14 Molecular Genetics

Content

14.1 The Structure of DNA

14.2 The Role of DNA in Protein Synthesis

14.3 Genes

14.4 Genetic Engineering and Medical Biotechnology

Learning Outcomes

Candidates should be able to:

(a) outline the relationship between DNA, genes and chromosomes

(b) state the structure of DNA in terms of the bases, sugar and phosphate groups found in each of their nucleotides

(c) state the rule of complementary base pairing

(d) state that DNA is used to carry the genetic code, which is used to synthesise specific polypeptides (details of transcription and translation are **not** required)

(e) state that each gene is a sequence of nucleotides, as part of a DNA molecule

(f) explain that genes may be transferred between cells. Reference should be made to the transfer of genes between organisms of the same or different species – transgenic plants or animals

(g) briefly explain how a gene that controls the production of human insulin can be inserted into bacterial DNA to produce human insulin in medical biotechnology

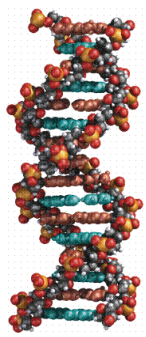
(h) discuss the social and ethical implications of genetic engineering, with reference to a named example

14.1 The Structure of DNA

Structure of DNA [*Examined in* 2010p2.9b]

DNA stands for deoxyribonucleic acid. It is a molecule that stores genetic information.

- DNA (deoxyribonucleic acid) is found in the nucleus of a cell.
  [*Examined in* 2010p1.36]
- DNA is a molecule that is made up of two strands that are tied together by hydrogen bonds; each strand being made up of a sugar, a phosphate group and one of four bases.
- The roles of DNA in living organisms are:
  - it constitutes the hereditary material of living organisms.
  - it acts as a long-term storage of genetic information that determines an organism's form and thus governs its existence. It is the sequence of the four bases along the DNA's sugar-phosphate backbone that encodes information.
  - its ability to be transmitted from generation to generation, ensuring a species' survival.
  - it is involved in protein synthesis.
- DNA is a long polymer of simple units called **nucleotides**, which consist of a base with a backbone made of sugars and phosphate groups joined by ester bonds.
  [*Examined in* 2015p1.34]
- One of four types of bases is attached to each sugar. It is the sequence of these four bases along the backbone that encodes information.


The DNA double helix

- These four bases are *adenine*, *cytosine*, *guanine* and *thymine*.
- In living organisms, DNA does not usually exist as a single molecule, but instead as a tightly-associated pair of molecules. These two long strands are entwined like vines, in the shape of a *double helix*.

Complementary base pairing

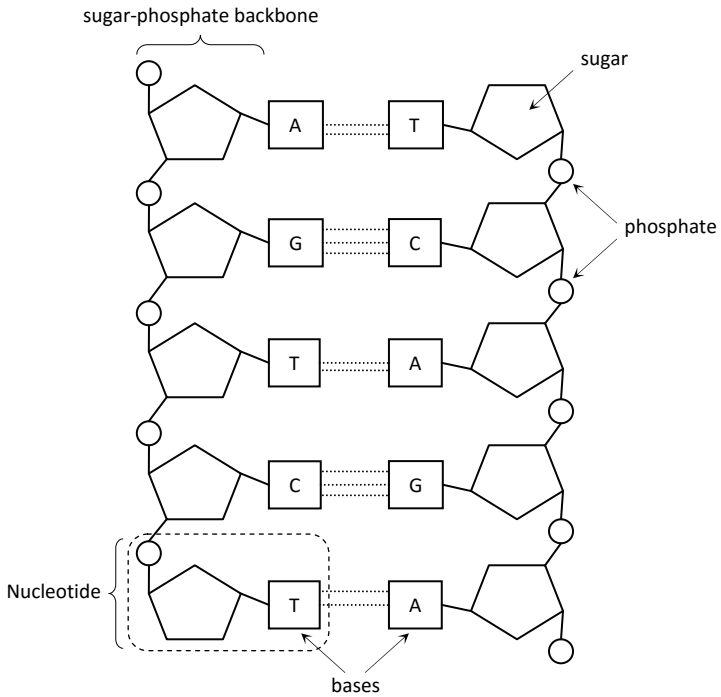
- Each type of base on one strand forms a bond with just one type of base on the other strand. This is called **complementary base pairing**.
- The two strands of DNA in a double helix can be pulled apart like a zipper, either by a mechanical force or high temperature.
- As a result of this property, all the information in the double-stranded sequence of a DNA helix is duplicated on each strand, which is vital in DNA replication.

