Bio Factsheet

September 1999 **Number 49**

Protein Synthesis II - Mechanisms

Before studying this Factsheet the student should have fully mastered the information in Factsheet Number 22 (Protein synthesis I, April 1998).

This Factsheet summarises the key aspects of the mechanisms of protein synthesis.

1. **The nature of the genetic code.**
2. **The relationships of transfer RNA (tRNA) to amino acids and their role in polypeptide synthesis.**
3. **The roles of messenger RNA (mRNA), rough endoplasmic reticulum(RER) and ribosomes in polypeptide synthesis (transcription and translation).**
4. **The modification of polypeptides into proteins in the RER and Golgi body.**

Questions on this topic usually test knowledge and understanding, by using flow diagram, tick box, 'fill in the missing word' or continual prose questions.

The nature of the genetic code

The genetic code can be found on DNA and on mRNA.

> ***Remember*** *- DNA contains the base thymine but mRNA contains uracil so the letters T or U must be used accordingly.*

This genetic code is universal to all life forms. Fig 1 illustrates the genetic code in its mRNA form.

> ***Exam Hint*** *- A frequent exam error is to say that 'protein synthesis occurs at the ribosomes'. Remember, protein synthesis is a two step process,* ***polypeptide*** *synthesis occurs at the ribosomes, but the assembly of* ***proteins*** *occurs in the spaces of the rough endoplasmic reticulum and Golgi body.*

The triplets of bases shown in Fig 1 are **codons**. A codon is the unit of the genetic code and each codon will always relate to the same amino acid. There are 64 possible codons but only 20 amino acids found in proteins, thus some amino acids have several codons. Because of this, the code is said to be **degenerate** and **redundant.** The code is also **non- overlapping**, meaning that adjacent codons do not share bases.

Fig 1. The genetic code on mRNA

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

U = uracil

C = cytosine

A = adenine

G = guanine

It is not necessary to learn this by heart, or to remember the amino acids

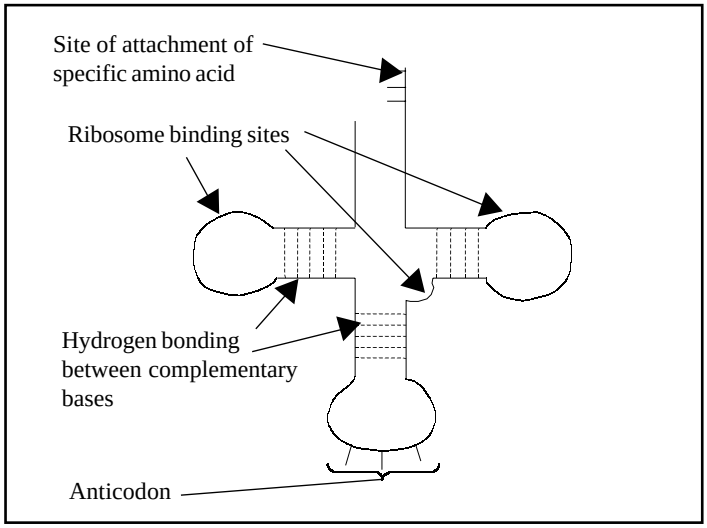
A gene is a length of DNA or mRNA which codes for the assembly of a specific **polypeptide**, and so the sequence of codons which make up the gene will determine the sequence in which amino acids are assembled into that polypeptide. This sequence of amino acids is the **primary structure** of the polypeptide. This will govern how the polypeptide folds and cross bonds into its **secondary structure** (alpha-helix or beta-pleated sheet) and **tertiary structure** (globular form) at the ribosomes, and how it will assemble into its **quaternary structure** (the arrangement and joining of polypeptides together) in the rough endoplasmic reticulum and Golgi body.

Three codons mark the end of genes and are responsible for the release of the polypeptides into the spaces of the rough endoplasmic reticulum. They are referred to as **chain termination codons** or **stop** codons. They may also mark the start of the next gene along the DNA or mRNA molecule.

