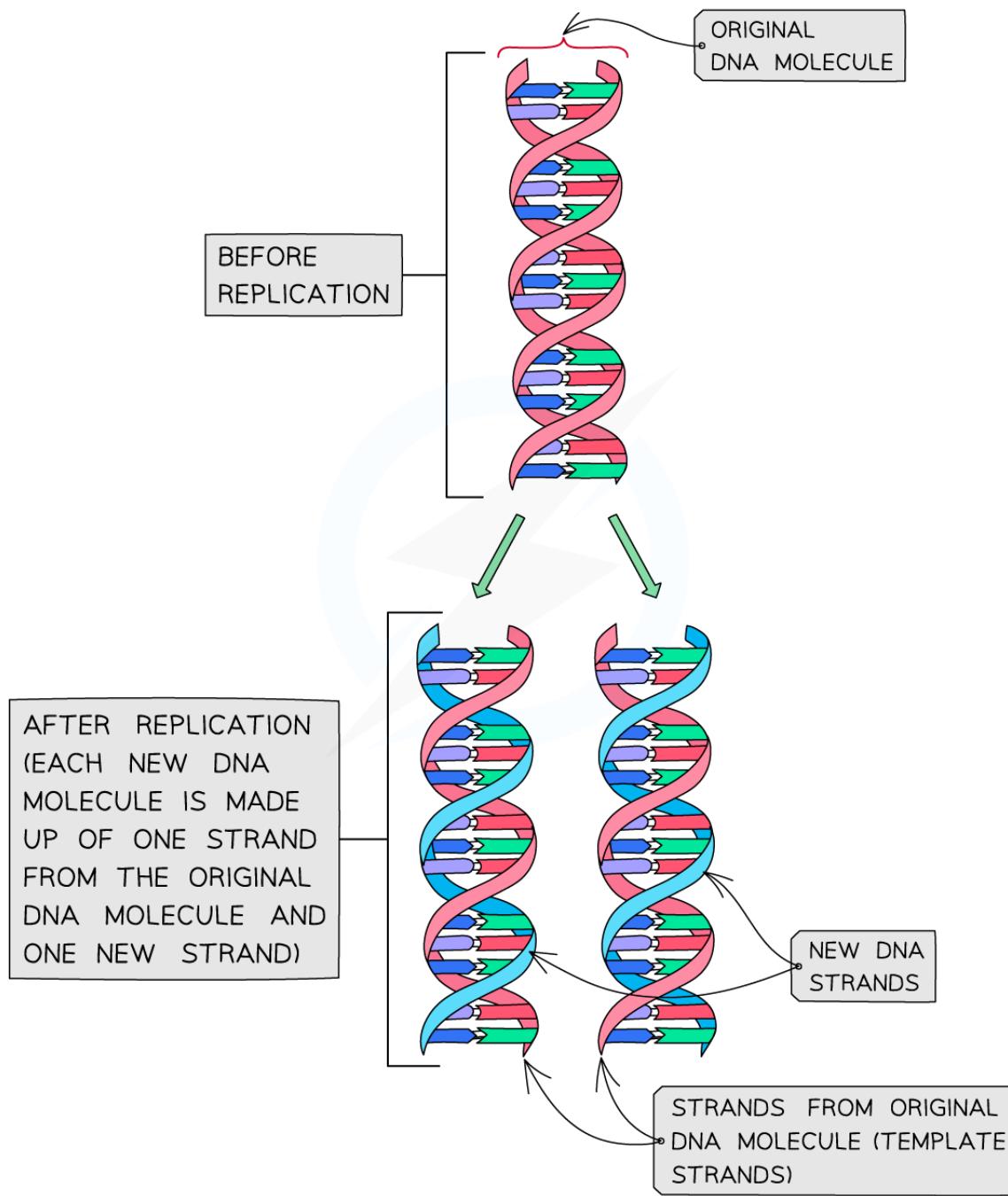


Your notes

### 6.1.3 Semi-Conservative DNA Replication

## Semi-Conservative DNA Replication

- DNA replication occurs in preparation for **mitosis**, when a parent cell divides to produce two genetically identical daughter cells – as each daughter cell contains the same number of chromosomes as the parent cell, the number of DNA molecules in the parent cell must be **doubled** before mitosis takes place
- DNA replication occurs during the **S phase** of the cell cycle (which occurs during **interphase**, when a cell is **not dividing**)
- The **hydrogen bonds** between the base pairs on the two antiparallel polynucleotide DNA strands are **broken**
- This '**unzips**' or **unwinds** the DNA double helix to form two single polynucleotide DNA strands
