Cambridge AS level Biology

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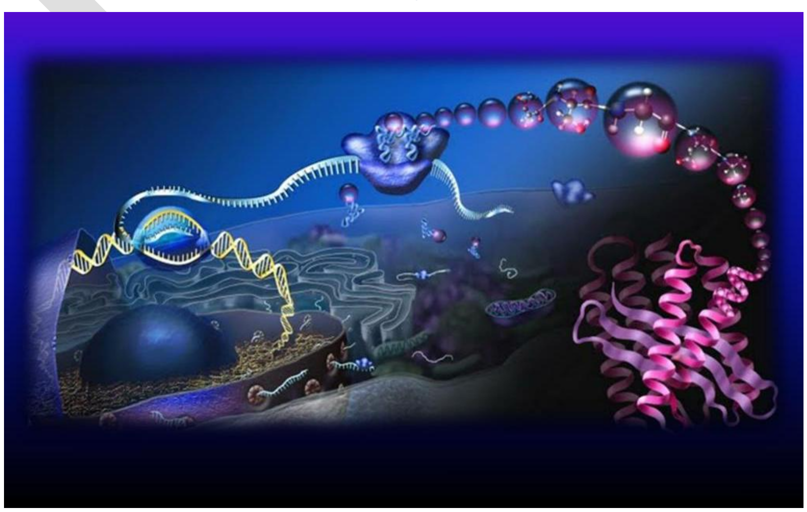
Chapter 06

Nucleic acid and protein synthesis



The structure of DNA and RNA

DNA stands for **deoxyribonucleic acid**, and RNA for **ribonucleic acid.** As we saw in Chapter 2, nucleic acids such as DNA and RNA, like proteins and polysaccharides, are **macromolecules.**

They are also **polymers**, made up of many similar, smaller molecules joined into a long chain.

The smaller molecules from which DNA and RNA molecules are made are **nucleotides**. DNA and RNA are therefore **polynucleotides**.

Nucleotides

Figure 6.2 shows the structure of nucleotides. Nucleotides are made up of three smaller components. These are:

■ A nitrogen-containing base ■ A pentose sugar ■ A phosphate group.

There are just five different nitrogen-containing bases found in DNA and RNA. In a DNA molecule, there are four: **adenine, thymine, guanine and cytosine**.

Instead, RNA molecules contain a base called **uracil**. These bases are often referred to by their first letters: **A, T, C, G and U.**

The pentose (5-carbon) sugar can be either ribose (in RNA) or **deoxyribose** (in DNA).

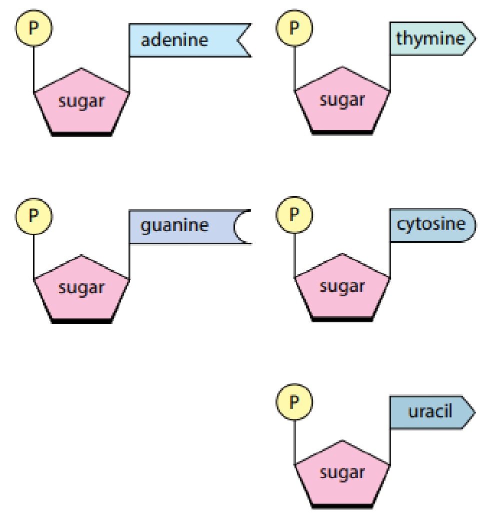


Figure 6.2 Nucleotides. A nucleotide is made of a nitrogen-containing base, a pentose sugar and a phosphate group Ⓟ.

ATP

Although ATP is not part of DNA or RNA, we will look at its structure here because it is very similiar to a nucleotide.