- This reversible and specific interaction between *complementary base pairs* is critical for all the functions of DNA in living organisms.

- The following are the rules of base pairing:
  - Cytosine (**C**) always pairs with guanine (**G**)
  - Adenine (**A**) always pairs with thymine (**T**)
  - Therefore, in a DNA molecule, the amount of A and T are the same while the amount of G and C are the same.

[***Examined in*** 2014p1.34, 2013p1.34, 2012p1.34]

- The following is a diagram showing the chemical structure of DNA:



[***Examined in*** 2015p1.34]

Worked Example

Example 1

(a) What is the relationship between DNA, gene and chromosome?

(b) Describe the structure of DNA.

(c) What is meant by complementary base pairing?

Solution:

(a) DNA is a molecule that forms the building block for genetic information storage.

Gene is a sequence of DNA that describes a particular characteristic of an organism.

Chromosome consists of a linear sequence of genes that determines the individual characteristics of an organism.

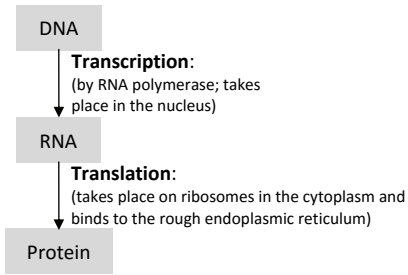
(b) DNA is a long polymer of simple units called nucleotides, with a backbone made of sugars and phosphate groups joined by ester bonds. Attached to each sugar is one of four types of molecules called bases. These four bases are *adenine*, *cytosine*, *guanine* and *thymine*.

(c) Complementary base pairing is the bond formed between each type of base on one DNA strand with just one type of base on the other DNA strand.

14.2 The Role of DNA in Protein Synthesis

Function of DNA [*Examined in* 2010p2.9b]

- DNA <u>stores</u> the information for protein synthesis
- The diagram describes the flow of genetic information from DNA to protein:



- DNA is found in the nucleus but protein synthesis occurs in the cytoplasm. Therefore there is a need to <u>transfer</u> the genetic information from the nucleus to the cytoplasm.
- The *messenger ribonucleic acid* (mRNA) is the entity that fulfils the transfer of genetic information from the nucleus to the cytoplasm. mRNA is produced by *transcribing* (copying) DNA in the nucleus. After which, mRNA is moved into the cytoplasm where the ribosomes are located.
- The ribosome translates (converts) the message in the mRNA into a protein molecule.

14.3 Genes

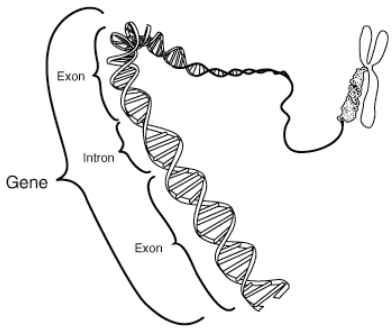
Genes

Gene is a hereditary unit consisting of a sequence of DNA that occupies a specific location on a *chromosome* and determines a particular characteristic in an organism.

[***Examined in*** 2012p2.1a]

- Each gene is a sequence of nucleotides (i.e. a single polypeptide), as part of a DNA molecule and controls the production of one protein.

[***Examined in*** 2013p1.35, 2012p1.35, 2011p1.34, 2010p1.34]



- Every gene consists of a linear sequence of bases in a nucleic acid molecule.
- Genes are specified by the sequence of bases in DNA in prokaryotic and eukaryotic cells, and in DNA or RNA in prokaryotic or eukaryotic viruses.
- The main function of gene is the formation of structural and regulatory RNA molecules and proteins. These macromolecules carry out the biochemical reactions and provide the structural elements that make up cells.

Chromosome

Chromosome is a threadlike structure which is found in the nucleus of plant and animal (eukaryotic) cells. It is composed of *chromatin* and carries the genes in linear sequence that determines the individual characteristics of the organism.

- Within the chromosomes, chromatin proteins such as *histones* compact and organise DNA, which helps control its interactions with other proteins.
- DNA specifies the synthesis of *polypeptides*. A gene does not build a protein directly, but rather dispatches instructions in the form of RNA (ribonucleic acid), which in turn programs protein synthesis.