Typical Exam Question
An interesting task is to imagine that life in another solar system has the same code but that it is overlapping. Compare the polypeptides made from identical base sequences with a non-overlapping code and an overlapping code. One exam board has asked a question on this theme.

tRNA and its roles in polypeptide synthesis
Transfer RNA is found in the cytoplasm. It is about 80 nucleotides long and is clover leaf in shape (Fig 2). There are 20 types of tRNA molecule, one for each amino acid. One end contains a triplet of exposed nucleotides called the **anticodon**, which is complementary to one of the codons found on the mRNA (Fig 1). The other end of the tRNA molecule has a site for the attachment of a specific amino acid. The amino acid which becomes attached must correspond to the anticodon at the other end, and thus also to the codon on the mRNA.

Fig 2. The structure of tRNA



***Remember - Transcription** is the copying of genentic code from DNA onto mRNA. **Translation** is the assembly of a polypeptide from the genetic code on the mRNA.*

Each molecule of tRNA thus picks up its own amino acid, and by matching its anticodon to the complementary codon on the mRNA the amino acids can be assembled into the correct sequence.

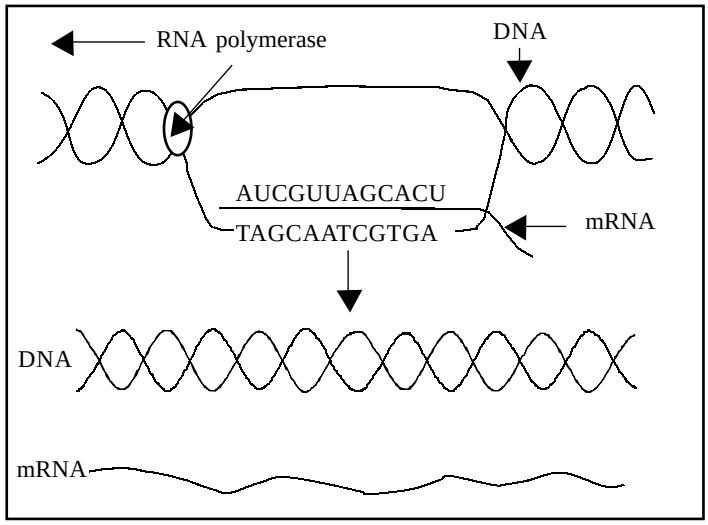
***Remember -** complementary bases will join by hydrogen bonding, A to U or A to T and C to G. This is essential knowledge to work out some exam answers.*

Before amino acids can join with tRNA they have to be activated using ATP as an energy source. The activation and combination with tRNA occurs in the cytoplasm. Thus protein synthesis is an **anabolic** or energy requiring process.

The roles of mRNA and ribosomes in polypeptide synthesis
The genetic code on the DNA is passed onto mRNA by a process of **transcription**. In this process the DNA helix unwinds for the part of its length which contains the genes to be copied, and one of its strands (called the coding strand) acts as a template for the synthesis of a complementary single strand or mRNA. The enzyme **RNA polymerase** catalyses the process**.**

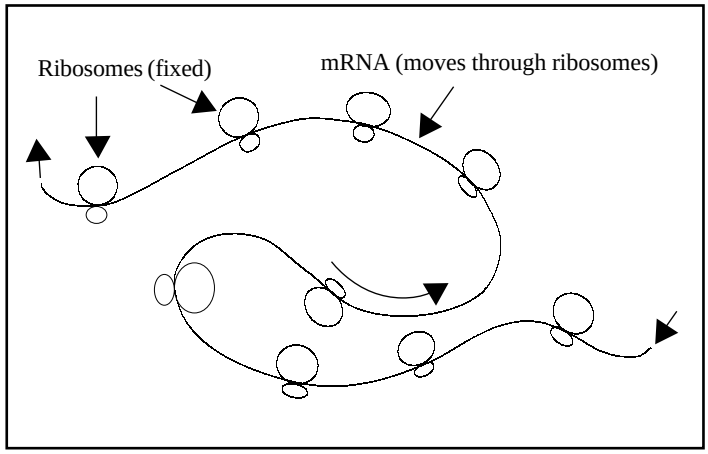
The process of transcription is shown in Fig 3. The mRNA is synthesised from free complementary nucleotides in the surrounding nuclear sap.