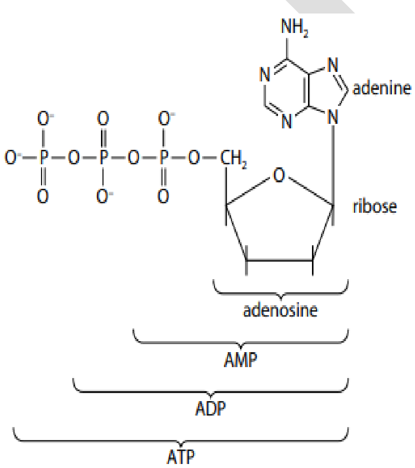
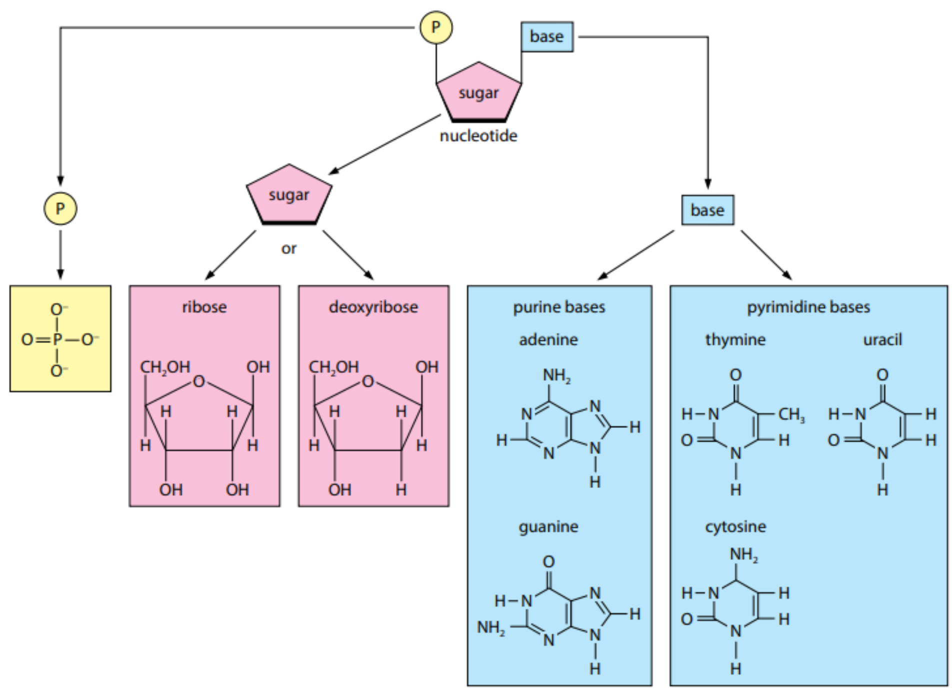


Figure 6.4 Structure of ATP.



ɀure 6.3 The components of nucleotides. Note that you do not need to learn these structural formulae.

Polynucleotides

DNA molecules are made of **two** polynucleotide strands lying side by side, running in opposite directions. The strands are said to be antiparallel. The two strands are held together by **hydrogen bonds** between the bases (Figure 6.5b and c). The way the two strands line up is very precise.

In fact, the pairing of the bases is even more precise than this. Adenine always pairs with thymine, while cytosine always pairs with guanine: **A** with **T**, **C** with **G**. This **complementary base pairing** is a very important feature of polynucleotides, as you will see later.

RNA molecules, unlike DNA, remain as **single** strands of polynucleotide and can form very different three-dimensional structures.

DNA replication

We said at the beginning of this chapter that one of the features of a 'genetic molecule' would have to be the **ability to be copied** perfectly many times over.

This idea proved to be correct. The process is shown in Figure 6.9 on page 116. This method of copying is called semi-conservative replication, because **half** of the original molecule is **kept** (conserved) in each of the new molecules.

