Study Guide - Molecular Genetics (DNA replication, transcription, and translation)

In our previous lesson we discussed the fact that genes and their ways of being expressed were carried on chromosomes. We also discussed how parents pass on the genes to the offspring. We did not discuss in depth what it is that genes and chromosomes are made of. In this lesson we are going to discuss the basis of the molecule known as DNA. DNA is ultimately responsible for carrying the information of inheritable traits. We will especially concentrate on the processes that DNA directs when making sure that genes are expressed (like eye color, etc.).

DNA

Understanding the structure of DNA is the basis for understanding gene expression. In the 1950s two men (James Watson and Francis Crick) brought to the scientific world the discovery that DNA had a structure that consisted of two long chains of **nucleotides**. They proposed that these chains twisted around each other resembling a spiral staircase. The structure was named a **double helix**. The bonds formed between the nucleotides in the double helix are considered weak bonds (they are hydrogen bonds), and we will see why in a few moments. Its interesting to note here though the importance of understanding even the basic amount of chemistry, particularly bonding between atoms and molecules. That is the basis of the whole structure.

The **nucleotides** are very important molecules in DNA. All the information that DNA contains is encoded on these nucleotides. There are three (3) parts to a nucleotide: 1) a **phosphate group** - which connects the deoxyribose molecules to each other, 2) a **five carbon carbohydrate** (in the case of DNA it is **deoxyribose**, and with RNA it is **ribose**) - which attaches to the next group (the nitrogenous bases), and 3) a **nitrogenous base**.

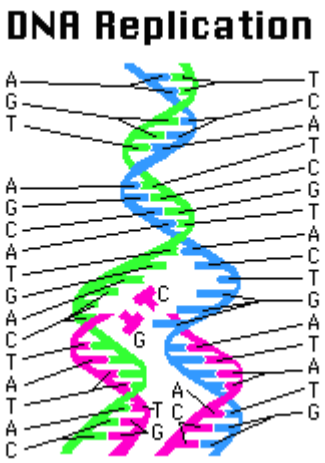
Lets talk a bit more about these bases. The nitrogen bases are divided into two major groups: the pyrimidines and the purines. The **pyrimadines** are small one ring structures made of carbon and nitrogen (and hydrogen). For DNA there are two pyrimadines: **thymine** (T) and **cytosine** (C). The **purines** are larger double ringed structures that are made of carbon and nitrogen (and hydrogen). The two purine molecules are: **adenine** (A) and **guanine** (G). The amounts of these molecules in organisms is as follows. The amount of adenine as compared to guanine may be different for every species, but the amount of adenine always equals the amount of thymine, and the amount of guanine always equals the amount of cytosine. This relationship is commonly illustrated by the following:

A=T and G=C

This relationship is described by the term **complementary base pairing**. This is because A is always complemented by T and G by C. These are the only two kinds of base pairing that occur along the entire length of DNA. The difference is the order in which these bases occur along the chains. Another important detail that we need to mention deals with the chains that form the actual double helix. The individual chains are described as moving in **opposing directions**. For convenience the different ends are labeled 5 (called five prime) and 3 (three prime). So that the 3 end of one chain bonds with the 5 end of the other chain. See the following diagram

5	3
T	A
T	A
G	C
A	T
C	G
3	5

DNA Replication



A few lessons ago, we spoke of the fact that an important result of reproduction (both sexual and asexual) is passing on the chromosomes (DNA) from the parent cell to the daughter cells. In the cell cycles we saw in mitosis and meiosis the interphase stage (interphase I in meiosis) included making copies of the DNA in the parent cell nucleus in order to pass it on to the daughter cells. In mitosis the **DNA replication** takes place in the S stage of the interphase. So lets see what happens. Please refer to the diagram in order to see what is actually happening.

Well remember that the replication of DNA takes place in the nucleus of a cell. There are a number of players in the replication itself. Among them are the DNA (of course) and some specialized enzymes that help the process along.

As we mentioned before, the bonds that are formed between the two chains to form the double helix are very weak bonds known as hydrogen bonds. These hydrogen bonds form between the nitrogenous bases we just finished talking about. Incidentally there are 3 hydrogen bonds between base pair C and G and 2 hydrogen bonds between A and T. When it is time for replication to begin a special enzyme starts by unwinding the double helix leaving the base pairs exposed. The nucleus of a cell has stores of nucleotides which pair with the exposed bases. And new chains form and are bound to each other with the help of the enzyme **DNA polymerase** and the result is two new DNA molecules.

