



Protein synthesis I - Nucleic Acids

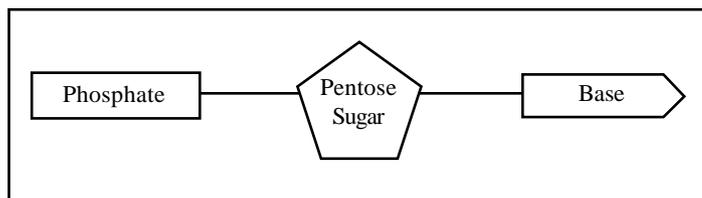
Proteins are large, organic molecules which play a fundamental role in metabolic activities including nutrition, respiration, transport, sensitivity, co-ordination and reproduction.

The characteristics of cells and organisms are determined by the particular proteins which are present. The synthesis of these proteins involves two types of nucleic acid; DNA and RNA. **DNA** is contained within the nucleus of a cell and carries the code to determine which particular proteins are made. Various forms of **RNA** then carry this information to the cytoplasm of the cell and assemble the protein. To understand protein synthesis, you must first have an understanding of DNA and RNA.

Nucleic acids

DNA and RNA are both nucleic acids. Nucleic acids are macromolecules (large molecules) made up of chains of individual units called **nucleotides**. Each nucleotide is made up of 3 parts (Fig 1):

Fig 1. Diagrammatic representation of a nucleotide



1. A **phosphate group** (H_3PO_4), which is the same in all nucleotides.
2. A **pentose (5 carbon atoms) sugar**. This sugar can either be **ribose** sugar ($C_5H_{10}O_5$) or **deoxyribose** sugar ($C_5H_{10}O_4$)
3. One of five **nitrogenous bases**. These bases are divided into two types, depending on their structure (Fig 2):
 - (a) **Purines** - Bases made up of one six-sided ring and one five-sided ring.
 - (b) **Pyrimidines** - Bases made up of a single six-sided ring. The details of these rings are given in Table 1.

Fig 2. The ring structure of pyrimidines and purines

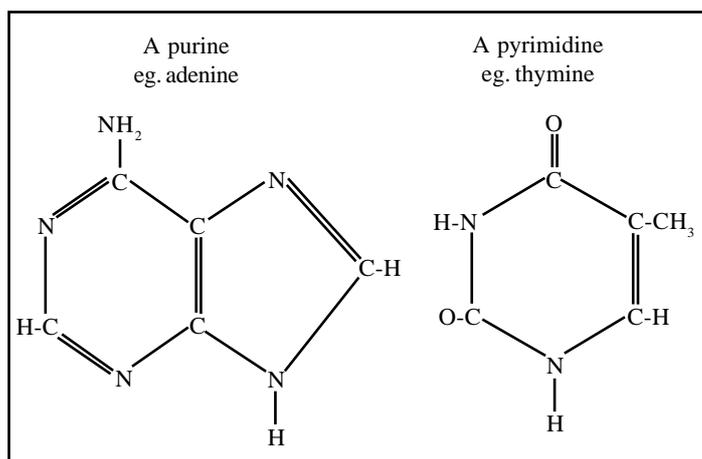
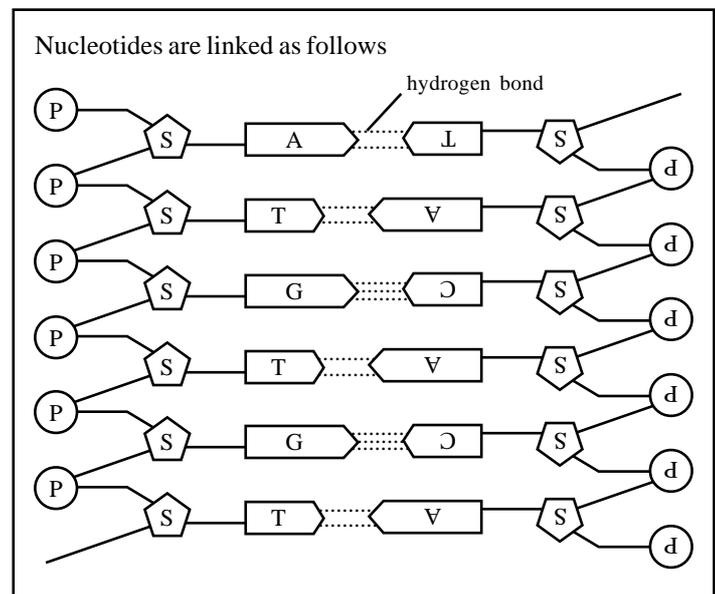


Table 1. Nitrogenous bases in nucleic acids

Ring structure	Base	Symbol	Nucleic acid
Purine (double)	Adenine	A	DNA/RNA
	Guanine	G	DNA/RNA
Pyrimidine (single)	Cytosine	C	DNA/RNA
	Thymine	T	DNA
	Uracil	U	RNA

The three components of nucleotides are joined together by **condensation** reactions (through the removal of water). Individual nucleotides are then joined together by similar condensation reactions between the phosphate group of one nucleotide and the pentose sugar of another (Fig 3). This linkage of nucleotides forms long chains, called **polynucleotides**, which make up nucleic acids.

