

Protein Synthesis:

Transcription & Translation

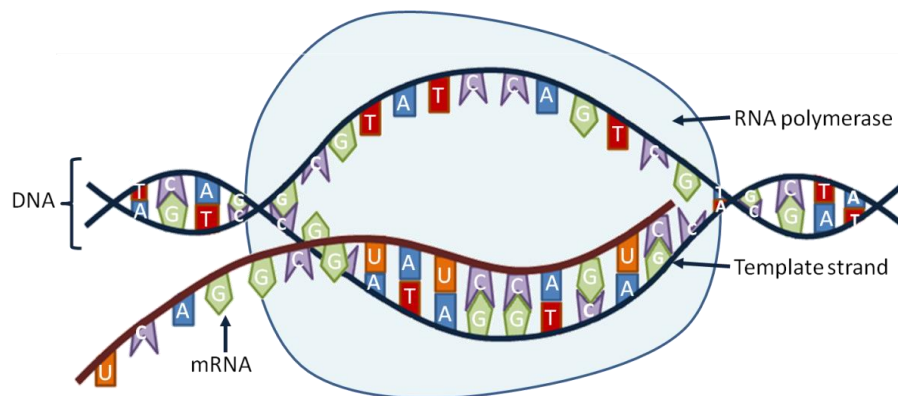
Proteins have multiple roles within the cell: as enzymes, signals, structural components, defense, transport, and storage among other things. The types of protein produced within a cell depend on the information stored in the cell's DNA (deoxyribonucleic acid).

In eukaryotic cells, DNA is housed in the nucleus. Because DNA cannot leave the nucleus, the information stored in the nucleotide sequence must be copied and then sent to the ribosomes located in the cytoplasm. This process is called **transcription**. During transcription, a section of one strand of DNA (called the template strand) is copied to produce a single-stranded RNA (ribonucleic acid) called **messenger RNA** (mRNA).

To ensure that genetic information is copied correctly, base pairing rules are used. Recall with DNA nucleotides, adenine (A) pairs with thymine (T), T pairs with A, guanine (G) pairs with cytosine (C), and C pairs with G. In transcription, the base pairing rules change slightly. **In RNA, thymine is replaced by uracil (U)**. A from DNA pairs with U from mRNA, T from DNA pairs with A from mRNA, G from DNA pairs with C from mRNA, and C from DNA pairs with G from mRNA. See image below.

The process of transcription occurs in three stages:

1. **Initiation:** Attachment of the enzyme RNA polymerase to the promoter region of the gene. The promoter region dictates which strand of DNA needs to be copied and where the copying should begin.
2. **Elongation:** RNA synthesis occurs. RNA polymerase unwinds and separates the DNA strands and RNA nucleotides are allowed to base pair with the exposed DNA nucleotides. RNA nucleotides are joined together forming the mRNA strand.



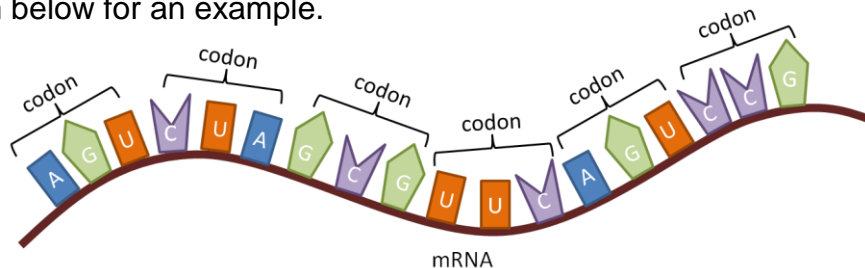
3. **Termination:** RNA polymerase reaches a sequence of bases called the terminator. RNA polymerase detaches from the DNA strand and mRNA production is complete.

Helpful animation: <http://bcs.whfreeman.com/thelifewire/content/chp12/1202001.html>

Before the mRNA strand can leave the nucleus, processing occurs. A guanine nucleotide (cap) is added to one end of the mRNA strand and a long chain of adenine nucleotides (poly-A tail) is added to the other end. Sections of the strand called introns (noncoding regions) are also removed leaving only exons (coding/ expressed regions).

After the mRNA strand leaves the nucleus, **translation** begins. Translation is a process in which the information on the mRNA strand is decoded and a protein molecule is produced.

Before looking at the steps of translation, we must first understand how information is coded in the mRNA. Information is stored in triplets of bases referred to as **codons**. See diagram below for an example.