I like to think of the whole process as being like a zipper. The part of the zipper that opens and closes the zipper is the enzyme and once the teeth (the nitrogenous bases) of each side of the zipper are exposed, they are joined by other teeth to form two new zippers. One thing we must note is that the two new molecules of DNA contain one of the original chains from the original molecule of DNA and are joined with the companion chain formed during replication.

After replication, the DNA is now duplicated and is ready to be passed on to the daughter cells produced by mitosis or meiosis.

Protein Synthesis

Life cannot exist without **enzymes** and **proteins**. Proteins are made of **polypeptide chains** that are made of **amino acids**. The key to a specific protein is the sequence in which the amino acids are linked. The sequence of amino acids that form the protein are located on genes - which is a specific sequence of the nucleotide bases (A, T, C, G) in DNA. In other words, **DNA directs the formation of proteins**. The process of forming proteins is known as protein synthesis and it has different steps: **transcription** and **translation**.

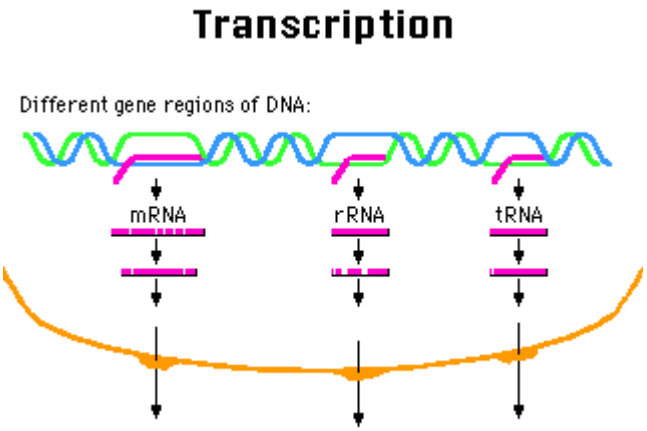
Tools involved in protein synthesis

Whenever something is built (like a house or car) certain tools are needed while putting it together. Protein synthesis is no different. The two steps of protein synthesis actually take place in two different places. Transcription in the nucleus of the cell, and translation outside the nucleus of the cell in the cytoplasm. The DNA never leaves the nucleus of eukaryotic cells during protein synthesis. So how does it direct the formation of the proteins that take place outside the cell? The answer is found in another nucleic acid called **RNA**. There are two basic differences between RNA and DNA. RNA contains the five carbon carbohydrate **ribose** instead of deoxyribose, and the nitrogenous base thymine is replaced by **uracil** (this means that now adenine will form a bond with uracil in RNA instead of thymine). There are three types of RNA that are involved in protein synthesis.

The first is **messenger RNA** (**mRNA**). mRNA is responsible for making a copy (in the nucleus of the cell) of the genetic code for any given protein and carrying it into the cytoplasm where protein synthesis takes place. A good way to remember it is that it carries a copy of the message from the DNA - thats where it gets the name messenger from. The second type of RNA is **ribosomal RNA** (**rRNA**) this form of RNA is used to manufacture ribosomes. Remember from our lesson on the cell that ribosomes are where protein synthesis takes place. The third type of RNA is **transfer RNA** (**tRNA**). tRNA is found in the cytoplasm of the cell and is used to carry the amino acids to the ribosomes for protein synthesis. But not just any tRNA can take any amino acid to the ribosome, each tRNA can take only one specific amino acid to form the protein.

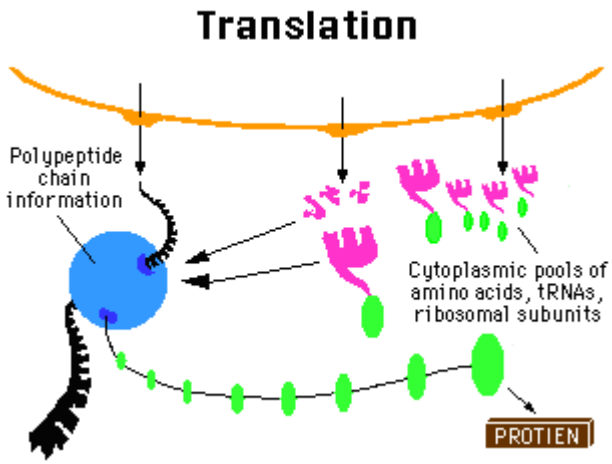
Another important tool is **RNA polymerase**. This enzyme is used in forming all these different types of RNA molecules used in protein synthesis.