Genes and mutations

A part of a DNA molecule, where the nucleotide sequence codes for just one polypeptide, is called a **gene**, and one DNA molecule contains many genes. A change in the nucleotide sequence of a gene, which may then result in an altered polypeptide, is called a **mutation**. Most genes have several different variants called **alleles**, which originally arose by the process of mutation

DNA, RNA and protein synthesis

DNA controls protein synthesis

DNA, a single molecule, controls all cell activities by coding proteins, which are made up of amino acids. Enzymes, proteins, control chemical reactions in cells, and DNA determines the order in which amino acids join, influencing the shape and behavior of proteins.

The triplet code

DNA molecule codes for amino acids in polypeptides through a three-letter triplet code. Each sequence of three bases represents one amino acid, read from the sense strand (lower strand) and the complementary anti-sense strand (complementary strand).

Reading from the left-hand end of the lower strand in Figure 6.12, the code is:

CAA which codes for the amino acid valine

TTT which codes for the amino acid lysine

GAA which codes for the amino acid leucine

CCC which codes for the amino acid glycine

So, this short piece of DNA carries the instruction to the cell: 'Make a chain of amino acids in the sequence valine, lysine, leucine and glycine'. The complete set of triplet codes is shown in Appendix 2.

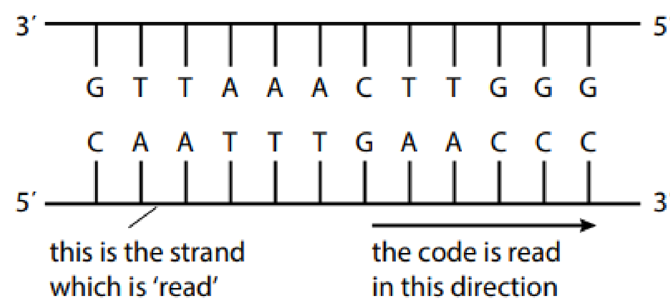


Figure 6.12 A length of DNA coding for four amino acids.

An example of mutation: sickle cell anaemia.

The gene which codes for the amino acid sequence in the β polypeptides is not the same in everyone. In most people, the β polypeptides begin with the amino acid sequence:

Val-His-Leu-Thr-Pro-Glu-Glu-LysThis is coded from the Hb^A (normal) allele of the gene.

But in some people, the base sequence CTT is replaced by CAT, and the amino acid sequence becomes:

Val-His-Leu-Thr-Pro-Val-Glu-LysThis is coded from the Hb^S (sickle cell) allele of the gene.

This type of mutation is called a substitution. In this case, the small difference in the amino acid sequence results in the genetic disease sickle cell anaemia in individuals with two copies of the Hb^S allele.

Protein synthesis

The code on the DNA molecule is used to determine the sequence of amino acids in the polypeptide.

