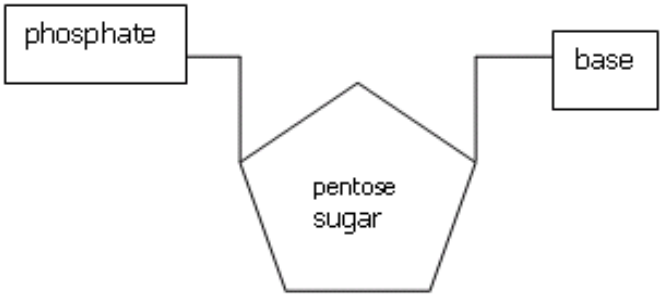
CAIE Biology A-level

Topic 6: Nucleic acids and protein synthesis

Notes

DNA and Protein Synthesis



Both **DNA** and **RNA** carry genetic information. DNA holds genetic information, whereas RNA transfers this genetic information from DNA to **ribosomes** (which are made of RNA and proteins). Both deoxyribonucleic and ribonucleic acid are **polymers of nucleotides**.

Nucleotides consist of **pentose** (a five-carbon sugar), a nitrogen-containing **organic base** and a **phosphate group**:

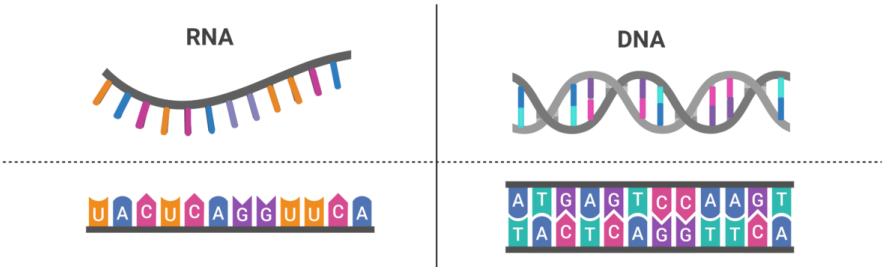
- The components of a **DNA** nucleotide are **deoxyribose, a phosphate group and one of these organic bases; adenine, cytosine, guanine or thymine.**
- The components of an **RNA** nucleotide are **ribose, a phosphate group and one of these organic bases; adenine, cytosine, guanine or uracil**.
- Adenine and guanine both have a double-ring structure and are classified as **purine** bases. Uracil, thymine and cytosine have a single-ring structure and are classified as **pyrimidines**. Uracil is found only in RNA, whereas thymine is found only in DNA.
- Nucleotides join together by **phosphodiester bonds** formed in **condensation reactions**.

DNA structure

- A **double helix** composed of two polynucleotides joined together by hydrogen **bonds** between complementary bases.
- In DNA the two strands lie **antiparallel** and complementary base pairing takes place between the **5' → 3'** strand and the **3' → 5'** strand.
- A purine always joins to a pyrimidine base.
- Depending on the bases involved, different numbers of hydrogen bonds are formed.
  - **adenine and thymine** join together by **two** hydrogen bonds
  - **cytosine and guanine** join together by **three** hydrogen bonds.
- Nucleotides are joined together by phosphodiester bonds.

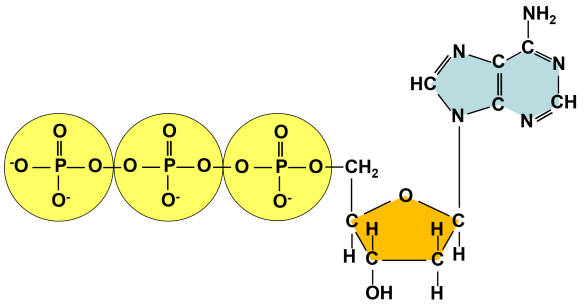
RNA structure

- **RNA is a relatively short, single-stranded polynucleotide chain.**
- An RNA nucleotide consists of **ribose** instead of deoxyribose, a **phosphate group and one of the organic bases adenine, cytosine, guanine and uracil** (instead of thymine).



