Edexcel International AS Biology

Your notes

DNA & Gene Expression

Contents

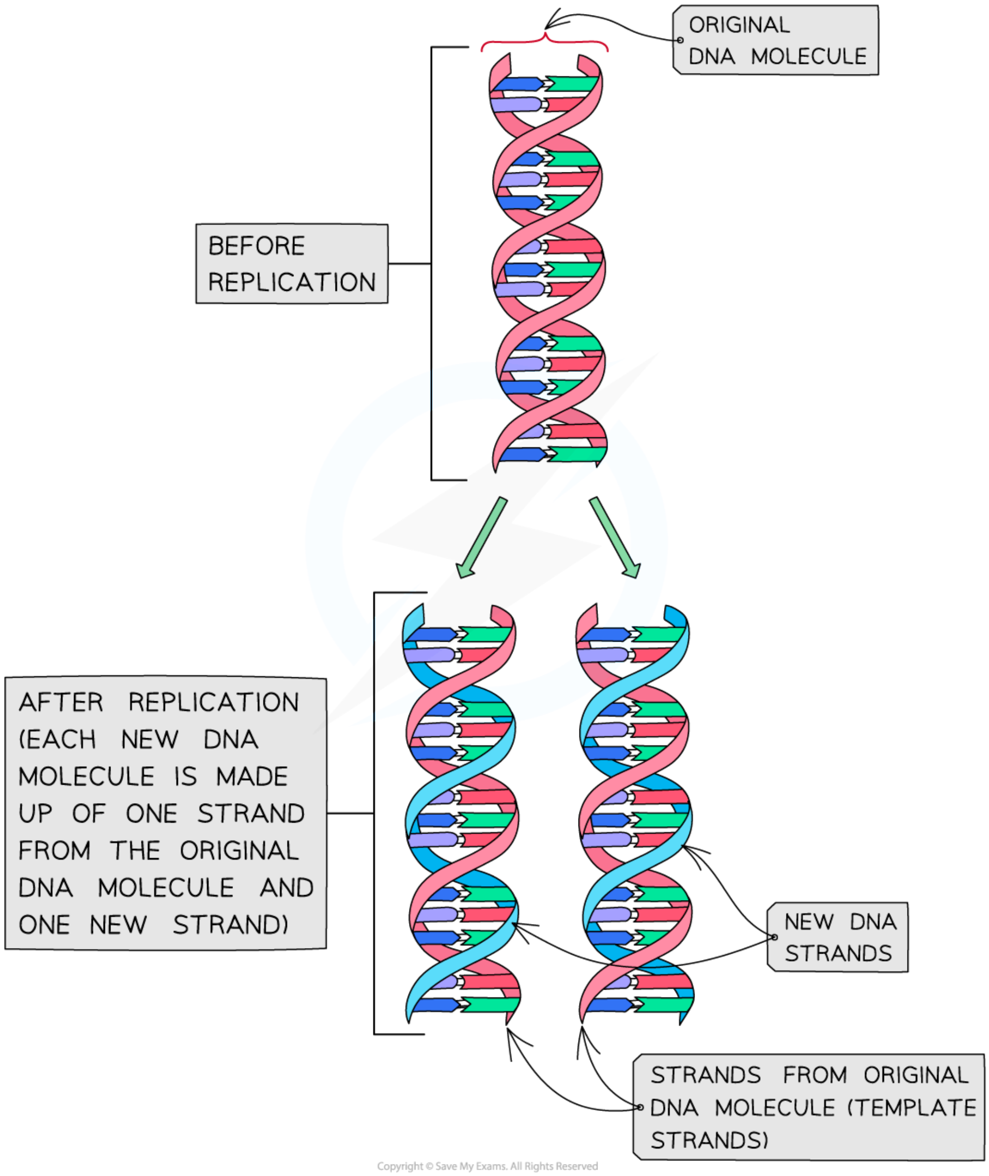
Your notes

DNA Replication

- Before a (parent) cell divides, it needs to **copy the DNA** contained within it
- **Doubling the DNA** ensures that the two new (daughter) cells produced will both receive **full copies of the parental DNA**
- The DNA is copied via a process known as **semi-conservative replication** (semi = half)
- The process is called this because in each new DNA molecule produced, one of the polynucleotide DNA strands (half of the new DNA molecule) is from the **original DNA** molecule being copied
- The other polynucleotide DNA strand (the other half of the new DNA molecule) has to be **newly created** by the cell
- Therefore, the **new DNA molecule has conserved half of the original DNA and then used this to create a new strand**

The importance of retaining one original DNA strand

- It **ensures** there is **genetic continuity** between generations of cells
- In other words, it ensures that the new cells produced during cell division **inherit all their genes** from their parent cells
- This is important because cells in our body are **replaced regularly** and therefore we need the new cells to be able to do the same role as the old ones
  - Replication of DNA and cell division also occurs during **growth**



Semi conservative replication of DNA

Semi-conservative replication

- DNA replication occurs in preparation for mitosis, 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 enzyme **helicase unwinds** the DNA double helix by breaking the **hydrogen bonds** between the base pairs on the two antiparallel polynucleotide DNA strands 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** made from free nucleotides that are attracted to the exposed DNA bases by **base pairing**