Fig 3. Formation of a polynucleotide



From Fig 3, it can be seen that polynucleotides have a 'backbone' of phosphate and sugar, with the nitrogenous bases projecting inwards.

Exam hint - Not all Examination Boards require candidates to be able to recognise purines and pyrimidines but all expect candidates to know that purines are larger molecules than pyrimidines and that A and G are purines etc.

Comparing DNA & RNA

DNA and RNA are both vital in protein synthesis. Table 2 summarises the similarities and differences between these two macromolecules:

Table 2. Comparison of DNA and RNA

DNA	RNA
Formed in nucleus	Formed in nucleus
Predominantly found in nucleus	Found throughout the cell
Double strand of nucleotides - coiled into a double helix. The two strands are linked by hydrogen bonding between the bases (Fig 3): Cytosine with Guanine, Adenine with Thymine	Single strand of nucleotides which can be folded into different shapes
Pentose sugar present - Deoxyribose	Pentose sugar present - Ribose
Bases present: Cytosine, Guanine, Adenine, Thymine	Bases present: Cytosine, Guanine, Adenine, Uracil
Larger molecule	Smaller molecule
One basic form	Three main forms: messenger RNA, transfer RNA, ribosomal RNA
Ratio of 1:1 for adenine:thymine, and cytosine:guanine	Ratio of adenine:thymine, and cytosine:guanine variable

Exam hint - Do not confuse thymine with thiamine.

To summarise, DNA and RNA are both made up of nucleotides. In DNA, there are two nucleotide strands which are wound around each other at approximately every ten bases. Thus DNA forms a helix. The strands are **anti-parallel** - i.e. they run in opposite directions to each other. The two strands of nucleotides which make up the DNA double helix are held together by the **hydrogen bonding** between nitrogenous bases. This pairing is always as follows:

- **Adenine with Thymine (A-T)**
- **Cytosine with Guanine (C-G)**

The different structures of the bases result in two hydrogen bonds being formed A to T (A=T), and three hydrogen bonds between C to G (C≡G).

The bonding of the nitrogenous bases ensures that purines always bond with pyrimidines, and more specifically, A to T and C to G. The precise nature of this bonding is biologically important for two reasons:

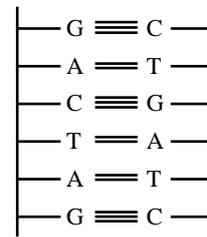
1. The structure of DNA remains exact and regular. This is vital since DNA carries the heredity material for an individual.
2. DNA can exist as a very long sequence of bases, with an enormous variety in order, to carry the large amount of genetic information for an individual.

DNA Replication

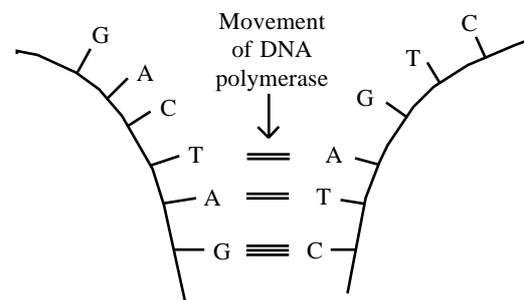
The replication of DNA takes place shortly before cell division, during a phase of the cell cycle called **interphase**. DNA replication is said to be **semi-conservative**. This means that when two new double helixes of DNA are produced, one of the strands of each helix is from the original (parental) DNA strand and the other is new. The sequence of diagrams in Fig 4 illustrate the replication of DNA.

