

### Nucleotides

Both **DNA** and **RNA** are made up of **monomers** called **nucleotides**

Each nucleotide contains a **phosphate group**, a **nitrogen-containing** organic base, and a **pentose** (5-carbon) sugar: either **ribose** (RNA) or **deoxyribose** (DNA)

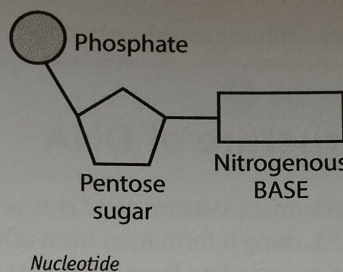
There are 2 groups of organic bases: **Pyrimidines** (single ring) and **purines** (double ring)

For **nitrogenous bases** found in DNA:

- Guanine (Purine)
- Cytosine (pyrimidine)
- Adenine (purine)
- Thymine (pyrimidine)

In **RNA** the pyrimidine **uracil** replaces **thymine**

### Nucleotide diagram

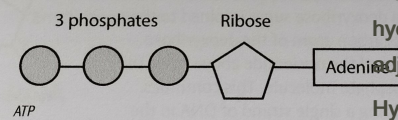


### ATP (cont)

When the **high-energy bond** between the **second** and **third phosphate** group is **broken** via **hydrolysis** by the enzyme **ATPase**, **30.6KJ** of energy is **released** for use in the cell, and **adenine diphosphate** is formed.

This reaction is **reversible**, requiring **energy** from **respiration** of **glucose** to **reform** the bond

### ATP Diagram



### Structure of DNA

DNA consists of **2 polynucleotide** strands that are **arranged** into a **double helix**.

First a **dinucleotide** is formed when a **condensation reaction** occurs between **2 nucleotides**:

The **5th carbon** atom of a **deoxyribose sugar** is joined to the **3rd carbon** atom of the **deoxyribose sugar** of the nucleotide above it, via the **phosphate molecule**.

This continues, building a **single strand** of DNA in the **5'-3' direction**.

DNA then forms a **double-stranded** molecule from **two strands**: one strand runs in the **opposite direction** to the other (**anti-parallel**).

### Structure of DNA (cont)

**Both strands** are held **together** by **hydrogen bonds** that form between **complimentary nitrogenous bases**.

The **double strand** then **twists** to form a **double helix**.

**Bases** between **both stands** pair up in a certain way which is called the **complementary base pairing rule**:

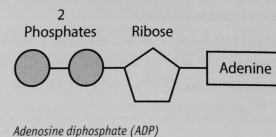
**Guanine** forms **hydrogen bonds** with an **adjacent cytosine** molecule and **adenine** forms **hydrogen bonds** with an **adjacent thymine** molecule.

**Hydrogen bonds** are **weak**, but the sheer number of them present in a **molecule of DNA** over a million **nucleotides** long, means that collectively they are **very strong**.

In fact you would need to **heat DNA** to **over 95 degrees C** to **break** them all.

### ADP Diagram

$ATP \rightarrow ADP + Pi + 30.6kJ \text{ energy}$   
(Pi = inorganic phosphate)



### Advantages and roles of ATP

Advantages of ATP:

Energy is **released quickly** from a **one-step reaction** involving just **one enzyme** (hydrolysis of glucose takes many steps)

### Advantages and roles of ATP (cont)

**Energy** is released in **small amounts**, **30.6KJ** where it is needed. By contrast just **one** molecule of **glucose** contains **1880KJ** which **couldn't safely** be released all at once.

It is the '**universal energy currency**', i.e. it's a common source of **energy** for all reactions in **all living things**.

