Protein synthesis (A2)

Expressing the message - the role of RNA

The genetic message encoded in the DNA of cells is used to form protein molecules through the processes of transcription and translation.

Gene expression through these two processes involves several different ribonucleic acid (RNA) molecules.

Three main types of RNA have different roles within the complex mechanism of translation:

rRNA (ribosomal RNA)

There are a number of different rRNAs that form part of the structure of the ribosomes.

Ribosomes are the small organelles where protein synthesis takes place within the cell.

Ribosomal RNA makes up to 80% of the RNA within a cell, and the larger molecules contain over 3500 nucleotides.

tRNA (transfer RNA)

There is a group of small RNA molecules, each one specific for a particular amino acid.
Their role is to carry the amino acids to the ribosomes for protein synthesis.
Each tRNA recognises the coding sequence for a particular amino acid in the mRNA.
tRNA molecules are about 75 nucleotides long and represent up to 15% of cellular RNA.

mRNA (messenger RNA)

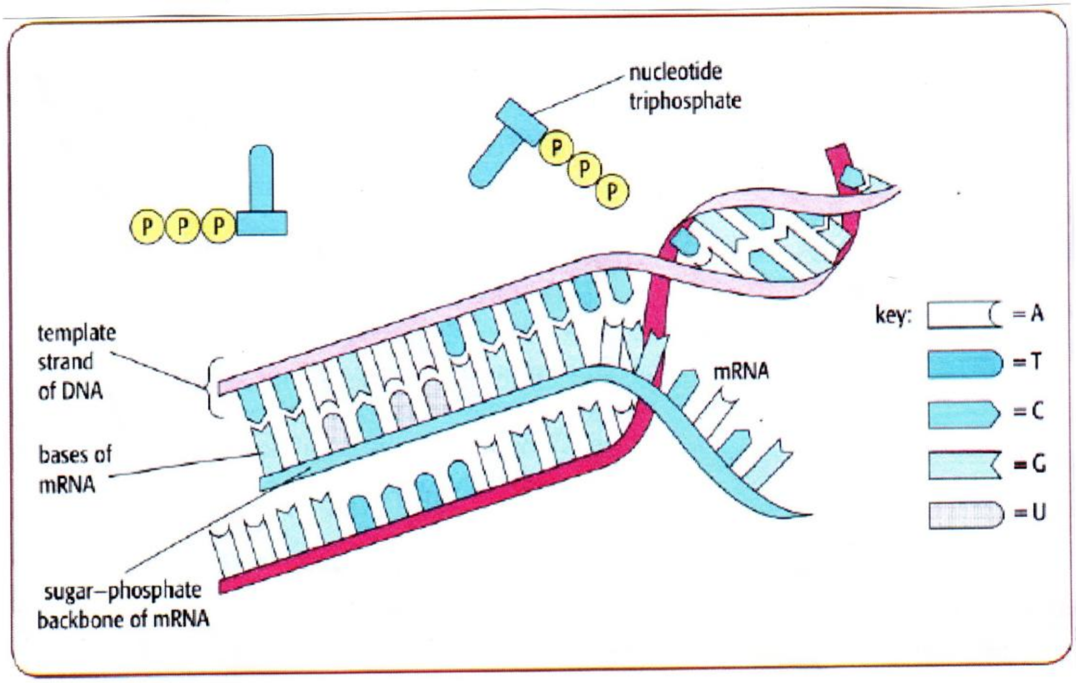
The RNA copied from the DNA gene sequence for a particular polypeptide chain.
The message encoded in the mRNA molecule is translated into the primary sequence of a polypeptide chain.

Delivering the message – transcription

Each gene contains a unique sequence of the four nucleotide bases and codes for a particular protein chain.

The gene sequence is always written in the 5'→3' direction.

The code is first transcribed into the mRNA for the protein chain by the enzyme RNA polymerase.



A diagram of the transcription process.

Transcription process:

- part of the DNA double helix unwind.
- a mRNA copy of the gene is made on a template strand of DNA using appropriate nucleotides and an enzyme called RNA polymerase.
- the mRNA diffuses away from the DNA and the DNA forms a double helix again.

Note:

- the base U in mRNA is complementary to A in DNA.
- the mRNA is synthesised on only one of the DNA strands (the template strand).
- the mRNA is synthesised from the 5' to 3' end. (this is also the direction in which the message is subsequently translated at the ribosome).
- only a small part of the DNA unwinds.