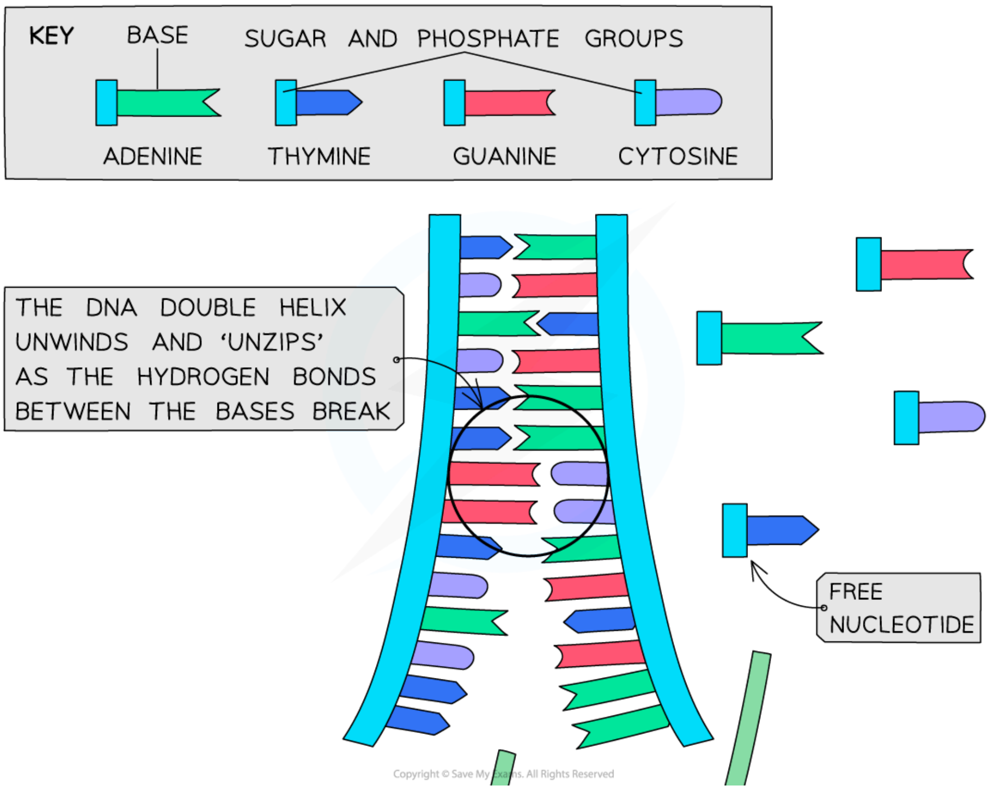
Your notes

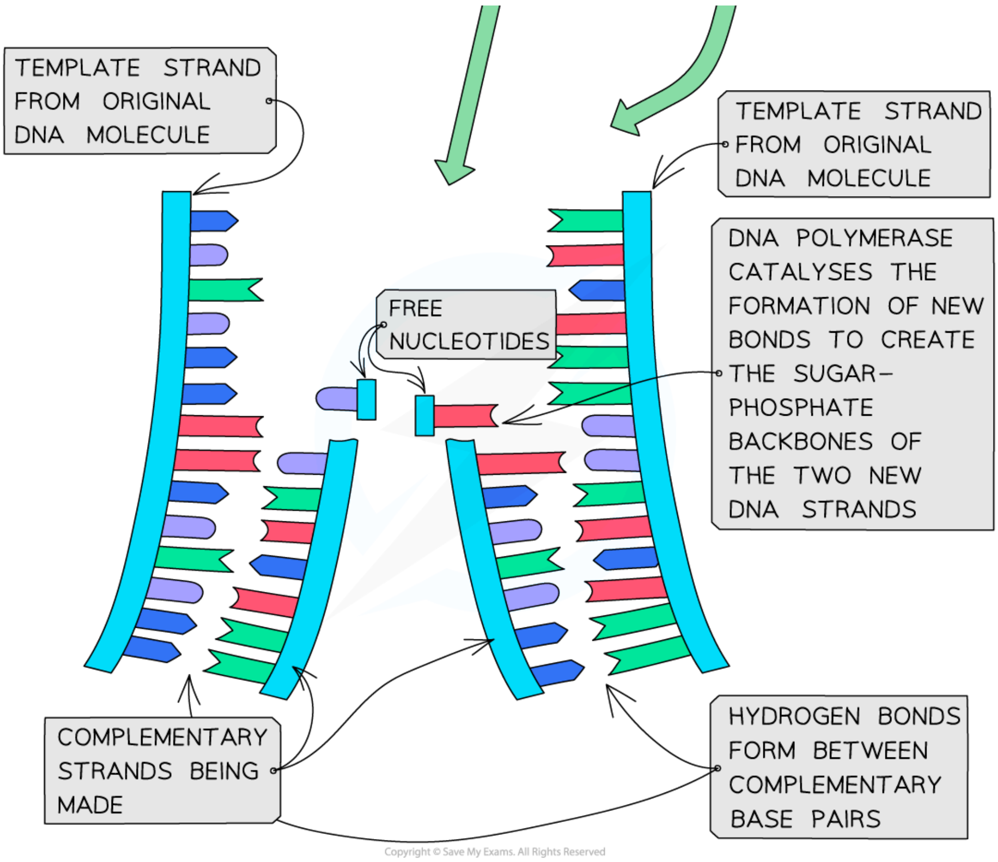
- The new nucleotides are then **joined together** by the enzyme DNA polymerase
- The original strand and the new strand join together through hydrogen bonding between base pairs to form the new DNA molecule
- This method of replicating DNA is known as **semi-conservative replication** because **half of the original** DNA molecule is kept (**conserved**) in each of the two new DNA molecules

Your notes

DNA Polymerase

- In the nucleus, there are **free nucleotides** which contain three phosphate groups
  - These nucleotides 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


KEY
BASE
SUGAR AND PHOSPHATE GROUPS
ADENINE
THYMINE
GUANINE
CYTOSINE
THE DNA DOUBLE HELIX UNWINDS AND 'UNZIPS' AS THE HYDROGEN BONDS BETWEEN THE BASES BREAK
FREE NUCLEOTIDE
Copyright © Save My Exams. All Rights Reserved