Human chromosomes

- The chain of command is from DNA in the nucleus of the cell to RNA to protein synthesis in the cytoplasm.

Worked Examples

Example 1

(a) What is a gene?

(b) What is the main function of a gene?

Solution:

(a) Gene is a hereditary unit consisting of a sequence of DNA that occupies a specific location on a chromosome and determines a particular characteristic in an organism.

(b) The main function of gene is the formation of structural and regulatory RNA molecules and proteins. These macromolecules carry out the biochemical reactions and provide the structural elements that make up cells.

Example 2

What is the role of DNA in protein synthesis?

Solution:

(a) DNA specifies the synthesis of proteins such as polypeptides. A gene does not build a protein directly, but rather dispatches instructions in the form of RNA, which in turn programs protein synthesis in other parts of the cell.

Example 3

What is the relationship between DNA, gene and chromosome?

Solution:

DNA is a molecule that forms the building block for genetic information storage.

Gene is a sequence of DNA that describes a particular characteristic of an organism.

Chromosome consists of a linear sequence of genes that determines the individual characteristics of an organism.

14.4 Genetic Engineering and Medical Biotechnology

Explain

- *Generic engineering* is used to produce desirable traits in the production of substance like herbicides.

- Genes of one cell may be transferred to another cell of the same or different species. Hence desirable traits of one organism could be introduced into another organism of a different species.

- Genetically modified organisms are also known as **transgenic** organisms, e.g. *transgenic* animal and *transgenic* plants.

[***Examined in*** 2015p1.35, 2013p2.9a]

- Bacterial plasmids can carry virtually any gene and can self-replicate inside the bacteria; they are key tools in *recombinant DNA technology*.

Genetically engineered sheep-goat

- The bacterium, with its recombinant plasmid, is allowed to reproduce. As the bacterium forms a cell clone (a group of identical cells descended from a single ancestral cell), any genes carried by the recombinant plasmid area are also cloned.

- Diabetes patients depend on insulin treatment. Before 1982, the main sources of this hormone were pig and cattle tissues. Insulin extracted from these animals is chemically similar, but not identical, to human insulin, and it causes harmful side effects in some people.

Genetically engineered wheat

- Genetic engineering has largely solved this problem by developing bacteria that actually synthesize and secrete human insulin. With this technique, human insulin can now be produced on a commercial scale.

- Some applications of genetic engineering technology are:

Applications	Mode of action
Control of disease	• Blocking of mosquito-borne disease.
Crops and farm animals	• To supplement dwindling world food supply. • Sweet corn with better taste, better resistance to pests.
Pharmaceuticals	• In human growth hormones. • Insulin to help in the fight against diabetes.
Therapy	• For treatment of inherited diseases. • Gene therapy to target only affected tissues.
Fingerprinting	• In organ donations and transplants • Used in criminal investigation.
Artificial life form	• The research of creating a life form from genes.

[***Examined in*** 2013p2.9b]

- The advantages of genetic engineering are:
  - Recombinant bacteria are used to mass-produce gene products such as human insulin and human growth hormone.
  - Choice of gene carrying medium, e.g. yeasts are often better than bacteria at producing eukaryotic proteins, such as those used to make vaccines.
  - Harmless viruses can be engineered to carry genes from disease-causing organisms and used to make vaccines.
  - Genetic engineering technology has been used to produce new genetic varieties of plants and animals.

- The dangers of genetic engineering are:
  - The safety of releasing genetically altered organisms into the environment that might disrupt ecosystems has been questioned.
  - Some scientists worry that the spread of transgenes through cross-pollination could lead to a reduction in genetic diversity in important crops.

Insulin production

- Existing commercial insulin production methods typically rely on yeast (Saccharomyces cerevisiae) or bacteria (E. coli) genetically engineered to produce synthetic human insulin.

- These organisms are grown in broths in large, steel bioreactors called the *fermenters*.

- During production of insulin, three factors are kept constant for the broth in the fermenter:
  - temperature
  - pH value
  - oxygen and nutrient levels

[***Examined in*** 2013p2.9c]

- Insulin is then extracted and purified for final formulation.