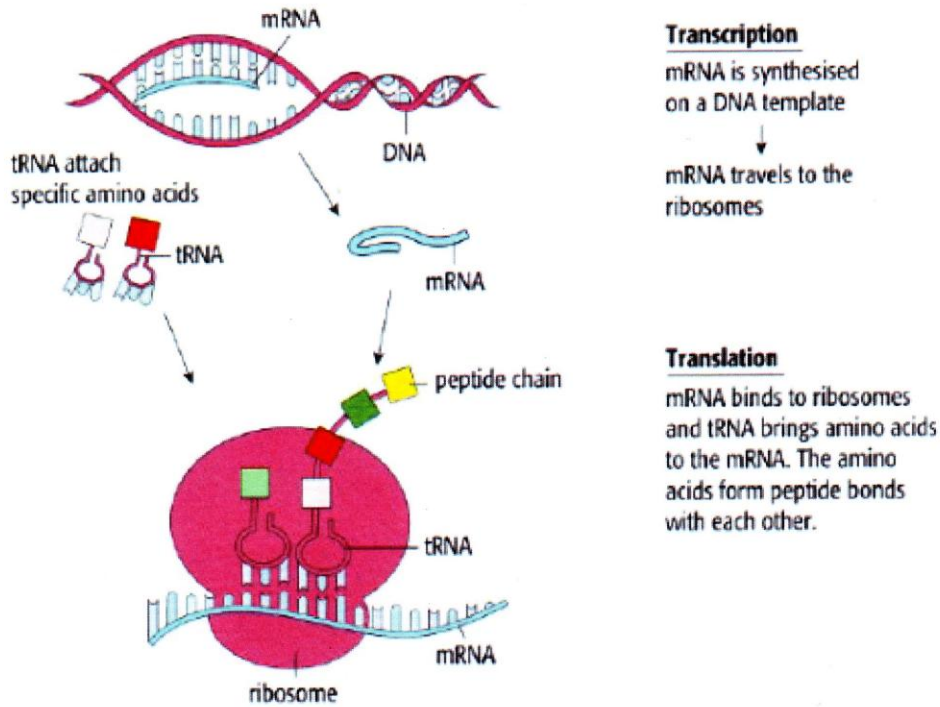
The mRNA copy is complementary to the part of the DNA (the gene) from which it was derived.

If the order of bases in part of the template strand of DNA is

– C C G T T A A G T T A C –

then the complementary sequence on the mRNA is:

5'– G G C A A U U C A A T G –3'



Protein synthesis involves transcribing the genetic code into mRNA and then translating the message to form protein.

Protein synthesis – translating the message

The ribosomes are involved in the protein chains synthesis.

During translation, several ribosomes can attach to a particular mRNA molecule at any one time.

As the ribosomes move along the mRNA, the sequence of bases directs the bringing together of amino acids in the correct order to produce proteins.

The order of the bases along the mRNA is translated into the order of amino acids along the polypeptide chain.

The genetic code

The sequence of bases on a molecule of mRNA, which is complementary to the sequence of bases in a section of DNA, specifies the sequence of amino acids in the protein that is to be synthesised. The mechanism by which the mRNA base sequence specifies an amino acid sequence is called the genetic code.

The main points about the code are:

- a sequence of three bases (a triplet) codes for specific amino acids; eg., CCA codes for proline, GCA codes for alanine.
- a set of three successive bases is called a codon.
- the coding is continuous - each codon follows directly from the one before; eg:

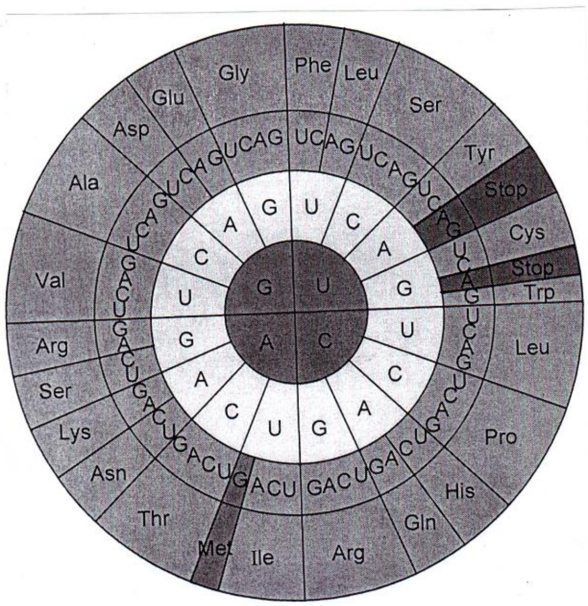
--- CCA GCA UUU CAU ---

codon for → Pro Ala Phe His

- the sequence of triplet codons determines the order in which the amino acids join together in the polypeptide chain.
- most amino acids are coded for by more than one codon; eg. the code for tyrosine can be UAU or UAC

• the sequence of the codons is read in the 5' to 3' direction.
• the sequence of bases in the mRNA is complementary to the sequence of bases in the DNA.