TEMPLATE STRAND FROM ORIGINAL DNA MOLECULE
TEMPLATE STRAND FROM ORIGINAL DNA MOLECULE
FREE NUCLEOTIDES
DNA POLYMERASE CATALYSES THE FORMATION OF NEW BONDS TO CREATE THE SUGAR–PHOSPHATE BACKBONES OF THE TWO NEW DNA STRANDS
COMPLEMENTARY STRANDS BEING MADE
HYDROGEN BONDS FORM BETWEEN COMPLEMENTARY BASE PAIRS
Copyright © Save My Exams. All Rights Reserved

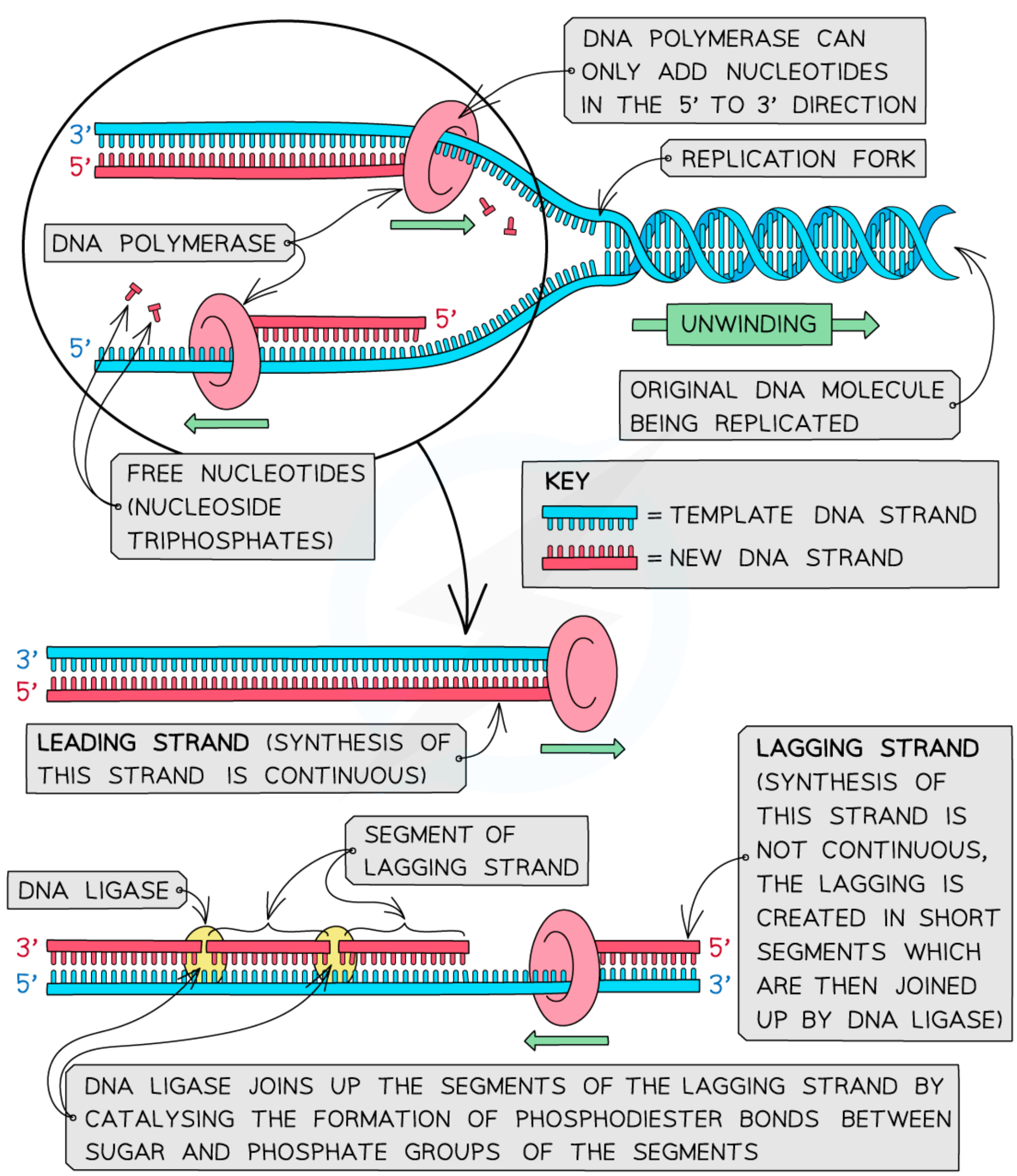
Your notes

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

Your notes

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)
- 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 complimentary strand occurs differently on the leading and lagging strands of DNA

Your notes

Evidence for Semi-Conservative Replication

- Scientists were unsure if DNA replication was conservative or semi-conservative
- Two scientists called **Matthew Meselson** and **Franklin Stahl**, showed that DNA replication was semi-conservative by experimenting with isotopes of nitrogen