Transcription

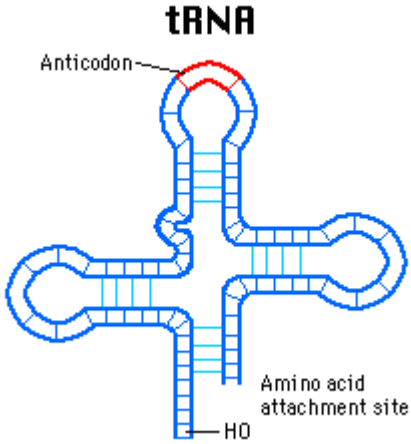


Transcription is the first step in the process by which proteins are formed and takes place in the nucleus. The word itself literally means making an exact copy of something. Transcription begins by the enzyme **RNA polymerase** unzipping a portion of the DNA molecule that carries the genetic code for a specified protein. The enzyme moves down the DNA molecule ”reading“ the genetic code and composing a strand of **mRNA** with the proper sequence of nucleotides for the protein (remember that all these sequences are made of the four bases weve talked about). We need to mention that the nucleotides are ”read“ in groups of three, and each group is referred to as a **codon**. An example then of a codon would be, ATT, GCT, or ACG - or any other combination of the bases for that matter, all depends on the sequence identified by the DNA. Each of these codons is a code word used to link the amino acids while forming the protein. The strand of mRNA lengthens until a ”stop“ message is reached. So basically, what we have after transcription takes place is a strand of mRNA that is made up of a sequence of codons copied from the DNA. The mRNA then leaves the nucleus through a pore in the nucleus into the cytoplasm where it moves into the second stage of protein synthesis - **translation**.

Translation



Since the mRNA was encoded with ”code words“ for specific amino acids, these code words need to be de-coded in order for the protein to finally be formed. This is the process of **translation**. Translation literally means to take something from one language that may not be understood by someone or something and put it in a language that is understood (like translating from Spanish to English). There is a kind of decoding device that is used. It is called the ribosome. The ribosome hooks onto the mRNA that has come from the nucleus and exposes the codons. Throughout the cytoplasm are tiny bits of RNA called **tRNA**.



The task of the tRNA is to carry (transfer) amino acids from the cytoplasm to the forming protein. The tRNAs have a specific structure and shape - that goes with their function. As you can see from the diagram, the tRNA has a part that is called the **anticodon**. The anticodon is the matching complementary base pair to whatever the sequence of codons is indicated on the mRNA. The anticodon of the tRNA is what specifies which amino acid it hooks on to and brings to the protein formation site.

The process of translation has three steps: **initiation**, **elongation**, and **termination**. The **initiation** stage is indicated by the **start codon**, and the tRNA with the complementary anticodon moves into the ribosome with its amino acid and the forming of a protein begins. The next stage is **elongation**, which is simply the continued delivery of amino acids by the tRNA molecules according to the sequence indicated on the mRNA. Elongation continues until the stop codon is reached. The **stop codon** indicates the **termination** of protein synthesis and has no corresponding amino acid, so this is an indication that the building of the protein has concluded and all the parts are released from their work. The protein that has been formed is now ready for further processing and packaging in order to be ready for its work. The mRNA breaks up, the tRNA molecules return to the cytoplasm and link with their corresponding amino acid, and the ribosome waits for the next mRNA strand to be sent from the nucleus.

To sum the whole process of protein synthesis we can say that the process starts in the nucleus of eukaryotic animals with the transcription of DNA onto a strand of mRNA for a specific protein, the mRNA moves to the cytoplasm and

hooks up with a ribosome that begins the process of translation. Tools called tRNA hook up with specific amino acids and bring them to the binding sites of the ribosome for protein synthesis. Once the process is complete, a protein has been built.

Mutations

Sometimes protein synthesis doesnt go as smoothly as it has been described here. Sometimes one nitrogenous base is substituted for another, or an extra base may be inserted, or a base is lost. These small changes are called **mutations**. Some of these mutations are caused by things like ultraviolet light, radiation, or chemical substances. The result of a mutation is the replacement of one amino acid for another, or skipping some amino acids all together while forming proteins. This can cause things like altered skin color in corn, sickle-cell anemia, just to mention some.