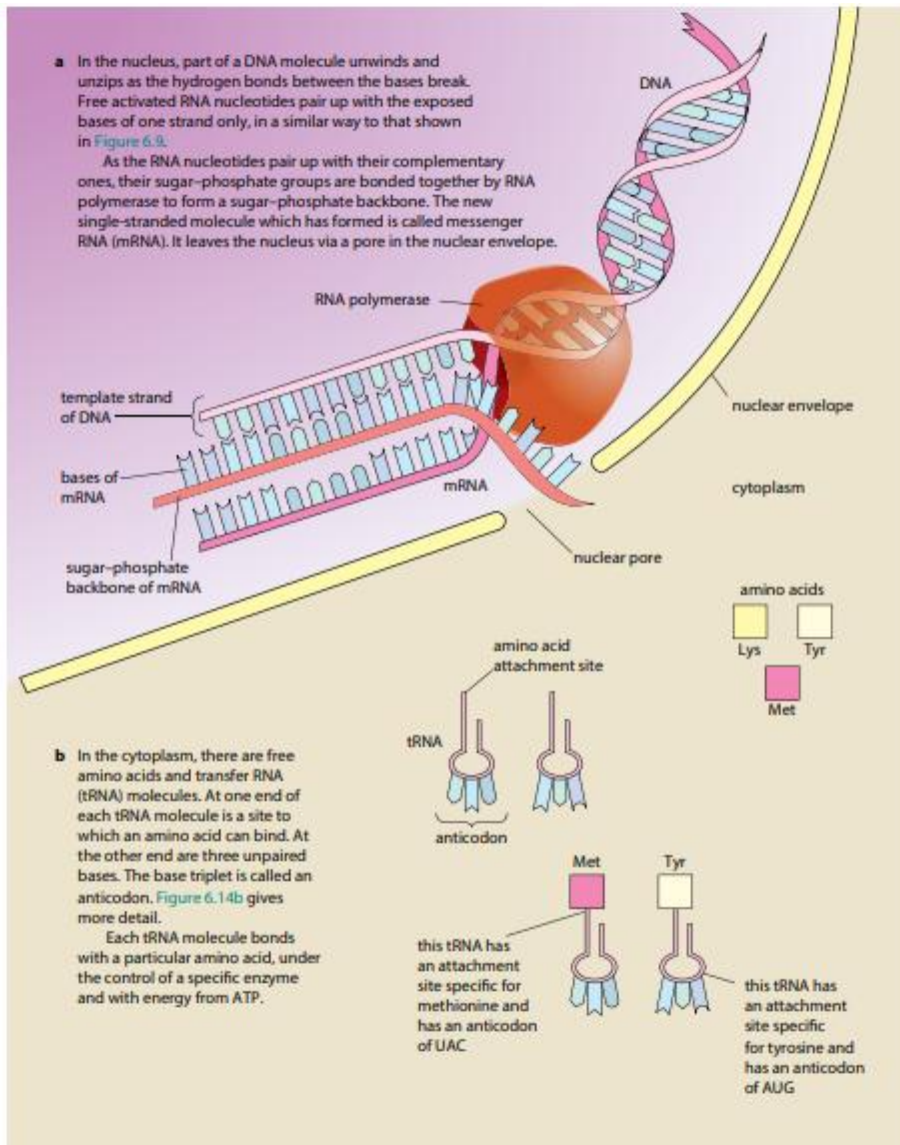


Figure 6.13 Protein synthesis – transcription.

continued ...

The first stage is called **transcription**. In the nucleus, a complimentary copy of the code from a gene is made by building a molecule of a different type of nucleic acid, called **messenger RNA** (**mRNA**), using one strand (the sense strand) as a template.

The next stage of protein synthesis is called **translation** because this is when the DNA code is translated into an amino acid sequence. The mRNA leaves the nucleus and attaches to a **ribosome** in the cytoplasm.

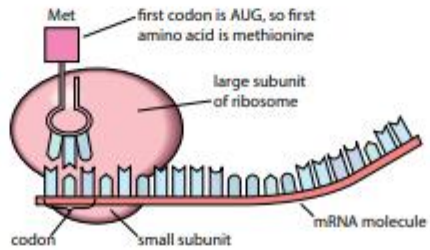
In the cytoplasm, there are molecules of **transfer RNA (tRNA).**

The triplet of bases (**an anticodon**) of each tRNA links up with a complementary triplet (**a codon**) on the mRNA molecule.

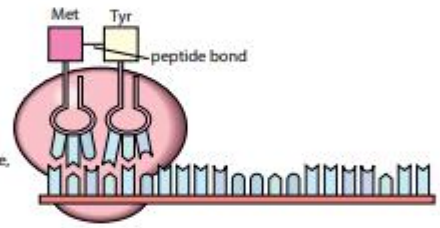
Usually, several ribosomes work on the same mRNA strand at the same time. They are visible, using an electron microscope, as **polyribosomes**.

c Meanwhile, also in the cytoplasm, the mRNA molecule attaches to a ribosome. Ribosomes are made of ribosomal RNA (rRNA) and protein and contain a small and a large subunit. The mRNA binds to the small subunit. Six bases at a time are exposed to the large subunit.