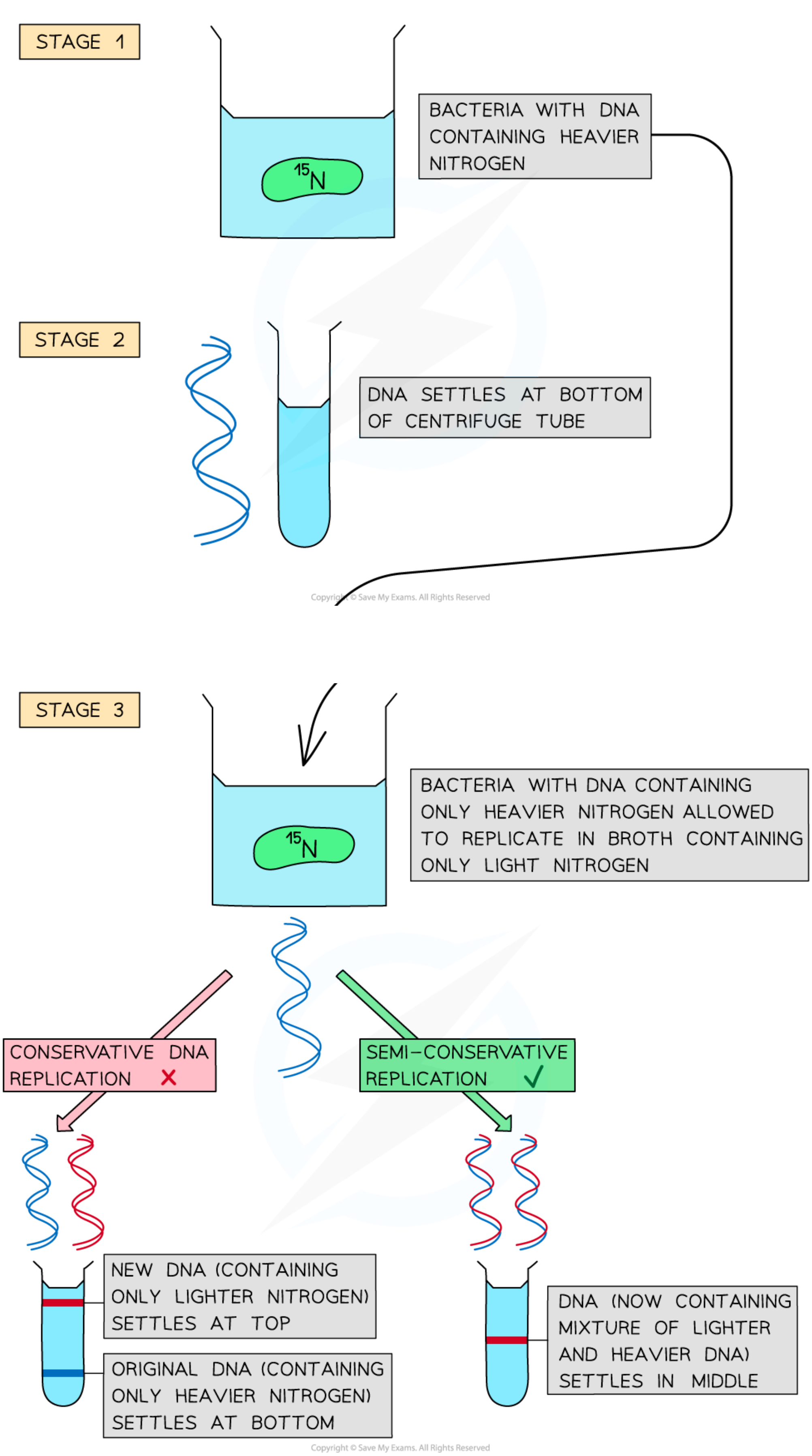
Meselson and Stahl's Experiment

- Bacteria were grown in a broth containing the **heavy (^{15}N) nitrogen isotope**
    - DNA contains nitrogen in its bases

- As the bacteria replicated, they used nitrogen from the broth to make **new DNA nucleotides**
- After some time, the culture of bacteria had DNA containing **only heavy (^{15}N) nitrogen**

- A sample of **DNA** from the ^{15}N culture of bacteria was extracted and **spun in a centrifuge**
  - This showed that the DNA containing the heavy nitrogen settled near the bottom of the centrifuge tube
- The bacteria containing only ^{15}N DNA were then taken out of the ^{15}N broth and added to a broth containing **only the lighter ^{14}N nitrogen**. The bacteria were left for enough time for **one round of DNA replication** to occur before their DNA was extracted and **spun in a centrifuge**
  - If **conservative DNA replication** had occurred, the original template DNA molecules would only contain the heavier nitrogen and would settle at the bottom of the tube, whilst the new DNA molecules would only contain the lighter nitrogen and would settle at the top of the tube
  - If **semi-conservative replication** had occurred, **all** the DNA molecules would now contain **both** the **heavy ^{15}N** and **light ^{14}N** nitrogen and would therefore settle in the **middle of the tube** (one strand of each DNA molecule would be from the original DNA containing the heavier nitrogen and the other (new) strand would be made using only the lighter nitrogen)
- Meselson and Stahl confirmed that the bacterial DNA had undergone **semi-conservative replication**.
  - The DNA from this second round of centrifugation settled in the middle of the tube, showing that each DNA molecule contained a **mixture** of the **heavier and lighter nitrogen isotopes**
  - If more rounds of replication were allowed to take place, the **ratio of ^{15}N:^{14}N** would go from 1:1 after the first round of replication, to 3:1 after the second and 7:1 after the third

Your notes


STAGE 1
15N
BACTERIA WITH DNA CONTAINING HEAVIER NITROGEN
STAGE 2
DNA SETTLES AT BOTTOM OF CENTRIFUGE TUBE
Copyright © Save My Exams. All Rights Reserved
STAGE 3
15N
BACTERIA WITH DNA CONTAINING ONLY HEAVIER NITROGEN ALLOWED TO REPLICATE IN BROTH CONTAINING ONLY LIGHT NITROGEN
CONSERVATIVE DNA REPLICATION ✗
SEMI-CONSERVATIVE REPLICATION ✓
NEW DNA (CONTAINING ONLY LIGHTER NITROGEN) SETTLES AT TOP
ORIGINAL DNA (CONTAINING ONLY HEAVIER NITROGEN) SETTLES AT BOTTOM
DNA (NOW CONTAINING MIXTURE OF LIGHTER AND HEAVIER DNA) SETTLES IN MIDDLE
Copyright © Save My Exams. All Rights Reserved

Meselson and Stahl's experiment that showed bacterial DNA replicated via semi-conservative DNA replication