Fig 3. Transcription of mRNA from DNA



After transcription the DNA returns to its double stranded form and the new mRNA passes through the pores in the nuclear membrane into the cytoplasm to become associated with the ribosomes that are fixed on the rough endoplasmic reticulum. Fig 4 shows the association between mRNA and ribosomes.

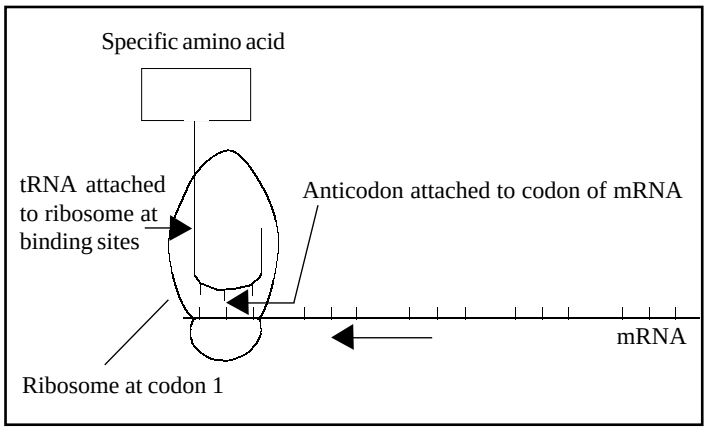
Fig 4. Ribosomes and mRNA



The process of **translation** can now take place. This is the synthesis of a specific polypeptide by the ribosomes using the genetic code on the mRNA to assemble the amino acids in the correct sequence.

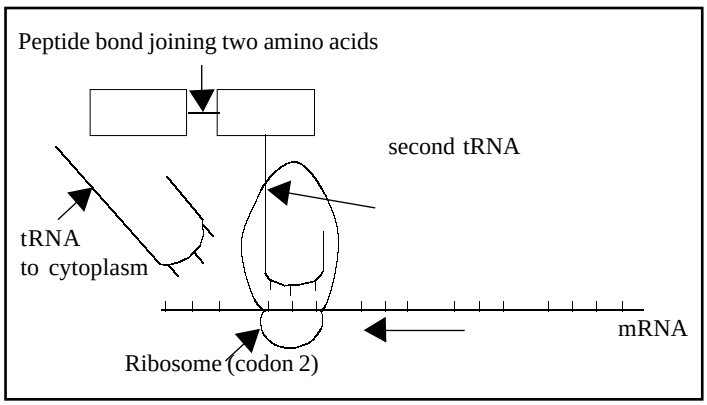
In the first step of translation codon 1 of the first gene is covered by the ribosome. This enables the complementary tRNA to attach to the codon with its anticodon, by hydrogen bonding and so the first specific amino acid is brought into place (Fig 5).

Fig 5. Translation Step 1



In the second step of translation the mRNA moves so that codon 2 of the gene is covered by the ribosome. This enables the second tRNA molecule to attach to the second codon by an anticodon-codon link and so the second specific amino acid is carried into place. The enzyme **peptide synthetase** in the ribosome catalyses the condensation reaction to form a **peptide bond** to join the first and second amino acids into a dipeptide. The first tRNA molecule is then released back to the cytoplasm for reuse (Fig 6).

Fig 6. Translation Step 2



Similar steps are repeated as each successive codon of the gene is covered by the ribosome, and so a polypeptide is assembled, the amino acid sequence of which is related to the codon sequence of the gene. At the end of the gene is a chain termination (stop) codon. When this is covered by the ribosome there is no complementary tRNA to join the codon and so the synthesised polypeptide is released into the spaces of the rough endoplasmic reticulum. The process of translation then proceeds along gene 2 of the mRNA.