ATP structure

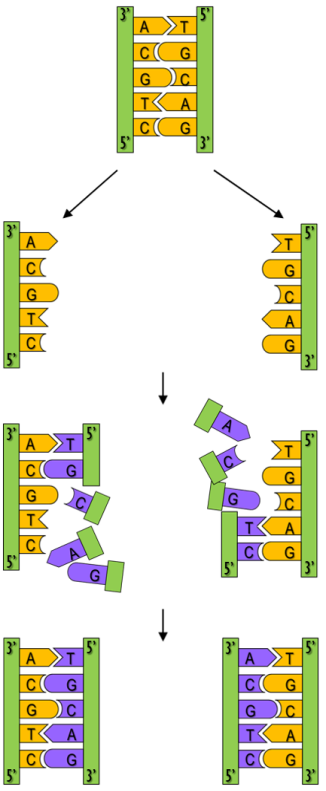
- **ATP is a phosphorylated nucleotide that is different from a DNA or RNA nucleotide.**
- ATP contains **3 phosphate groups**, a pentose (**ribose**) sugar, and a specific nitrogen-containing base (**adenine**).



DNA replication

The **semi-conservative replication** of DNA ensures genetic continuity between generations of cells, meaning that genetic information is passed on from one generation to the next. DNA replication occurs during the S phase of the cell cycle.

The steps of semi-conservative replication of DNA are as follows:



- The **double helix unwinds** and the **hydrogen bonds between the complementary bases are broken** by **DNA helicase,** thus separating the two strands of DNA.
- One of the strands is used as the **template** and **complementary base pairing occurs** between the template strand and **free nucleotides.**
- Adjacent nucleotides are joined by **phosphodiester bonds** formed in condensation reactions using **DNA polymerase.**

DNA polymerase only works in the **5' → 3' direction,** meaning it can only add nucleotides **to the 3' end of the growing strand.**

- **The leading strand** is replicated **continuously** in the **5' to 3' direction.**
- The second strand which is called the **lagging strand,** is replicated **discontinuously** in the **5' to 3' direction.** This means it is replicated in short sections forming **Okazaki fragments.**
- The Okazaki fragments are joined together with **DNA ligase.**

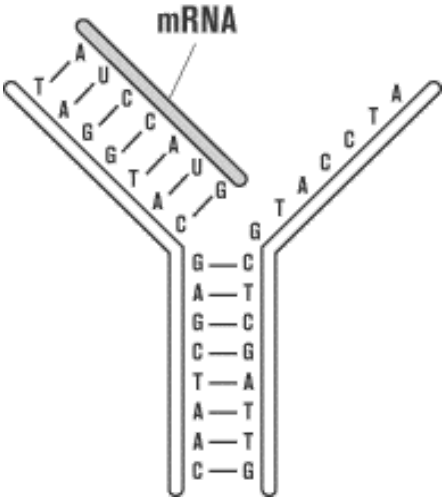
Protein synthesis

Proteins are **polypeptide chains**, coded for by a gene.

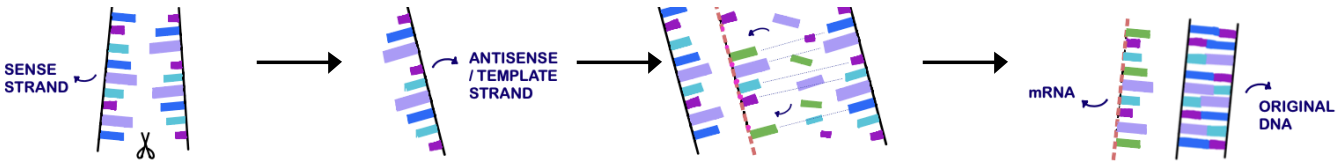
- A gene is a sequence of nucleotides that forms part of a DNA molecule and codes for a polypeptide.
- The genetic code is **universal** and the sequence of bases determines which protein the gene is coding for.
- The **triplet code** is the sequence of 3 nucleotides which code for either an **amino acid, start codon or stop codon.**

There are two stages of protein synthesis: **transcription**, which occurs in the nucleus and involves **DNA and mRNA**, and **translation**, which involves **mRNA, tRNA and ribosomes**. During transcription, a DNA strand is transcribed into mRNA and translation is the process during which the amino acids are assembled together to form a polypeptide chain/protein.