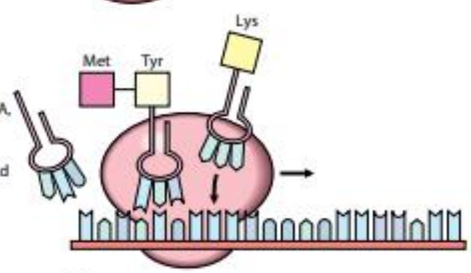
The first three exposed bases, or codon, are always AUG. A tRNA molecule with the complementary anticodon, UAC, forms hydrogen bonds with this codon. This tRNA molecule has the amino acid methionine attached to it.



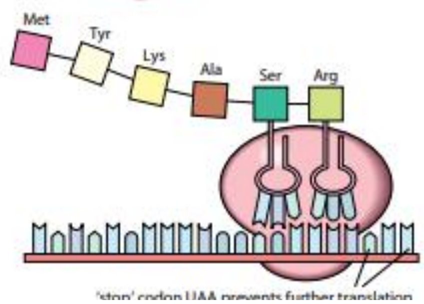
d A second tRNA molecule bonds with the next three exposed bases. This one brings a different amino acid. The two amino acids are held closely together, and a peptide bond is formed between them. This reaction is catalysed by the enzyme peptidyl transferase, which is found in the small subunit of the ribosome.



e The ribosome now moves along the mRNA, 'reading' the next three bases on the ribosome. A third tRNA molecule brings a third amino acid, which joins to the second one. The first tRNA leaves.



f The polypeptide chain continues to grow until a 'stop' codon is exposed on the This is UAA, UAC or UGA.



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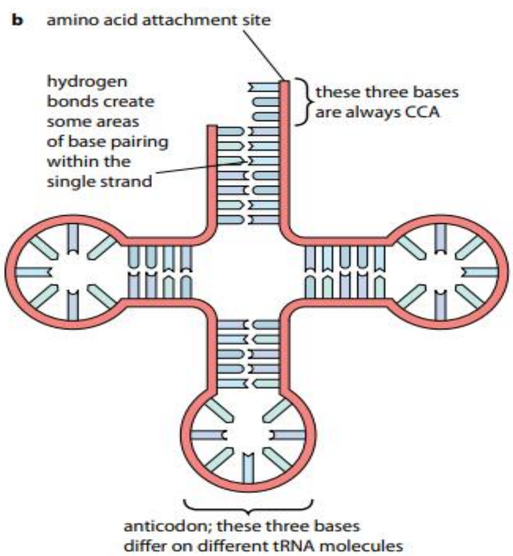


a

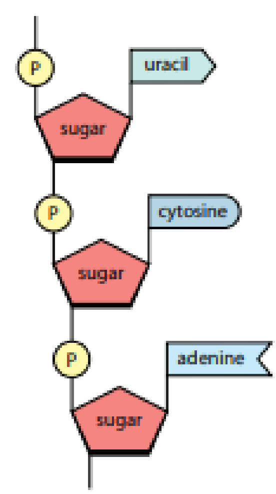


Figure 6.14 RNA **a** Part of a messenger RNA (mRNA) molecule. **b** Transfer RNA (tRNA). The molecule is a single-stranded polynucleotide, folded into a clover-leaf shape. Transfer RNA molecules with different anticodons are recognised by different enzymes, which load them with their appropriate amino acid.

Revision questions

(1) (a)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 .... on 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 .... This is released and passes to the .... where it associates with other similar molecules to make protein.

(b) The table below relates to certain features of messenger RNA and transfer RNA. If a feature is correct mark the box with a tick and if a feature is incorrect mark the box with a cross.

Feature	mRNA	tRNA
Contains anticodons		
May contain several genes/alleles		
Can associate with any amino acid		
Contains uracil instead of thymine		
A short molecule 70-90 nucleotides long.		

(2) With reference to the genetic code, explain the meaning of the terms:

(a) codon.