Each codon refers to a particular amino acid or a stop codon. In total there are 64 codons, 61 refer to an amino acid and 3 are stop codons. When a stop codon is reached, protein production stops. See the mRNA codon table on next page. Note: the names of the amino acids have been abbreviated.

Practice: Given the above strand of mRNA, use the codon table to determine the order of the amino acids that would be used to produce a protein.

Solution: Ser – Leu – Ala – Phe – Ser – Pro

The translation of the genetic code into a protein is accomplished by transfer RNAs (tRNA). These RNA molecules have the ability to “read” codons and match them with the appropriate amino acid. Each tRNA molecule consists of an amino acid at one end and the corresponding **anticodon** at the other end (a triplet of bases that are complementary to a codon). The anticodon of a tRNA must correctly pair with the codon of mRNA in order for the amino acid to be used in the protein chain. Example: A codon CCA must complementary base pair with a tRNA that has the anticodon GGU for the amino acid, Pro, to be used. Note: There are no tRNAs for stop codons.

Practice: Given the above strand of mRNA, determine the anticodon of the tRNAs that would complement them.

Solution: UCA – GAU – CGC – AAG – UCA – GGC

Note: Because tRNA uses RNA nucleotides, no thymine is present.



mRNA Codon Table

1 st base	2 nd base								3 rd base
	U		C		A		G		
U	UUU	Phe	UCU	Ser	UAU	Tyr	UGU	Cys	U
	UUC		UCC		UAC		UGC		C
	UUA	Leu	UCA		UAA	Stop	UGA	Stop	A
	UUG		UCG		UAG	Stop	UGG	Try	G
C	CUU	Leu	CCU	Pro	CAU	His	CGU	Arg	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	Gln	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	Ile	ACU	Thr	AAU	Asn	AGU	Ser	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	Lys	AGA	A	
	AUG	Met	ACG		AAG		AGG	G	
G	GUU	Val	GCU	Ala	GAU	Asp	GGU	Gly	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	Glu	GGA		A
	GUG		GCG		GAG		GGG		G

The process of translation occurs in three stages:

1. **Initiation:** Small subunit of the ribosome binds the mRNA strand. An initiating tRNA binds to the start codon, usually AUG. This determines where translation should begin. The large ribosomal subunit then binds to the small subunit and initiation is complete.
2. **Elongation:** A tRNA pairs with the next codon on the mRNA strand. The amino acid from the first tRNA is covalently bonded to this new amino acid and transferred. Then the ribosome shifts down the mRNA strand. This process continues and new amino acids are added to the growing polypeptide chain until a stop codon is reached.
3. **Termination:** UAA, UAG or UGA is reached. The polypeptide chain is freed from the last tRNA molecule and the ribosome and mRNA strand separates. The polypeptide chain folds into its new conformation and will become a functioning protein.

Helpful animation: <http://bcs.whfreeman.com/thelifewire/content/chp12/1202003.html>

Online practice: <http://learn.genetics.utah.edu/content/begin/dna/transcribe/>



Practice Questions:

1. Complete the following table.

DNA	A	T	G	C	C	A	T	T	T	G	G	A	T	A	A
DNA (template)															
mRNA codon															
tRNA anticodon															
amino acid															

2. Complete the following table.

DNA															
DNA (template)															
mRNA codon															
tRNA anticodon	U	A	C	U	G	G	C	A	A	U	U	A	C	C	U
amino acid															

3. If a tRNA molecule has the anticodon UCC on one end, what amino acid should it carry on the other end?

4. A mutation occurred in the DNA template strand and the nucleotide sequence changed from CCG to CTG. What was the original amino acid that was supposed to be used in the production of the protein? What is the new amino acid that is used? Mutations like these can sometimes have profound effects on protein shape and function.

Solutions:

1.

DNA	A	T	G	C	C	A	T	T	T	G	G	A	T	A	A
DNA (template)	T	A	C	G	G	T	A	A	A	C	C	T	A	T	T
mRNA codon	A	U	G	C	C	A	U	U	U	G	G	A	U	A	A
tRNA anticodon	U	A	C	G	G	U	A	A	A	C	C	U			
amino acid	MET			PRO			PHE			GLY			STOP		

2.

DNA	A	T	G	A	C	C	G	T	T	A	A	T	G	G	A
DNA (template)	T	A	C	T	G	G	C	A	A	T	T	A	C	C	T
mRNA codon	A	U	G	A	C	C	G	U	U	A	A	U	G	G	A
tRNA anticodon	U	A	C	U	G	G	C	A	A	U	U	A	C	C	U
amino acid	MET			THR			VAL			ASN			GLY		

3. Arg

4. Gly to Asp