The Nature of the Genetic Code

The triplet code

- The sequence of DNA nucleotide bases found within a gene is determined by a **triplet** (three-letter) **code**
- Each sequence of **three bases** (i.e. each triplet of bases) in a gene codes for **one amino acid**
- These **triplets codes for different amino acids** – there are 20 different amino acids that cells use to make up different proteins
- For example:
    - CAG codes for the amino acid valine
    - TTC codes for the amino acid lysine
    - GAC codes for the amino acid leucine
    - CCG codes for the amino acid glycine
- Some of these triplets of bases code for **start** (AUG – methionine) **and stop signals**
- These start and stop signals **tell the cell where individual genes start and stop**
- As a result, the cell **reads the DNA correctly** and **produces the correct sequences of amino acids** (and therefore the correct protein molecules) that it requires to function properly

The genetic code is non-overlapping

- The non-overlapping nature of the genetic code means that each base is **only read once**
- **The adjacent codons do not overlap**
- A non-overlapping code means that the same letter is not used for two different codons; in other words, no single base can take part in the formation of more than one codon

The genetic code is degenerate

- There are **four bases**, so there are **64** different codons (triplets) possible ($4^3 = 64$), yet there are only 20 amino acids that commonly occur in biological proteins
    - This is why the code is said to be **degenerate**: multiple codons can code for the same amino acids
    - The degenerate nature of the genetic code can **limit** the effect of **mutations**

SECOND LETTER

FIRST LETTER	U	C	A	G	THIRD LETTER
U	UUU UUC Phe UUA UUG Leu	UCU UCC UCA Ser UCG	UAU UAC Tyr UAA Stop UAG Stop	UGU UGC Cys UGA Stop UGG Trp	U C A G
C	CUU CUC CUA Leu CUG	CCU CCC CCA CCG Pro	CAU His CAC CAA CAG Gln	CGU CGC CGA CGG Arg	U C A G
A	AUU AUC Ile AUA AUG Met	ACU ACC ACA Thr ACG	AAU AAC Asn AAA AAG Lys	AGU AGC Ser AGA AGG Arg	U C A G
G	GUU GUC GUA Val GUG	GCU GCC GCA Ala GCG	GAU GAC Asp GAA GAG Glu	GGU GGC GGA Gly GGG	U C A G

The mRNA codons and their amino acids, showing the degenerate nature of the genetic code

The genetic code is universal

- The genetic code is also **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 (the transfer of genes from one species to another) is possible

Examiner Tips and Tricks

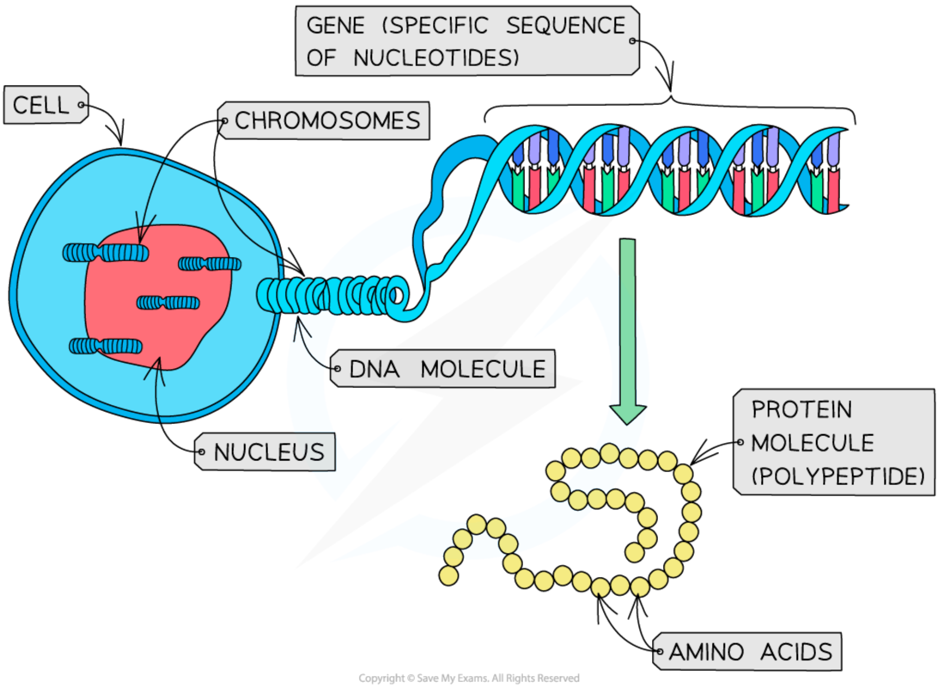
You will not be required to memorise specific codons and the amino acids for which they code.

Your notes

Your notes

Crick's Central Dogma

- A **gene** is a **sequence of nucleotides** that forms part of a DNA molecule (one DNA molecule contains many genes)
- This sequence of nucleotides (the gene) **codes for the production of a specific polypeptide** (protein)
- Protein molecules are made up of a series of **amino acids** bonded together
- The **shape** and **behaviour** of a protein molecule depends on the **exact sequence** of these amino acids (the initial sequence of amino acids is known as the **primary structure** of the protein molecule)
- The **genes in DNA molecules, therefore, control protein structure** (and as a result, protein function) as **they determine the exact sequence in which the amino acids join together** when proteins are synthesised in a cell