Roles of ATP in cells:

Used in many **anabolic reactions**, e.g. **DNA** and **protein synthesis**

**Active transport**

**Muscle contraction**

**Nerve impulse transmission**

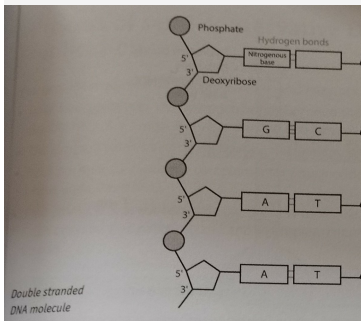
### Key Term

**Codon** The **triplet of bases** in **mRNA** that codes for a **particular amino acid**, or a **punctuation signal**.

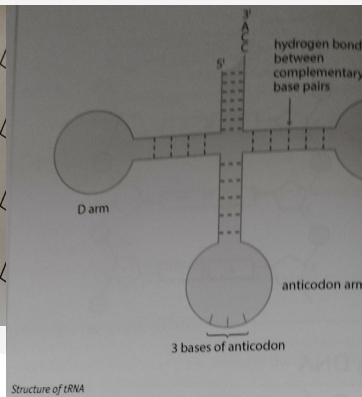
**Introns** **Non-coding** nucleotide sequence in **DNA** and **pre-mRNA**, that is **removed** from **pre-mRNA**, to produce **mature mRNA**.

**Exons** **Nucleotide** sequence on **one strand** of the **DNA molecule** and the **corresponding mRNA** that codes for the **production** of a **specific polypeptide**.

### Structure of DNA diagram



### Structure of tRNA



### Process of semi-conservative DNA replication

The process requires ATP, free nucleotides and enzymes.

- DNA helicase breaks the hydrogen bonds between the bases causing the double helix to unwind and separate into two strands.

- The exposed bases bind to free floating nucleotides in the nucleoplasm.

- DNA polymerase binds the complimentary nucleotides (forming the phosphodiester bond).

- One strand acts as the template for the new molecule, so newly synthesised DNA contains one parent strand and a complimentary newly synthesised strand.

### Functions of DNA

DNA has 2 main functions in organisms

1. **Protein synthesis** - the sequence of bases in one strand, called the **template strand**, determines the order of amino acids in the **polypeptide** (primary structure).

2. **Replication** - when cells divide, a complete copy of the DNA in the cell needs to be made. Both DNA strands separate and each strand acts as a **template** to synthesise a **complimentary strand**.

Three theories for how DNA replicates have been proposed:

### Functions of DNA (cont)

1. **Conservative replication:** original parent stranded molecule is **conserved**, and a **new double-stranded DNA** molecule **synthesised** from it.

2. **Semi-conservative** replication: **parental strands separate**, and each strands acts as a **template** to **synthesise** a new strand. The new molecule consists of one original parent strand and one newly synthesised strand.

3. **Dispersive:** the **newly synthesised** molecules contain **fragments** from the **original parent strand** and **newly synthesised** DNA.

### Key Term

Silent Mutation	A <b>change</b> in the <b>sequence</b> of nucleotide <b>bases</b> without a <b>subsequent change</b> in the <b>amino acid</b> .
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### Meselson-stahl experiment

1. Grow **bacteria** on a **<sup>15</sup>N** is a **heavy isotope** of nitrogen so all DNA produced would be a **heavier weight** than normal. When DNA was **extracted** by **centrifuging** in **caesium chloride**, the DNA band appeared **low down** in the tube.

### Extracting DNA

DNA can be **easily extracted** from cells by **grinding** up a sample in a solution of **ice cold salt** and **washing up liquid**.

The **detergent** dissolves the **lipids** in the **phospholipid membranes**, allowing **DNA** to be **released**, and the **cold temperature** protects the DNA from **cellular DNAases**.

**Addition** of **protease** will **digest** any remaining **cellular enzymes** and the **histones** that the DNA is wound around.

Finally, **adding ethanol** to the salt already present, will cause the DNA to **precipitate** out from the **solution**.

### Structure of RNA

**RNA** is usually **shorter** than **DNA** and **single-stranded**.

**Nucleotides** also differ in that the **sugar** is **ribose**, the one base **thymine** replaced with **uracil**.

**Three** different types of RNA are involved in **protein synthesis**.

### Types of RNA

**mRNA** **Messenger RNA** is a **single-stranded** molecule typically **300-2000** nucleotides long. It is **produced** in the **nucleus** using one of the **DNA strands** as a **template** during **transcription**.