The code for the 20 amino acids found in proteins:



The genetic code.

The code is read out from the centre - 5' to 3'.

Example 1:
UGG is the code for tryptophan (Trp)
meaning: the base sequence UGG on the mRNA causes the amino acid tryptophan to be incorporated into the protein when it is synthesised.

Example 2:

Arginine (Arg) has more than one possible code.
The code can start with A (in the centre) and both AGG and AGA code for arginine.
The code can also start with C (in the centre).
Four possible codes starting with C code for arginine:
CGG, CGA, CGC and CGU.

All polypeptide chains have a defined length.
There must be a codon for the first amino acid in the chain (the N-terminal end).
This start signal at the 5' end is provided by the codon AUG for methionine.
Methionine is the amino acid at the N-terminal end when the polypeptide chain is first synthesised, it is later removed from particular proteins.
The start signal ensures that the triplet code is read in the correct group of three.
There are also several codons for the last amino acids in the chain to show when assembly of the polypeptide is complete.
Stop codon: UAA, UAG and UGA

Exercise 1.

Use the genetic code wheel, write down all the possible codes for the following amino acids:

a. Phe

b. Pro

c. Lys

d. Ile.

Workings

a. Phe

possible code: UUU; UUC

b. Pro

possible code: CCU; CCC; CCA; CCG

c. Lys

possible code: AAA; AAG

d. Ile

possible code: AUU; AUC; AUA.

Translating the message at the ribosomes

Amino acids on their own cannot bind to mRNA.

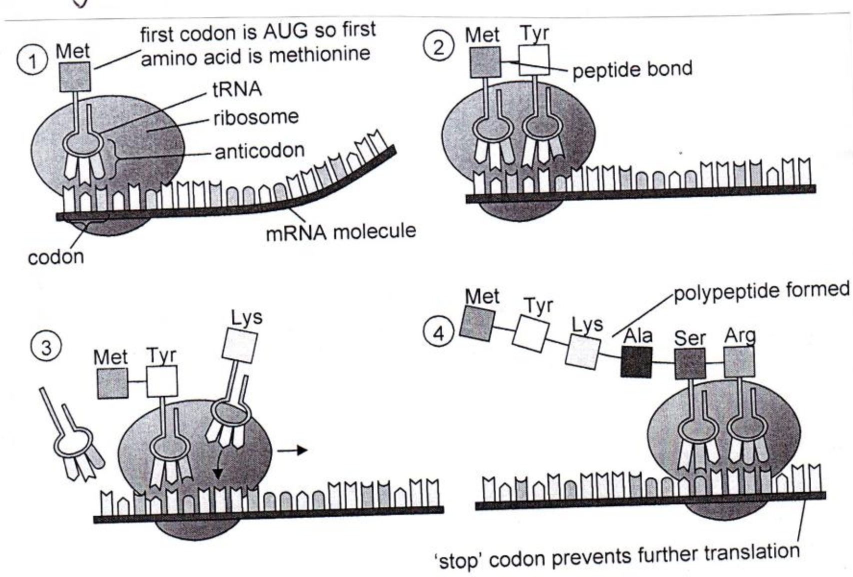
tRNA molecules act as the vehicles for these interactions.

Each tRNA binds a specific amino acid at one end of the molecule.

At the other end it has a specific triplet of bases (the anticodon) which can bind to the codon triplet on the mRNA.

Each tRNA, carrying its specific amino acid, can interact with the ribosome and the correct codon on the mRNA to continue the process of translation.