Remember *- It is now known that the ribosome covers two codons of the mRNA at a time.Thus two tRNA molecules with their amino acids can be held in place while a peptide bond forms.*

The process of polypeptide synthesis is **amplified** by having the length of mRNA attached to several or many ribosomes at a time so that they can all carry out translation at the same time. Such an assembly of mRNA and ribosomes attached to the rough endoplasmic reticulum is called a **polyribosome**. The same length of mRNA can pass through the same assembly of ribosomes time and time again. The polyribosomes in an activated plasma cell enable the production of around 2000 antibody molecules per cell per second for 4 to 5 days.

(The mRNA and associated ribosomes illustrated in Fig 4. is a polyribosome system).

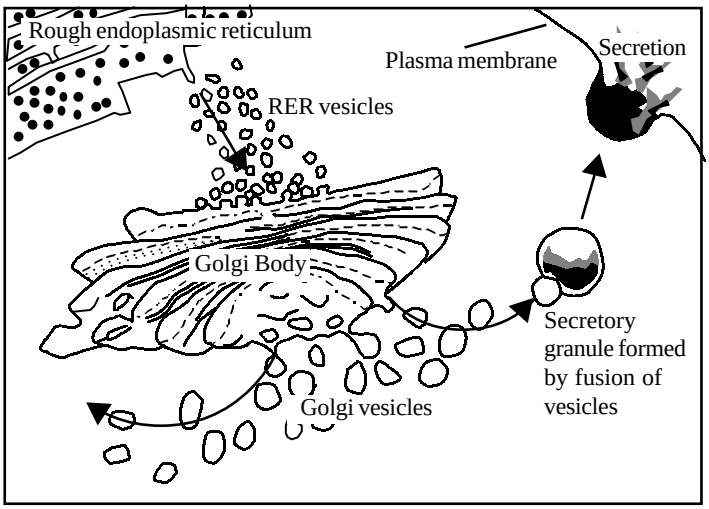
Modification of polypeptides into protein

The synthesised polypeptides are transferred to the Golgi body in vesicles which bud off from the rough endoplasmic reticulum, migrate through the cytoplasm and fuse with the cisternae (cavities) of the Golgi body. Here (and also in the rough endoplasmic reticulum and its vesicles) the polypeptides couple by hydrogen bonding and sulphur bonding, between amino acid side chain groups, to form proteins. Examples of proteins formed in this way are **lysozyme** and **catalase**.

The Golgi body also allows the assembly of other protein derivatives. For instance, carbohydrates may be joined to proteins to make **glycoproteins** such as mucus, lipids may be joined to proteins to make **lipoproteins,** iron containing haem groups may be joined to proteins to make molecules such as **haemoglobin, myoglobin** and **cytochromes.**

The products of the Golgi body are budded off as Golgi vesicles.They either remain in the cytoplasm as, for example, lysosomes (containing lysozyme) and peroxisomes (containing catalase), or fuse together into secretory granules. These can then fuse with the plasma membrane to secrete their contents out of the cell, for example, antibodies, plasma proteins, digestive system enzymes. This process is called **exocytosis**. The functions of the Golgi body are shown in Fig 7.

Fig 7. The functions of the Golgi body



Practice Questions

1. Read through the following account of protein synthesis and then fill in the spaces with the most **appropriate word or words.**

   Messenger RNA formed by _____ from the nuclear DNA passes through pores in the _____ and attaches to _____ fixed to the _____. _____ amino acids are brought to the mRNA by the molecules of _____ which attach to the _____ of the mRNA by their _____. Adjacent amino acids then join by _____ to form a _____. These assemble into proteins either in the spaces or vesicles of the _____ or are transported to the _____ for assembly there.