- Each of these single polynucleotide DNA strands acts as a **template** for the formation of a **new strand** – the original strand and the new strand then join together to form a new DNA molecule
- This method of replicating DNA is known as **semi-conservative replication** because **half of the original DNA molecule is kept (conserved)** in each of the two new DNA molecules
- Semi-conservative replication was shown to be the method of replication by **Meselson and Stahl** in 1958. They used *E. coli* (a bacteria) and two nitrogen isotopes, a heavy form  $^{15}\text{N}$  and the 'normal' form  $^{14}\text{N}$ , to demonstrate how the density of DNA changes over generations as the  $^{15}\text{N}$  isotope was replaced with the  $^{14}\text{N}$  isotope

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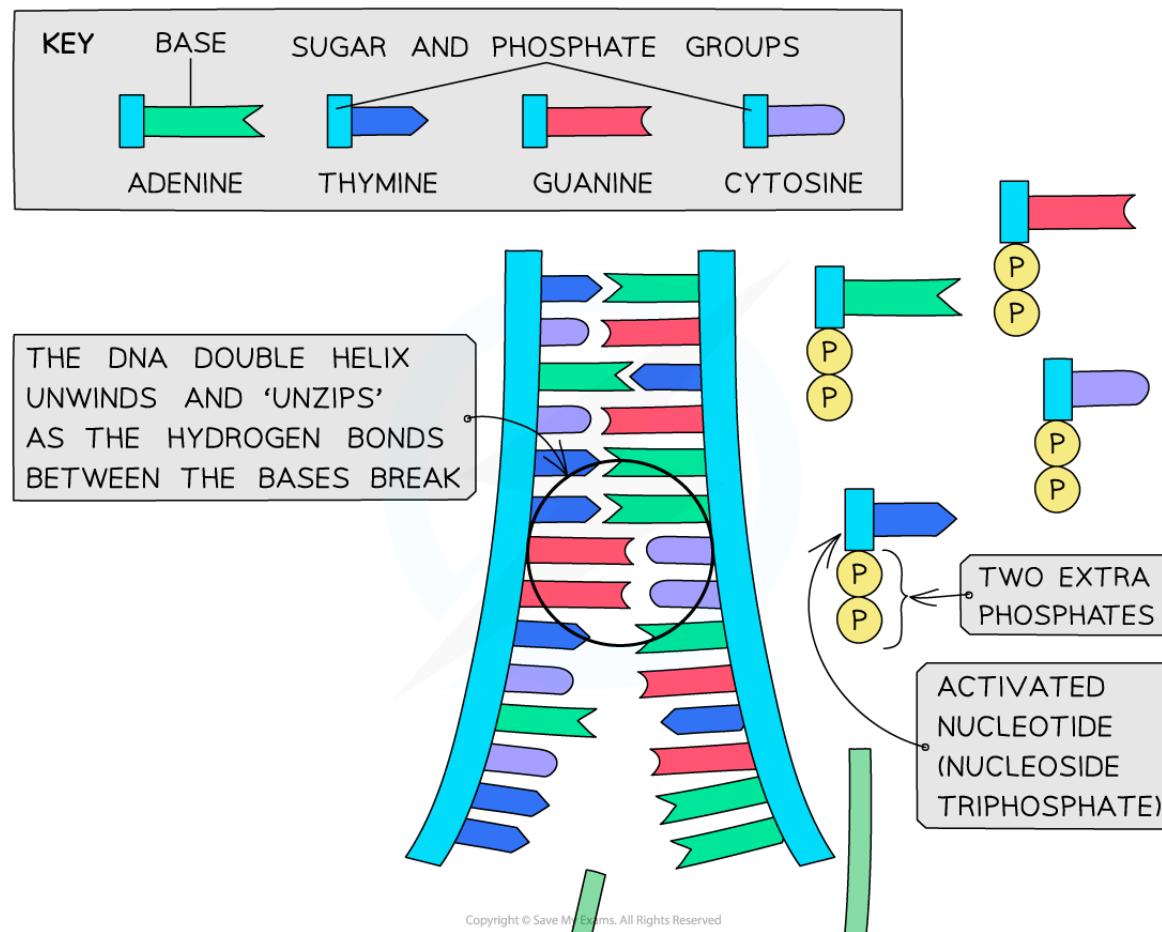
### Semi-conservative replication of DNA