Transcription:
During transcription, a molecule of mRNA is made in the nucleus:



- **RNA polymerase** causes the DNA to unwind and the **hydrogen bonds** between complementary bases to break, separating the two strands.
- One of the DNA strands is used as a **template** to make the mRNA molecule - this is called the **template or transcribed strand.**
- **Free nucleotides** bind to the exposed bases via **complementary base pairing** until a termination sequence is reached.
- Adjacent nucleotides are joined by phosphodiester bonds, forming mRNA - this is done by **RNA polymerase.**
- mRNA detaches from DNA and moves out of the nucleus through a **pore.** The mRNA molecule attaches to a **ribosome** in the cytoplasm for the next stage (**translation**).



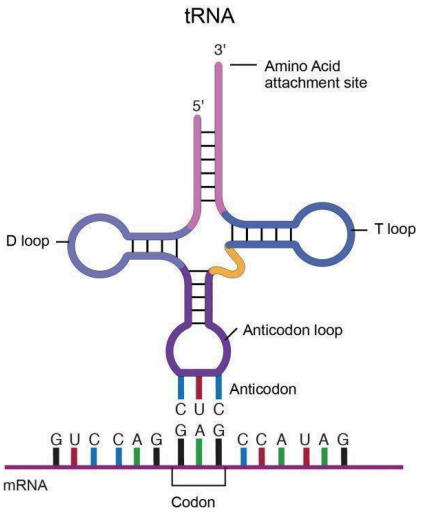
In eukaryotic cells, the RNA molecule formed from transcription is called the **primary transcript (pre-mRNA).** This is then modified by;

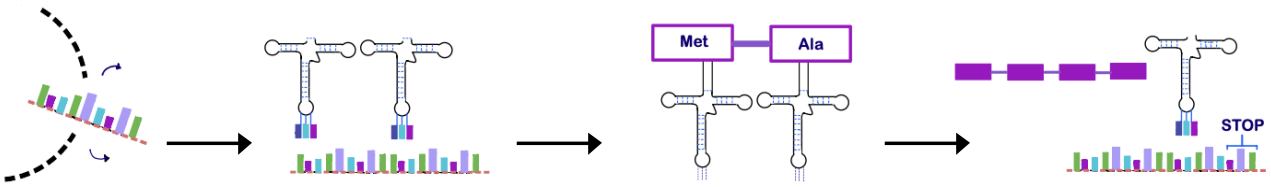
- Removal of non-coding sequences called **introns**
- Joining together coding sequences called **exons**
- This forms **mRNA**

Translation:

During translation, amino acids join together to form a polypeptide chain. Translation occurs on ribosomes in the cytoplasm.

- **mRNA** attaches to a subunit of a ribosome at the start codon. **Transfer RNA** is a type of RNA. It has an anticodon on one end and an amino acid bonded to the other, which is carried to the ribosome.
- The **anticodon of the tRNA** binds itself to the first codon on the mRNA by **complementary base pairing.**
- Another tRNA molecule binds to the second codon of the mRNA. The amino acids attached to the tRNA join by a **peptide bond** and then the **tRNA molecules detach,** leaving the amino acids behind on the growing polypeptide chain.
- This process is repeated, leading to the formation of a **polypeptide chain** until a **stop codon** is reached on the mRNA, ending the process of protein synthesis.





Gene mutations

A gene mutation occurs when the **base sequence of DNA is altered**. If the DNA sequence is altered, this change is replicated in the mRNA chain and thus can result in an **altered polypeptide chain**. Gene mutations are caused by **mutagenic agents** such as chemicals and ionising radiation.

Mutations are a result of:

- **Substitution** - when 1 or more nucleotides are substituted by another in the DNA strand
- **Insertion** - when 1 or more nucleotides are inserted into the DNA strand
- **Deletion** - when 1 or more nucleotides are deleted in the DNA strand

Effects of mutations:

- **Nonsense** - a mutation resulting in a stop codon hence no polypeptide chain will be formed
- **Missense** - a mutation resulting in a different amino acid being coded for hence changing the polypeptide chain
- **Silent** - a mutation resulting in a different codon, however it still codes for the same amino acid meaning the polypeptide chain produced is the same
- **Frameshift** - insertions and deletions can cause a frameshift which alters every subsequent triplet/codon in the sequence