(b) degenerate code.

(c) non overlapping code.

(d) gene.

(e) chain termination codon

(f) The table below shows some of the 64 available codons and their associated amino acids.

Codon	Amino acid
AGG	arginine
CAG	glutamine
GGG	glycine
GGU	glycine
GUU	valine
UUA	leucine
UCA	serine
UUU	phenylalanine

(a) The diagram below shows the coding strand of a length of DNA with its bases indicated

A G T C C C A A A T DNA

(i) Identify each of the four bases:

A. ....C. .... G................ T..............................

(ii) Write down the base sequence of a length of messenger RNA that would be transcribed from this DNA.

mRNA

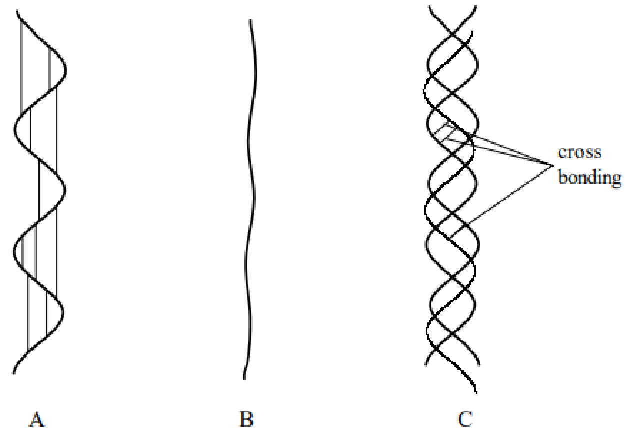
(iii) In all known life forms on Earth the code is non-overlapping. Explain what is meant by the term 'nonoverlapping

(iv) State the sequence of amino acids which would result from the DNA sequence in (a).

(v) An organism from another planet might have an overlapping code. Write down the sequence of amino acids which would be assembled in this case.

(b) Explain why glycine has two codons in the above table

(3) The drawings represent different three-dimensional structures of a protein.



(a) (i) Indicate whether A, B and C are primary, secondary, tertiary or quaternary structures. A: .... B: .... C: ....

(ii) Name two types of bonds involved in cross bonding

(iii) Is this protein a fibrous or a globular protein? Give a reason for your answer.

(b) Distinguish between each of the following pairs. (i) Primary structure and secondary structure of a protein.

(ii) Tertiary structure and quaternary structure of a protein.

(4) Explain the roles of the following in protein synthesis.

(a) ATP.

(b) Peptide bonds

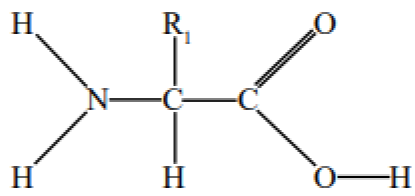
(c) Hydrogen and sulphur bonds.

(d) Complimentary bases.

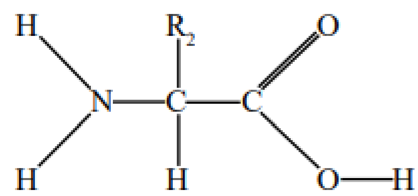
(5) The diagrams below show the structural formulae of two amino acids, X and Y

(a) (i) Name two elements other than carbon, oxygen or hydrogen which could be present in the groups R_1 and R_2.

(ii) Name a reactive chemical group, other than an acid or amine group, which could be present in R_1 and R_2.



Amino acid X



Amino acid Y

(b) During polypeptide synthesis amino acids X and Y could become linked.

(i) In the space below draw the structural formula of the dipeptide produced. Label the type of bond formed and indicate the byproduct formed.

(ii) Where in the eukaryotic cell are the primary, secondary and tertiary structures of a protein assembled?

(iii) Where in a eukaryotic cell is the quaternary structure of a protein mainly assembled?