**rRNA** **Ribosomal RNA** forms **ribosomes** with the **addition** of **protein**.

**tRNA** **Transfer RNA** is a **small molecule** that winds itself into a **cloverleaf** shape. It has an **anticodon** at one end, and an **amino acid** at the other. As the name suggests, it **'transfers'** the correct amino acid to the **growing polypeptide** during **translation**.

### Meselson-stahl experiment (cont)

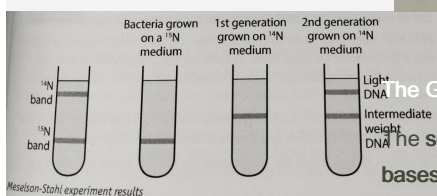
2. **Bacteria** were then grown on a  **$^{14}\text{N}$  medium** (normal weight nitrogen), and after **one generation** the DNA extracted formed an **intermediate band** half way up the tube. This is because the DNA molecule contained **one strand** from the **heavy parent** and **one newly synthesised light** DNA strand. (Because one band was produced this **rules out conservative replication**).

3. The **bacteria** were grown for a **further generation** using  **$^{14}\text{N}$  medium**. The DNA extracted formed an **intermediate band** half way up the tube, and a **lighter band** towards the top of the tube. Because **half** of the DNA was **intermediate weight** and **half light**, this rules out **dispersive replication**.

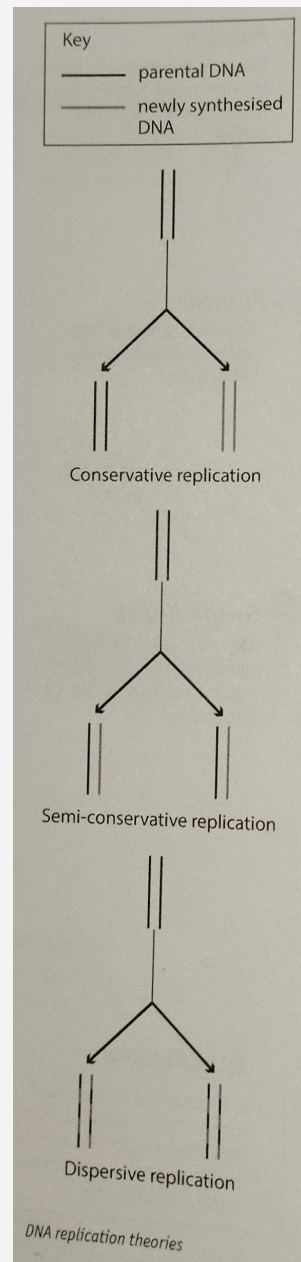
4. DNA therefore **replicates semi-conservatively**.

5. If grown for **further generations** using  **$^{14}\text{N}$  medium**, whilst **intermediate weight** DNA would remain, the **proportion of light DNA** produced would **increase**.

### Meselson-stahl experiment diagram



### DNA replication theories



### The Genetic code

the sequence of nucleotide bases forms a code.

Each **'code word'** has 3 letters called a **triplet code** or **codon**, which codes for a **specific amino acid**.

### Genetic code examples:

DNA codon	mRNA codon	Amino acid that is coded for	Amino acid
GGG	CCC	Proline	Pro
CGG	GCC	Glycine	Gly
ATG	UAC	Tyrosine	Tyr
TAC	AUG	Methionine	Met
ACT	UGA	Stop	

### The Genetic code part 2

There are **20 amino acids** that are coded by **4 power 3 bases**, i.e. **64 different combinations** of **A, G, C, T(U)**.

Therefore, there are **'spare' base codes**.

This is referred to as **degeneracy** or the **'degenerate code'**.

This code is **universal**, i.e. it is the **same in all living things**.

One **codon** acts as a **START** codon, marking the point on the **DNA** where **transcription** begins - this is **AUG** on the **mRNA** and codes for **methionine**.

**Each gene** found on the DNA will code for a **different polypeptide**: this is called the **one gene, one polypeptide hypothesis**.