## DNA Polymerase



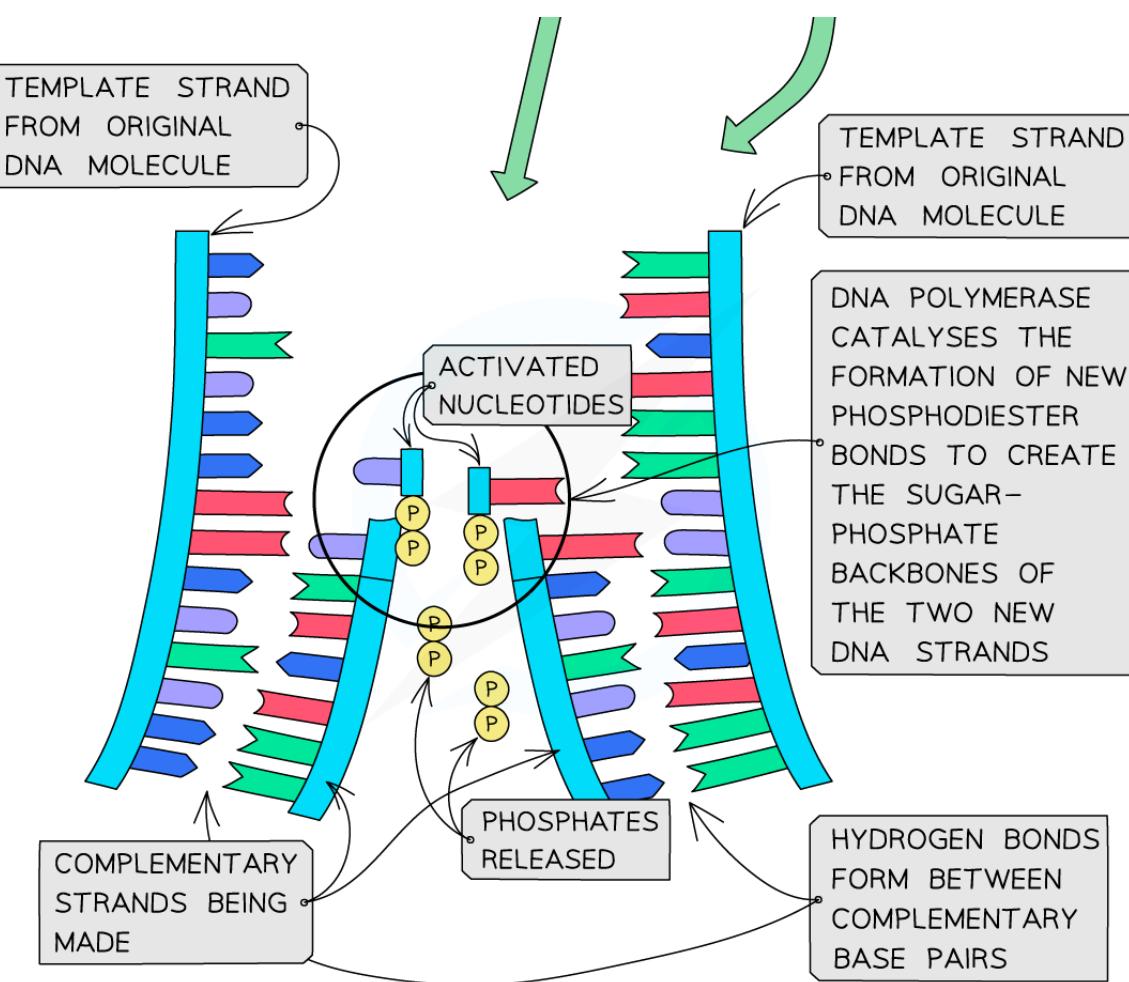
Your notes

- In the nucleus, there are **free nucleotides** to which **two extra phosphates** have been added (these free nucleotides with three phosphate groups are known as **nucleoside triphosphates** or '**activated nucleotides**'')
- The extra phosphates activate the nucleotides, enabling them to take part in DNA replication
- The bases of the free nucleoside triphosphates **align** with their **complementary bases** on each of the **template** DNA strands
- The enzyme **DNA polymerase** **synthesises** new DNA strands from the two template strands
- It does this by **catalysing condensation reactions** between the deoxyribose sugar and phosphate groups of adjacent nucleotides within the new strands, creating the sugar-phosphate backbone of the new DNA strands
- DNA polymerase cleaves (breaks off) the two extra phosphates and uses the **energy released** to create the **phosphodiester bonds** (between adjacent nucleotides)
- Hydrogen bonds** then form between the **complementary base pairs** of the template and new DNA strands