Fig 4. Replication of DNA

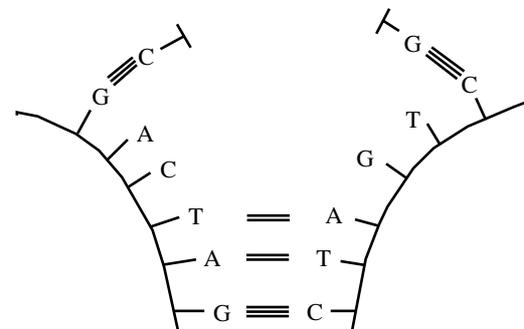
1. A portion of the DNA double helix about to be replicated



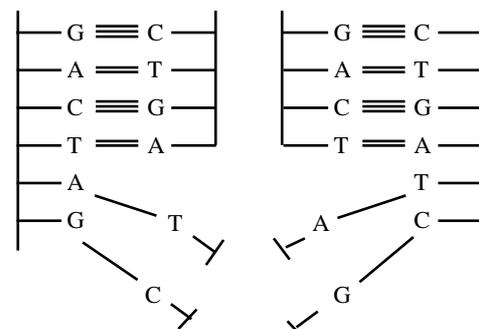
2. Replication has started. The enzyme **DNA polymerase** moves along the DNA double helix unwinding it and 'unzipping it' by breaking the hydrogen bonds between the nitrogenous bases.



3. **Free nucleotides** in the nucleoplasm of the nucleus are attracted to the exposed complementary bases and form new hydrogen bonds with them.



4. DNA polymerase continues to move along the DNA, exposing the bases for free nucleotides to come into and bond. Once these new nucleotides are in place they bond together (phosphate to deoxyribose sugar) forming a new strand of DNA.



5. Replication is now complete, forming two identical strands of DNA which are exact copies of the original strand. This method is said to be semi-conservative, since each strand retains **half** of the original DNA material.

Evidence for semi-conservative DNA replication

The evidence for semi-conservative DNA replication came from experiments by **Matthew Meselsohn** and **Franklin Stahl**, two scientists at the California Institute of Technology, using the bacterium *Escherichia coli*. Matthew and Franklin experiments can be explained in the following series of steps:

1. *E. coli* were cultured in a growth medium containing nitrogen in the form of the isotope ^{15}N (known as 'heavy nitrogen').
2. By leaving the *E. coli* in the culture for a long enough period of time, all DNA in the *E. coli* became made up of 'heavy nitrogen'. This meant that the molecular weight of the DNA in these *E. coli* was measurably greater.
3. The *E. coli* containing the 'heavy nitrogen' were then placed into a medium containing normal nitrogen (^{14}N), so that any new DNA manufactured would be from this normal nitrogen.
4. The *E. coli* was allowed to divide once and the first generation cells were then collected.
5. When the DNA was extracted from these cells and the relative weight determined using a centrifugation technique, the molecular weight of the DNA was found to be **intermediate** between heavy and light types. This confirmed that the DNA was made up of one original (heavy) strand of DNA and one new (light) strand of DNA - Semi-conservative replication.

Practice Questions

1. Define the following terms:
 - (a) DNA double helix (3 marks)
 - (b) complementary base pairing (3 marks)
 - (c) semi-conservative replication of DNA (2 marks)

2. (a) Read through the following account of DNA replication, then find the most appropriate word or words to complete the account.

During DNA replication, the enzyme binds to the DNA double This causes the DNA to and breaks the bonds between the nucleotides. These nucleotides are bound together at bases. The base adenine binds with and binds with guanine. Free nucleotides found in the bind with the exposed bases producing two strands of DNA. The process is said to be because in both of the two DNA strands produced, one sequence of nucleotides is new and the other is from theDNA. (10 marks)

- (b) When a sample of DNA is extracted from the nucleus of a cell, chemical analysis showed that 38% of the bases were adenine. What percentage of the bases are guanine (3 marks)

3. DNA and RNA are major molecules involved in the transfer of hereditary material and protein synthesis.
 - (a) To which group of molecules do DNA and RNA belong? (1 mark)
 - (b) DNA and RNA are both composed of nucleotide sub-units. Describe the structure of a nucleotide. (3 marks)
 - (c) State four similarities and four differences between a DNA molecule and an RNA molecule (8 marks)

Answers

Marking points are shown by semicolons

1. (a) Two strands of nucleotide; held together by hydrogen bonding; coiled or twisted around each other (approximately every 10 bases).
 - (b) hydrogen bonding between pairs of organic bases; (projecting from the sugar-phosphate backbone of nucleic acids); pairing occurs between adenine-thymine, guanine-cytosine in DNA; pairing between adenine-uracil, guanine-cytosine in RNA. (Any 3)
 - (c) Half of the original parent molecule is retained/conserved; half is composed of new nucleotide molecules.
2. (a) DNA polymerase; helix; unwind; hydrogen; nitrogenous/exposed; thymine; cytosine; nucleoplasm/nucleus; semi-conservative; parental/original.
 - (b) 38% adenine, \therefore 38% thymine; remaining 24% is cytosine and guanine (50% each); \therefore 12% guanine.
3. (a) nucleic acids.
 - (b) phosphate; ribose/5C sugar; nitrogenous base; components joined by condensations reactions
 - (c) (see Table 2)

Acknowledgements;

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