Social and ethical implications of genetic engineering

- While genetic engineering brings about numerous benefits in improving the quality of living of humans, there are also social and ethical implications that need to be considered:
  - Would offspring of parents who could not afford to genetically 'modify' them while still in an embryo, have a chance of achieving high standards of living compared to the people who were 'modified' to be perfect? Should government pay for genetic engineering to prevent this inequality?
  - Is it ethical to experiment on embryos that have yet to be born?
  - How would genetic engineering be used to revolutionise warfare?
  - Can we and should we eliminate the flaws in human nature that cause violence and conflict through genetic engineering?
  - In gene therapy, does the government have a right to limit what people do with their own bodies?
  - In combining human genes and non-human genes, and modifying non-humans with human genes, the question comes about what makes something human or not?
  - If gene therapy can ever prevent aging, how far does the moral obligation to save lives extend?
  - If a person's genetics are drastically altered, should they still be considered the same person?

Worked Examples

Example 1

(a) What is genetic engineering?

(b) Explain how a gene that controls the production of human insulin can be inserted into bacterial DNA to produce human insulin in medical biotechnology.

Solution:

(a) Genetic engineering is the manipulation of an organism's genes by introducing or eliminating specific genes through molecular biology techniques.

(b) This can be done using recombinant DNA technology. A human gene responsible for insulin production is inserted into a bacterium. Bacterial plasmids can carry virtually any gene and can self-replicate inside the bacteria.

The bacterium, with its recombinant plasmid, is allowed to reproduce. As the bacterium forms a cell clone (a group of identical cells descended from a single ancestral cell), any genes carried by the recombinant plasmid area are also cloned.

These bacteria that secrete insulin are bred on a large scale to harvest insulin for medical use.

Example 2

What are the social and ethical implications of genetic engineering?

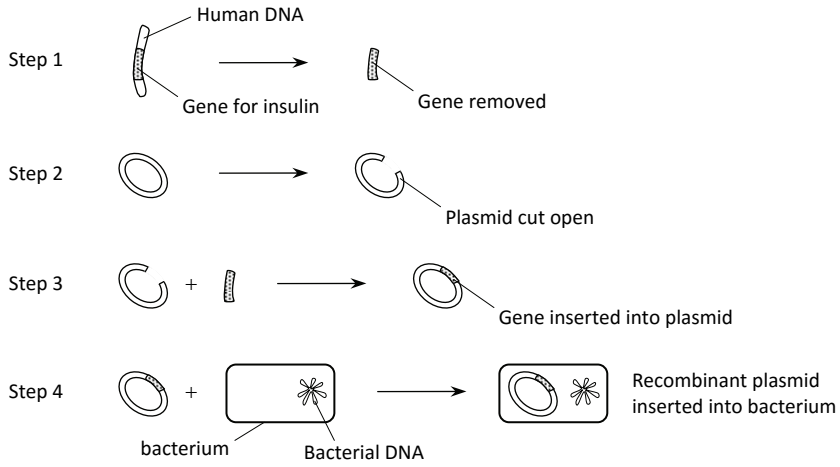
Solution:

- Affordability of genetic engineering. Should government pay for genetic engineering to prevent this inequality?
- Is it ethical to experiment on embryos that have yet to be born?
- How would genetic engineering be used to revolutionise warfare?
- Can we and should we eliminate the flaws in human nature that cause violence and conflict through genetic engineering?
- In gene therapy, does the government have a right to limit what people do with their own bodies?
- In combining human genes and non-human genes, and modifying non-humans with human genes, the question comes about what makes something human or not?
- If gene therapy can ever prevent aging, how far does the moral obligation to save lives extend?
- If a person's genetics are drastically altered, should they still be considered the same person?

Example 3

[***Examined in*** 2014p1.35, 2011p1.35, 2010p1.35]

A human gene responsible for insulin production is inserted into a bacterium plasmid using recombinant DNA technology. The diagrams below show four steps in the process.



DNA ligase enzyme is a specific type of enzyme that facilitates the joining of DNA strands together.

DNA restriction enzyme is an enzyme that cuts DNA at specific sites of the DNA sequence.

DNA polymerase enzyme is an enzyme that replicates DNA.

Which of the following is correct about the type of enzymes used?

	Step	Ligase enzyme	Restriction enzyme
A	1	Y	N
B	2	N	Y
C	3	N	Y
D	4	Y	N

Solution:

B (ans)

Restriction enzymes are used in steps 1 and 2. Ligase enzyme is used in step 3.