Your notes


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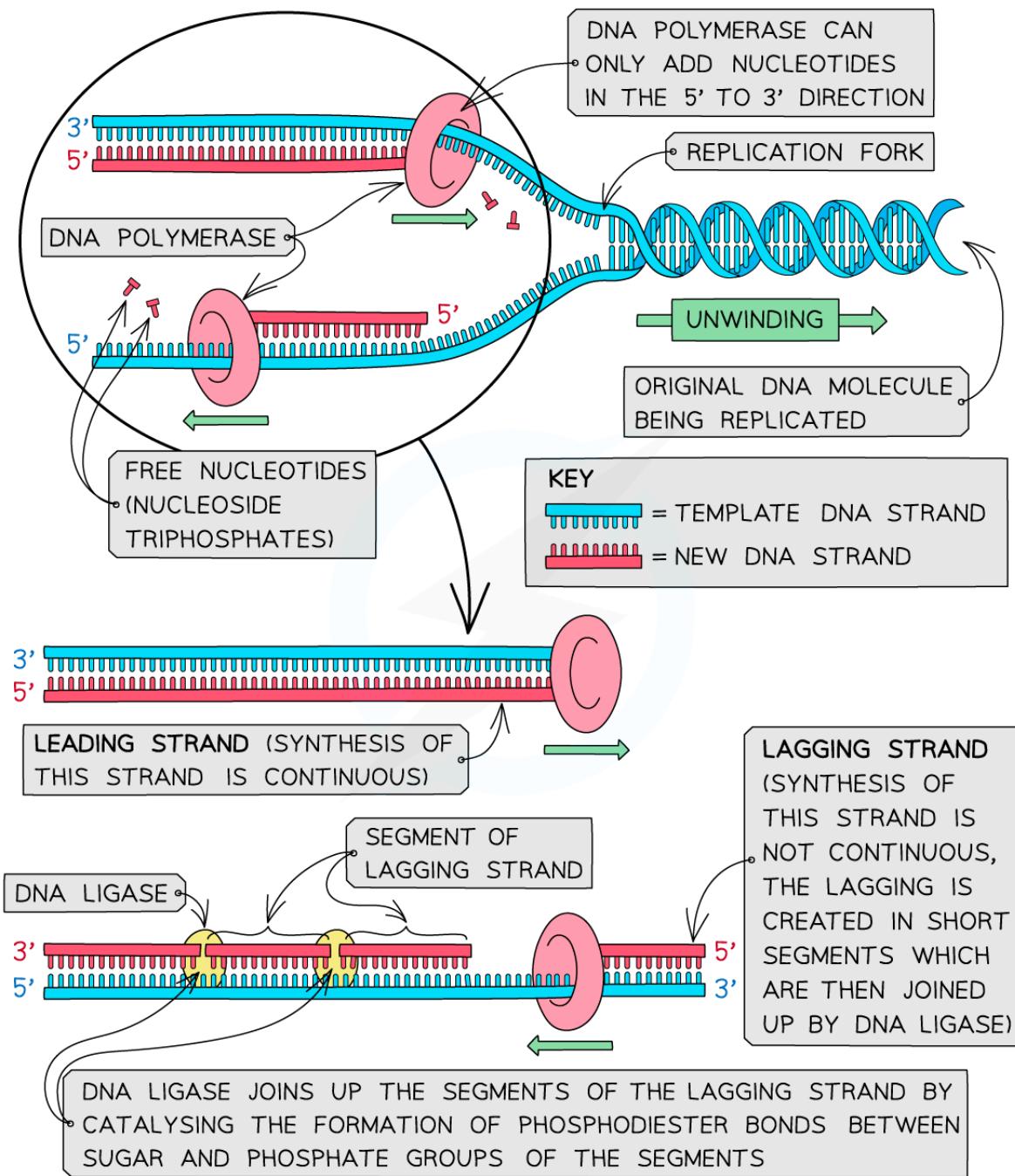
**Nucleotides are bonded together by DNA polymerase to create the new complementary DNA strands**

### Leading & lagging strands

- DNA polymerase can only build the new strand in one direction (5' to 3' direction)
- As DNA is 'unzipped' from the 3' towards the 5' end, DNA polymerase will attach to the **3' end of the original strand** and **move towards the replication fork** (the point at which the DNA molecule is splitting into two template strands)
- This means the DNA polymerase enzyme can synthesise the leading strand **continuously**
- This template strand that the DNA polymerase attaches to is known as the **leading strand**
- The other template strand created during DNA replication is known as the **lagging strand**
- On this strand, **DNA polymerase moves away from the replication fork** (from the 5' end to the 3' end)
- This means the DNA polymerase enzyme can only synthesise the lagging DNA strand in **short segments** (called Okazaki fragments)


**Your notes**

- A second enzyme known as **DNA ligase** is needed to **join these lagging strand segments together** to form a continuous complementary DNA strand
- DNA ligase does this by catalysing the formation of **phosphodiester bonds** between the segments to create a **continuous sugar-phosphate backbone**



**The synthesis of the complementary strands occurs slightly differently on the leading and lagging template strands of the original DNA molecule that is being replicated**