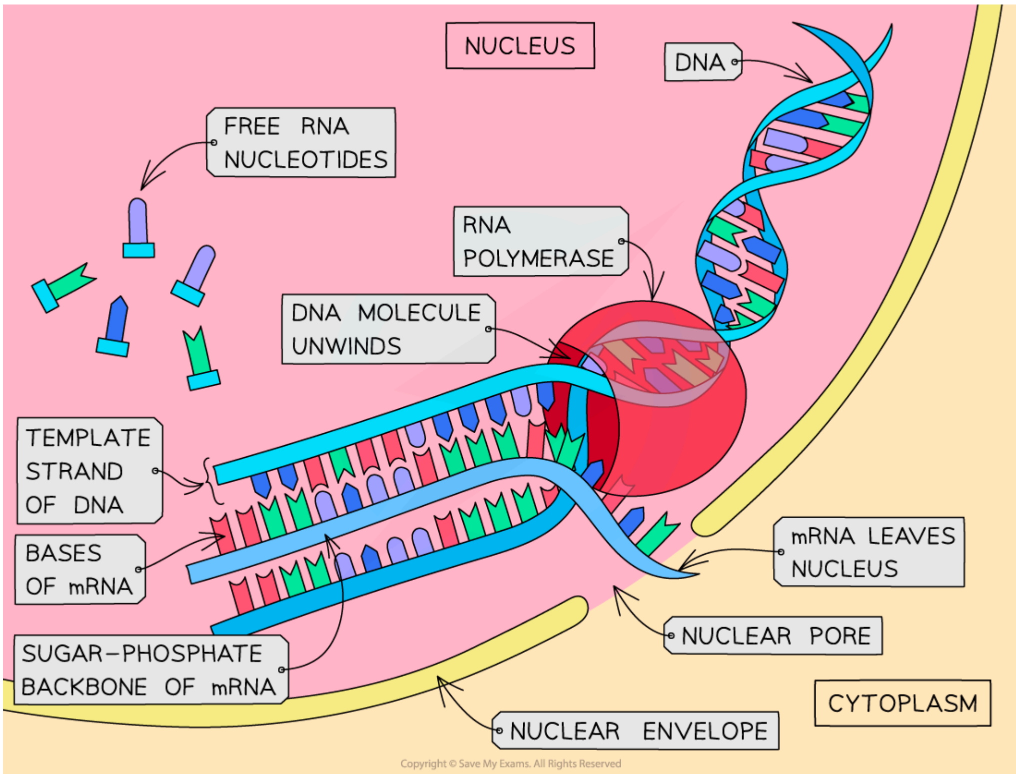
A gene is a sequence of nucleotides that codes for the production of a specific protein molecule (polypeptide)

Transcription

- A **gene** is a **sequence of nucleotide bases** in a DNA molecule that **codes for the production of a specific sequence of amino acids**, that in turn make up a **specific polypeptide** (**protein**)
- This process of protein synthesis occurs in **two stages**:
  - **Transcription** – **DNA** is transcribed and an **mRNA** (messenger RNA) molecule is produced
  - **Translation** – **mRNA** is translated and an **amino acid sequence** is produced
    - mRNA is a single-stranded molecule made up of many **RNA nucleotides** joined together
    - The role of mRNA is to carry the information encoded in the DNA from the nucleus to the site of translation on ribosomes

The process of transcription

- This stage of protein synthesis occurs in the **nucleus** of the cell
- Part of a DNA molecule unwinds and the hydrogen bonds between the complementary base pairs break
- This **exposes the gene to be transcribed** (the gene from which a particular polypeptide will be produced)
- A **complimentary** copy of the code from the gene is made by building a **single-stranded nucleic acid molecule known as mRNA**
  - This reaction is catalysed by **RNA polymerase**
- **Free activated RNA nucleotides** pair up, via hydrogen bonds, with their **complementary** bases on the exposed strand of the **'unzipped' DNA molecule**
- The sugar-phosphate groups of these RNA nucleotides are then bonded together in a reaction catalysed by the enzyme RNA polymerase to form the sugar-phosphate backbone of the mRNA molecule
- When the gene has been transcribed and the mRNA molecule is complete, the hydrogen bonds between the mRNA and DNA strands break and the **double-stranded DNA molecule reforms**
- The **mRNA molecule then leaves the nucleus** via a pore in the nuclear envelope

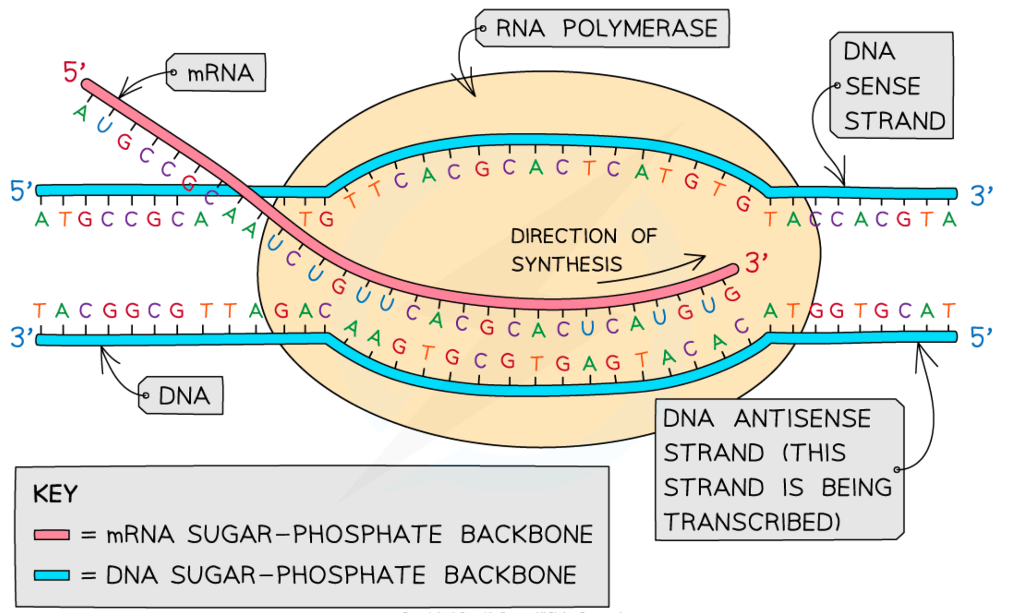


The transcription stage of protein synthesis - DNA is transcribed and an mRNA molecule is produced