(c) How may groups R1 and R2 be involved in the formation of the secondary, tertiary or quaternary structures of a protein?

(6) (a) In which cells are the following proteins synthesised? 1. insulin: .

2. pepsin:

3. haemoglobin:

4. antibodies:

5.somatotropin:

(b) Which of the above proteins are manufactured by genetic engineering?

(c) Protein synthesis may be switched on and off by the action of a regulator gene. Some proteins are synthesised continuously throughout life and some are only synthesised occasionally in response to a specific stimulus.

(i) How does the regulator gene act to switch protein synthesis on or off?

(ii) Name a protein from the list in

(a) which is only produced occasionally in response to a specific stimulus.

(iii) Suggest a specific stimulus which would cause synthesis of this protein

(iv) Haemoglobin synthesis is sometimes deficient. Suggest a cause for this.

(7) (a) Suggest explanations for each of the following:

(i) During polypeptide synthesis a ribosome accommodates two transfer RNA molecules at a time

(ii) A ribosome contains enzymes such as peptide synthetase (peptidyl transferase)

(iii) For polypeptide synthesis to occur, amino acids must first react with ATP

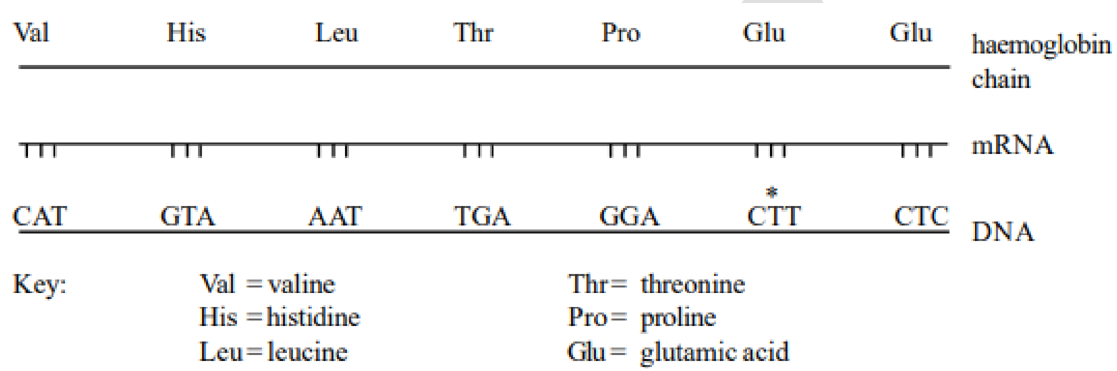
(iv) The genetic code possesses stop-go (chain termination) codons

(8) (a) For polypeptide synthesis animals can use readymade amino acids obtained through the diet. Plants, however, must synthesise their own amino acids using an available nitrogen source.

Outline the steps involved when a flowering plant, such as a daisy, manufactures its required amino acids.

(b) How would the process of obtaining amino acids differ from the daisy in a plant of the family Papilionaceae (Leguminoseae)?

(c) The diagram below shows the sequence of amino acids in part of a haemoglobin molecule. This sequence of amino acids was determined by the specified genetic code on the DNA which, in turn, determined the base sequence of the messenger RNA during transcription. The mRNA sequence was translated to form the amino acid chain of the haemoglobin



(a) Write in the complimentary base sequence on the mRNA strand on the diagram.

(b) In what way does the code in the diagram show redundancy (degeneracy)?

(c) (i) If the base marked * was substituted with A, how would the haemoglobin chain be different?

(ii) This mutation produces an abnormal form of haemoglobin called haemoglobin S. What condition is associated with this abnormality

(iii) In what ways might the haemoglobin S be abnormal?

(9) Name one cell organelle associated with high levels of the following enzymes. Describe the function of the enzyme within the organelle.

(a) DNA polymerase.

(b) RNA polymerase.

(c) Cytochrome oxidase

(d) Peptide synthetase (Peptidyl transferase).