### Post-translational modification

**Translation** produces a **polypeptide**, but **further modification** is needed in order to **produce a protein** with a **secondary, tertiary or quaternary structure**.

### Post-translational modification (cont)

This **modification** occurs within **abbrev Golgi body**.

**Modification** also occurs to **produce molecules** such as **glycoproteins, lipoproteins, and complex quaternary structures** such as **haemoglobin**.

To form **haemoglobin**, **2 alpha chains** and **2 beta chains** (coded by 2 different genes) need to be assembled together with **iron** as a **prosthetic group**.

### Protein Synthesis

**Transcription** occurs in the **nucleus**.

**Translation** occurs at the **ribosomes**.

**Post-translational modification** occurs in the **Golgi apparatus** prior to **packaging** of the **protein** into **vesicles**.

### Transcription

**DNA** acts as a **template** for the **production of mRNA**.

**DNA helicase** acts on a **specific region** of the DNA molecule called the **cistron**, **breaking** the **hydrogen bonds** between both **DNA strands**, causing the strands to **separate** and **unwind**, exposing **nucleotide bases**.

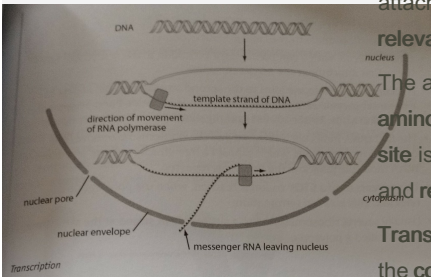
### Transcription (cont)

Free RNA nucleotide pair to exposed bases on the DNA template strand and RNA polymerase joins them by forming the phosphodiester bonds between the phosphate group on one nucleotide and the ribose sugar on the next.

This continues until the RNA polymerase reaches a STOP codon, when the RNA polymerase detaches and production of mRNA is complete.

The mRNA strand leaves the nucleus via the nuclear pores and moves to the ribosomes.

### Transcription diagram



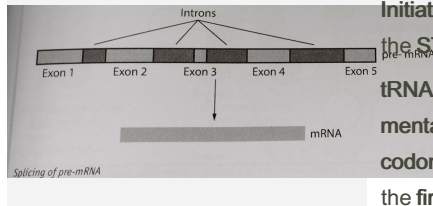
### Introns and Exons

In eukaryotes, introns are present within many genes so are also transcribed producing pre-mRNA.

The coding regions are referred to as exons.

The pre-mRNA is spliced to remove the non-coding regions before passing to the ribosomes. In prokaryotes, the DNA does not contain introns, and so the mRNA is produced directly from the DNA template.

### Splicing of pre-mRNA



### Translation

Involves another specific RNA molecule called transfer RNA (tRNA).

At one end of the tRNA molecule there are 3 exposed bases called the anticodon, these are complimentary to the mRNA codon.

At the opposite end of the tRNA molecule is an amino acid attachment site where the relevant amino acid is found.

The attachment of the relevant amino acid to the attachment site is called amino acid aviation and requires ATP.

Translation involves converting the codons on the mRNA into a sequence of amino acids known as a polypeptide.

Each ribosome (found free in the cytoplasm, or attached to the rough endoplasmic reticulum) is made up of 2 subunits made from ribosomal RNA and protein.

The mRNA binds to the smaller subunit, whilst tRNA to one of 2 attachment sites on the larger subunit.

### The process of translation

**Initiation:** ribosome attaches to the START codon. tRNA molecule with a complimentary anticodon to the first codon, binds to the first attachment site on the ribosome.

A second tRNA molecule joins to the second attachment site, and a ribosomal enzyme catalyses the formation of a peptide bond between the 2 amino acids. This is known as elongation.

The first tRNA molecule is released and the ribosome now moves one codon along the mRNA, which exposes a free attachment site and another tRNA molecule joins and the process is repeated.

This repeats until a STOP codon is reached, when the polypeptide is released. This is called termination.

Usually several ribosomes bind to a single mRNA strand at the same time. This is called a polysome.

### Translation Diagram