Your notes



Your notes

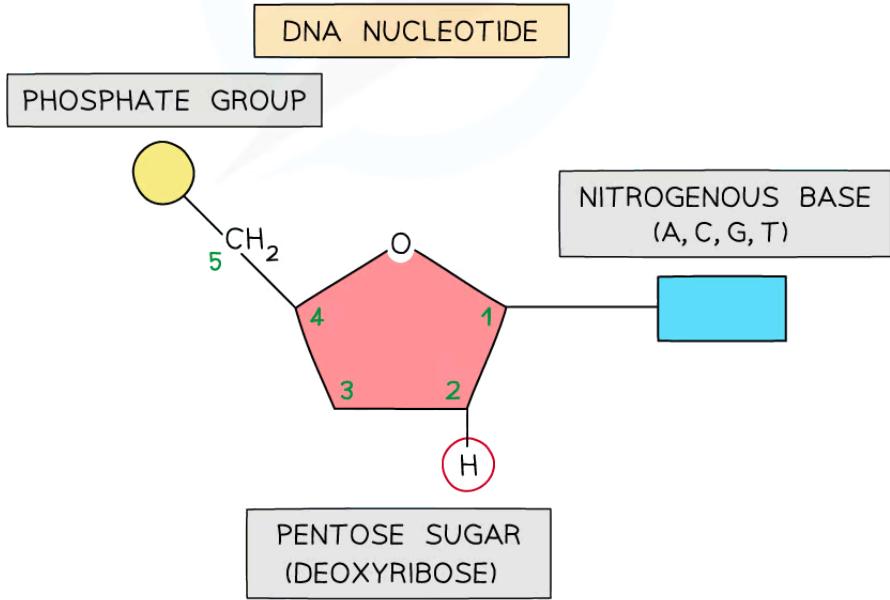
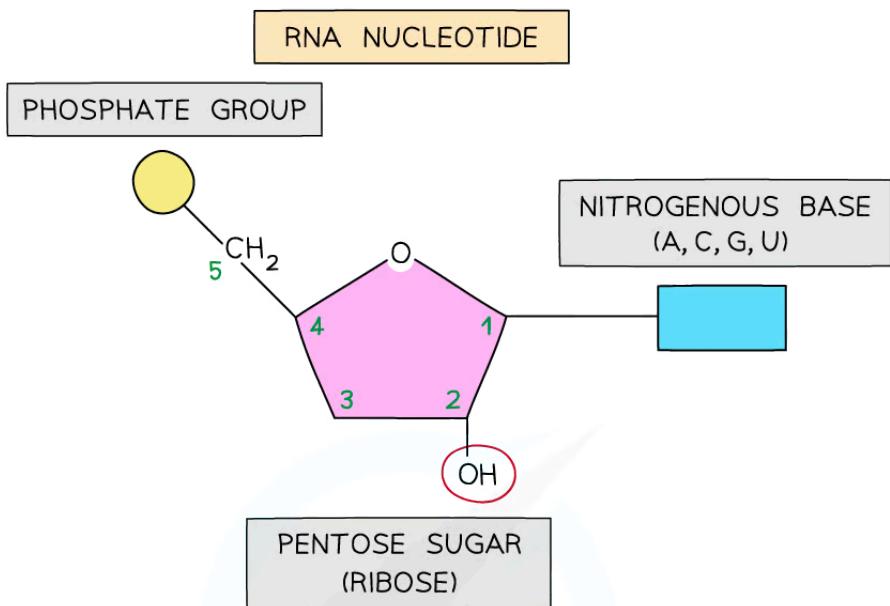
## 6.1.4 The Structure of RNA

### RNA Structure

- **Like DNA**, the nucleic acid RNA (ribonucleic acid) is a **polynucleotide** – it is made up of **many nucleotides** linked together in a **long chain**
- **Like DNA**, RNA nucleotides contain the nitrogenous bases adenine (A), guanine (G) and cytosine (C)
- **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)