Anti-sense and sense strands

- In the **transcription** stage of protein synthesis, free RNA nucleotides pair up with the exposed bases on the DNA molecule
- RNA nucleotides only pair with the bases on **one strand of the DNA molecule**
  - This strand of the DNA molecule is known as the **antisense** or **template strand** (or the **transcribed strand**) and it is used to produce the **mRNA molecule**
  - The other strand is known as the **sense** or **coding strand** (or the **non-template** or **non-transcribed strand**)
- **RNA polymerase** moves along the template strand in the **3' to 5' direction**
  - This means that the **mRNA** molecule grows in the **5' to 3' direction**
- Because the mRNA is formed by complementary pairing with the DNA template strand, the mRNA molecule contains the **exact same sequence of nucleotides** as the DNA **coding strand** (although the mRNA will contain **uracil** instead of **thymine**)

Your notes



The antisense strand of DNA is the one that is transcribed into mRNA

Examiner Tips and Tricks

Be careful – **DNA** polymerase is the enzyme involved in DNA replication; **RNA** polymerase is the enzyme involved in **transcription** – don't get these confused.

Note the use of **sense** and **anti-sense strands** in transcription can be replaced with non-transcribed and transcribed/template strands respectively.

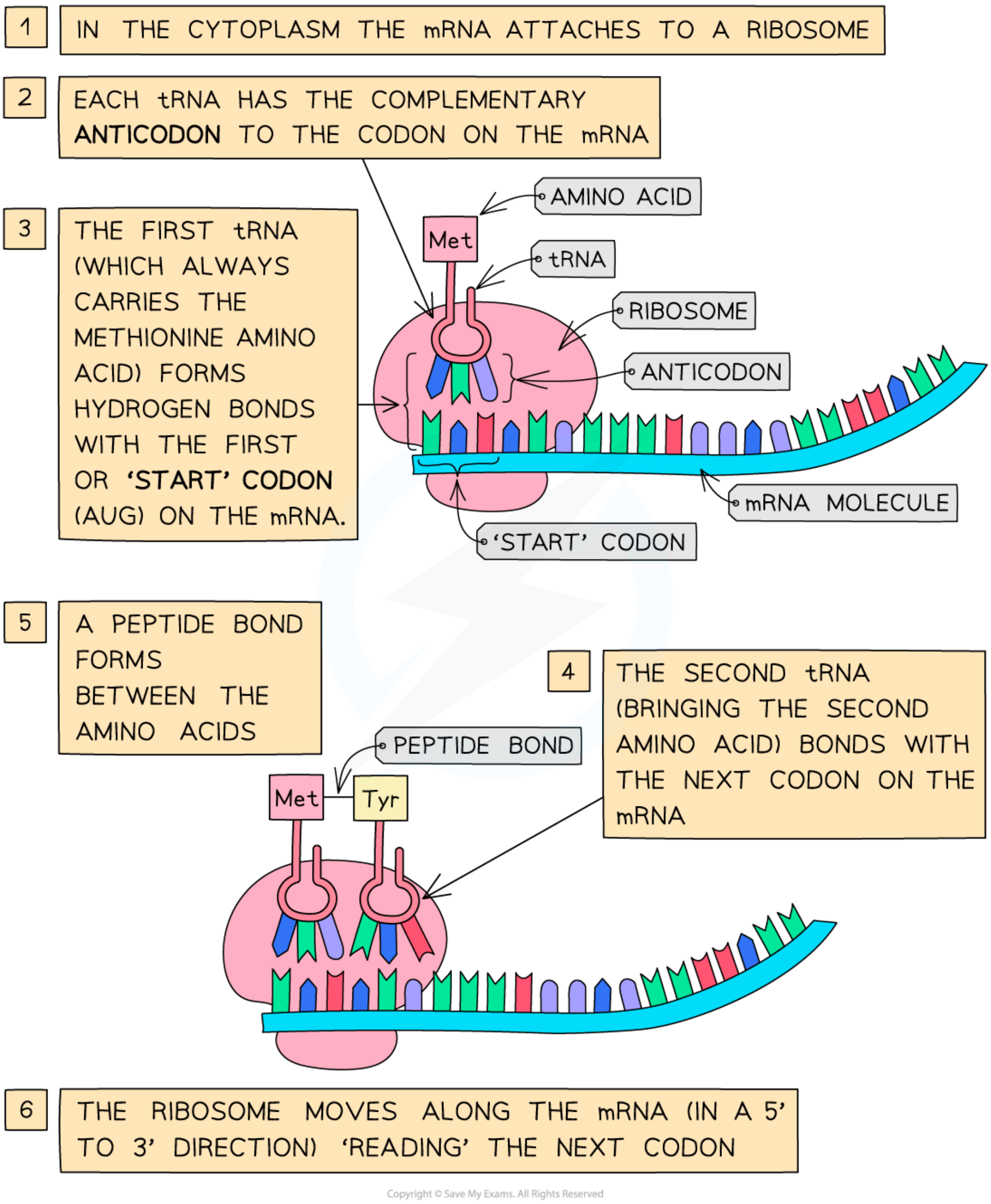
The mRNA strand will have the same base sequence as the sense strand **except** on RNA the base **U**racil replaces **T**hymine from the DNA strand.