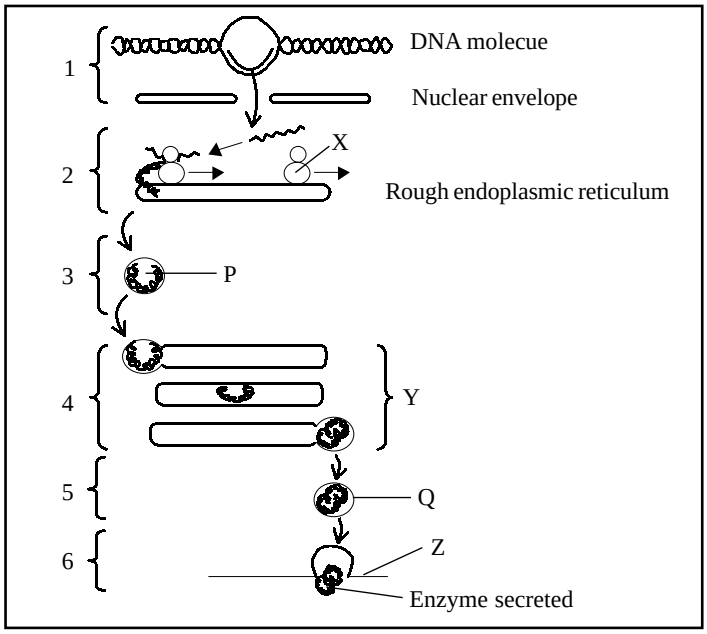
   (12 marks)

2. The table below refers to some features of mRNA and tRNA. If a feature is correct mark the relevant box with a tick and if it is incorrect mark the box with a cross.

Feature	mRNA	tRNA
Contains anticodons		
May contain several genes or alleles		
Has a clover leaf shape		
Can associate with any amino acid		
Contains uracil instead of thymine		
A short molecule 70 –90 nucleotides long		

. (6 marks)

3. The diagram below shows some of the stages involved in the secretion of an enzyme by a stomach cell. The stages are labelled 1 to 6.



(a) Name the structures X, Y and Z.

(b) Name the processes occuring in stages 1, 2, 4 and 6.

(4 marks)

(c) Distinguish between vesicles P and Q and their contents.

(4 marks)

4. The following sequence of codons is from the gene on DNA which codes for part of the haemoglobin molecule.

(a) Using the genetic code shown on page I work out the haemoglobin gene codons on the mRNA and the sequence of amino acids found in the haemoglobin molecule.

(3 marks)

(b) If the DNA base T, marked with an arrow was substituted with A, how would the haemoglobin chain differ?

(1 mark)

Answers

Semicolons indicate marking points.

1. transcription; nuclear membrane; ribosomes; rough endoplasmic reticulum; specific; tRNA; codons; anticodons; peptide bonds/ condensation/peptide links; polypeptide; rough endoplasmic reticulum; Golgi body;

2.

Feature	mRNA	tRNA
Contains anticodons	✗	✓
May contain several genes or alleles	✓	✗
Has a clover leaf shape	✗	✓
Can associate with any amino acid	✗	✗
Contains uracil instead of thymine	✓	✓
A short molecule 70 –90 nucleotides long	✗	✓

3. (a) X = ribosome; Y = vesicle of RER;
   Z = Golgi vesicle;

   (b) 1 = transcription; 2 = translation;
   4 = protein assembly/modification;
   6 = exocytosis;

   (c) P is a vesicle from the rough endoplasmic reticulum;
   Q is a vesicle from the Golgi body;

   P contains polypeptides/proteins assembled in RER:
   Q contains proteins assembled in Golgi body/modified proteins/ glycoproteins/any correct example;

4. (a) GUA CAU UUA ACU CCU GAA GAG;;
   (deduct 1 mark per error)

   Val His Leu Thr Pro Glu Glu ;

   (b) last but one amino acid/penultimate amino acid would be valine/ Val instead of glutamic acid/Glu;

Acknowledgements;
This Factsheet was researched and written by Martin Griffin.
Curriculum Press, Unit 305B, The Big Peg, 120 Vyse Street, Birmingham. B18 6NF

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