Your notes


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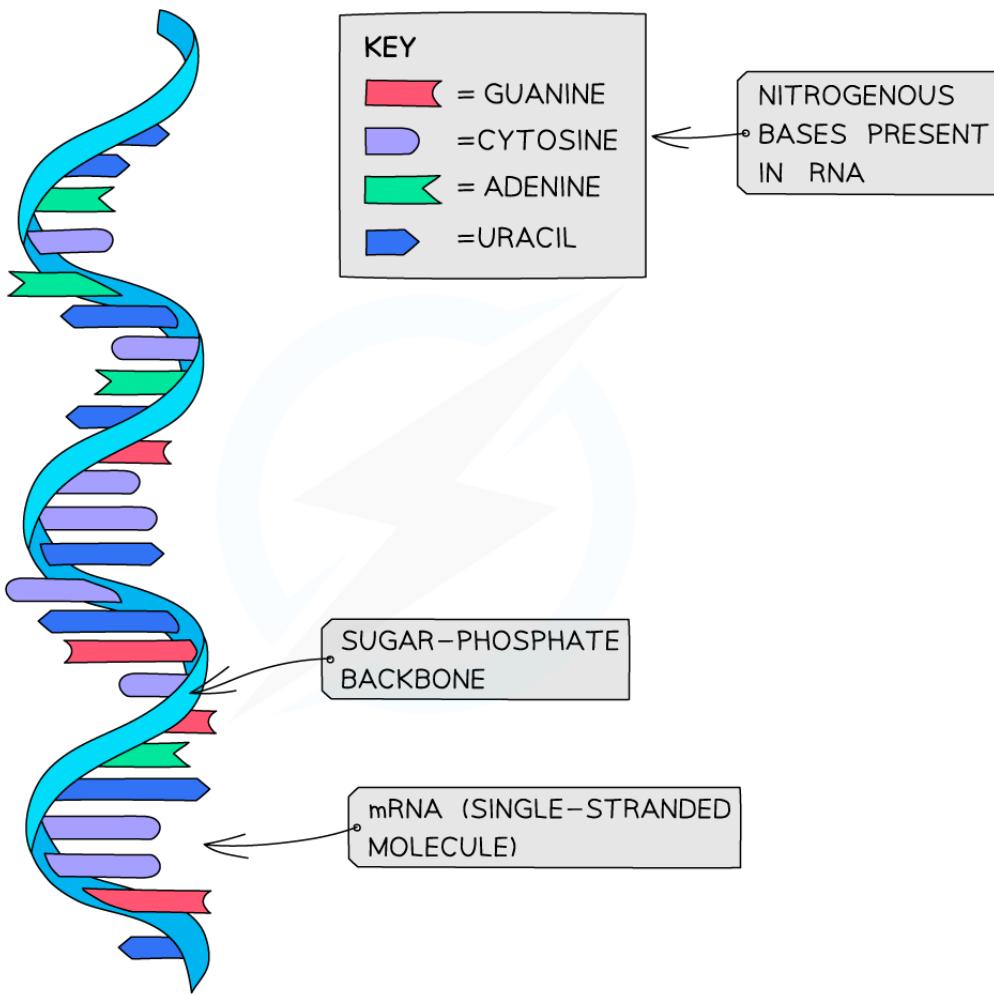
### An RNA nucleotide compared with a DNA nucleotide

- Unlike DNA, RNA molecules are only made up of **one polynucleotide strand** (they are single-stranded)
- Each RNA polynucleotide strand is made up of **alternating ribose sugars and phosphate groups linked together**, with the nitrogenous bases of each nucleotide projecting out sideways from the single-stranded RNA molecule

- The **sugar-phosphate bonds** (between different nucleotides in the same strand) are **covalent bonds** known as **phosphodiester bonds**
  - These bonds form what is known as the **sugar-phosphate backbone** of the RNA polynucleotide strand
  - The phosphodiester bonds link the **5-carbon of one ribose sugar** molecule to the phosphate group from the same nucleotide, which is itself linked by another phosphodiester bond to the **3-carbon of the ribose sugar molecule of the next nucleotide** in the strand
- An example of an RNA molecule is **messenger RNA (mRNA)**, which is the transcript copy of a gene that encodes a specific polypeptide. Two other examples are **transfer RNA (tRNA)** and **ribosomal RNA (rRNA)**



Your notes



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**Messenger RNA (mRNA) provides a good example of the structure of RNA**

 **Examiner Tip**

You need to know the difference between DNA and RNA molecules (bases, number of strands, pentose sugar present).

**Your notes**