Translation

- Translation occurs **in the cytoplasm** of the cell
- After leaving the nucleus via a nuclear pore, the **mRNA molecule attaches to a ribosome**
- In the cytoplasm there are **free molecules of tRNA** (transfer RNA)
  - tRNA is a single stranded molecule of RNA that folds into a clover-like structure
  - tRNA molecules have a **triplet of unpaired bases at one end,** known as the **anticodon**, and a region at the other end where a specific **amino acid can attach**
  - There are about 20 different tRNA molecules, each with a **specific anticodon** and **specific amino acid** binding site

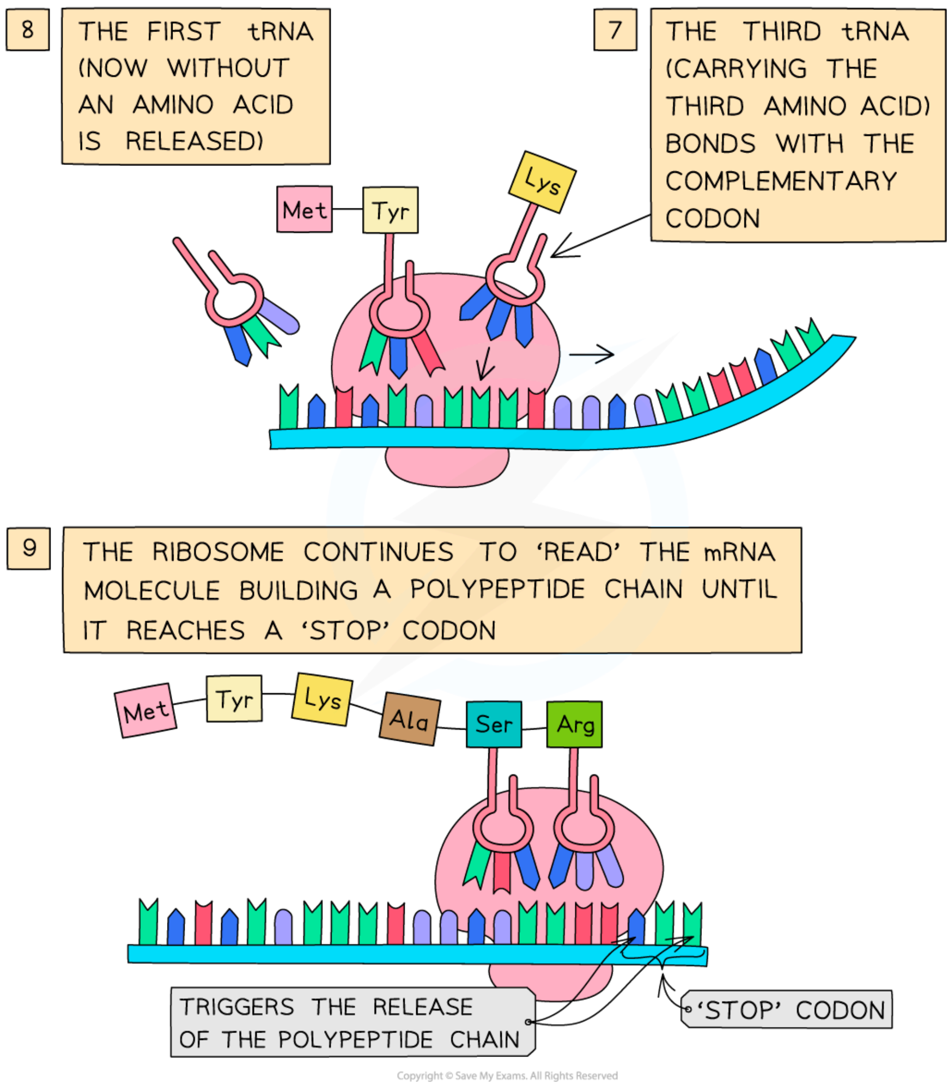
Your notes

- The **tRNA molecules bind with their specific amino acids** (also in the cytoplasm) and bring them to the mRNA molecule on the **ribosome**
- The triplet of bases (anticodon) on each tRNA molecule pairs with a **complementary triplet** on the mRNA molecule called the **codon**
  - Near the beginning of the mRNA is a triplet of bases called the **start codon (AUG)**
  - This is a signal to **start off translation**
  - AUG codes for an **amino acid** called **methionine**
- **Two tRNA molecules fit onto the ribosome at any one time**, bringing the amino acid they are each carrying side by side
- A **peptide bond** is then formed, via a **condensation reaction**, between the two amino acids
- This process continues until a **'stop' codon** on the mRNA molecule is reached – this acts as a signal for translation to stop and at this point the amino acid chain coded for by the mRNA molecule is **complete**
- The amino acid chain then forms the **final polypeptide**



1
IN THE CYTOPLASM THE mRNA ATTACHES TO A RIBOSOME
2
EACH tRNA HAS THE COMPLEMENTARY ANTICODON TO THE CODON ON THE mRNA
3
THE FIRST tRNA (WHICH ALWAYS CARRIES THE METHIONINE AMINO ACID) FORMS HYDROGEN BONDS WITH THE FIRST OR 'START' CODON (AUG) ON THE mRNA.
AMINO ACID
Met
tRNA
RIBOSOME
ANTICODON
mRNA MOLECULE
'START' CODON
5
A PEPTIDE BOND FORMS BETWEEN THE AMINO ACIDS
4
THE SECOND tRNA (BRINGING THE SECOND AMINO ACID) BONDS WITH THE NEXT CODON ON THE mRNA
PEPTIDE BOND
Met
Tyr
6
THE RIBOSOME MOVES ALONG THE mRNA (IN A 5' TO 3' DIRECTION) 'READING' THE NEXT CODON
Copyright © Save My Exams. All Rights Reserved

Your notes



The process of translation

Examiner Tips and Tricks

Make sure you learn both stages of protein synthesis fully. Don't forget – transcription occurs in the nucleus but translation occurs in the cytoplasm!

Your notes