The translation process involves 3 steps: initiation, elongation and termination:



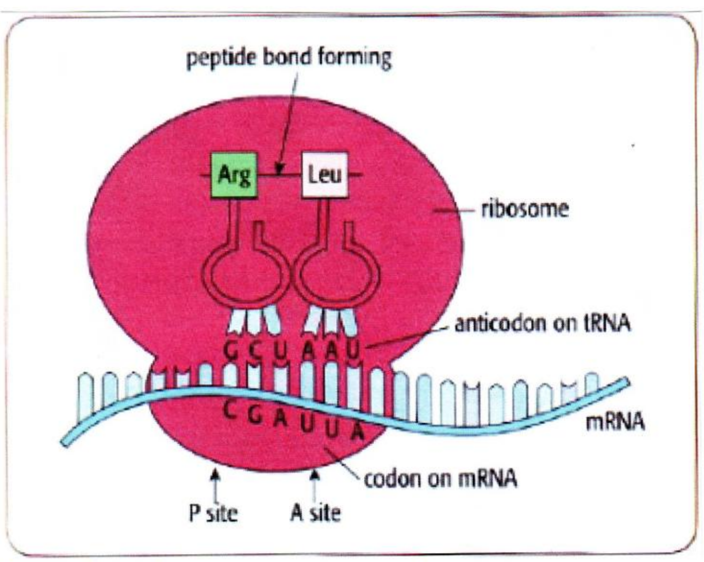
The process of translation.
stage 1: initiation stage 2 & 3: elongation
stage 3: termination.

Initiation

- The start codon (AUG) of the mRNA binds to the ribosome.
- The tRNA with the correct anticodon pairs with the start codon on mRNA.

Elongation

- Further tRNA molecules with their amino acids are brought up to the ribosome.
- Each tRNA anticodon binds to the correct codon on mRNA in the correct 5' to 3' sequence.
- As the ribosome moves along the mRNA, the bond between the tRNA and amino acid breaks and the new amino acid is bonded to the growing polypeptide chain by a peptide link.



Complementary base pairing at the ribosome.
There are two sites on the ribosome - 1) one where the incoming tRNA binds, -2) one where the peptide chain lengthens

Termination

- When the stop codon on the mRNA is reached, the mRNA detaches itself from the ribosome and the peptide chain folds up spontaneously.

Exercise 2

The peptide fragment

—Tyr—Ser—Ala—Ala—Glu—Gly—Q—R—

is coded somewhere inside the fragment of mRNA with the base sequence shown below,

5'—GUUACUCUGCUGCGGAAGGAGCCGUAC—3'

i) Use the genetic code wheel to identify the codons in the mRNA fragment that code for the named amino acids.

ii) Use the mRNA fragment and the genetic code wheel to identify the amino acids Q and R in the peptide fragment.

iii) Give the base sequence matching the codon for tyrosine in the DNA from which the RNA was trascribed, indicating the direction of the bases in the DNA strand.

Workings

Q: GCC, R: GUA

5'-GU|UAC|UCU|GCU|GCG|GAA|GGA|GCC|GUA|C-3'

i) peptide fragment –Tyr–Ser–Ala–Ala–Glu–Gly–

	Tyr	Ser	Ala	Ala	Glu	Gly
codon	✓UAC	UCG	GCG	✓GCG	✓GAA	GGG
	UAU	UCA	GCA	GCA	GAG	✓GGA
		UCC	GCC	GCC		GGC
		✓UCU	✓GCU	GCU		GGU

ii)

	Q	R
codon	GCC	GUA
amino acid	Ala	Val

iii)

amino acid	Tyr
codon	UAC
bases in DNA strand	ATG

Exercise 3

Why is it important that there is a 'stop' codon in the mRNA?

Workings

The stop codon give information that the polypeptide chain and the mRNA should be released from the ribosome.

This allows another mRNA to bind to the ribosome and starts new process of translation.

Without a stop codon, more tRNAs can bind to the mRNA and adding more amino acids to the growing polypeptide chain, making an incorrect protein.

Exercise 4

Outline the role of mRNA and tRNA in protein synthesis.

Workings

Process of transcription transfers the coded message for the primary structure of a protein to a mRNA.

The code is a series of triplet bases – codons.

At the ribosomes, the message is translated from the mRNA to form the protein.

tRNA binds to specific amino acids in the cytoplasma and carries them to the ribosomes.

At ribosomes, tRNA binds to specific triplets in the mRNA by its triplet anticodon.

It then releases the amino acid to growing polypeptide chain.

Exercise 5

Explain how the codons on the mRNA are translated into amino acid sequence in a polypeptide chain.

Workings

mRNA contains a set of consecutive codons.

Each codon in mRNA contains a set of three bases.

Each codon codes for a particular amino acid

Each tRNA carries a specific amino acid and contains a particular anticodon,

The tRNA anticodon can only link to the codon on the mRNA which is complementary to it.

So the tRNAs carrying a specific amino acid can only be brought up to the mRNA in the sequence specified by the code on the mRNA.

The sequence of codons in the mRNA produces the sequence of amino acids in the polypeptide chain.