VCE BIOLOGY UNIT 3 & 4
Australian Curriculum

WORKBOOK

# Biology

## TOPICS

**UNIT 3: HOW DO CELLS MAINTAIN LIFE?**

Area of Study 1: What is the role of nucleic acids and proteins in maintaining life?

Area of Study 2: How are biochemical pathways regulated?

**UNIT 4: HOW DOES LIFE CHANGE AND RESPOND TO CHALLENGES?**

Area of Study 1: How do organisms respond to pathogens?

Area of Study 2: How are species related over time?

SASTA South Australian Science Teachers Association

Supporting Teachers of Science
**Advancing Science Education**

**FIRST EDITION**
Rhys Lewis

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## UNIT 4: HOW DOES LIFE CHANGE AND RESPOND TO CHALLENGES?

### Area of Study 1: How do organisms respond to pathogens?



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# UNIT 3:
## How do cells maintain life?

### AREA OF STUDY 1: What is the role of nucleic acids and proteins in maintaining life?

#### 3.1 The Relationship Between Nucleic Acids and Proteins

## 3.1 The Relationship Between Nucleic Acids and Proteins

### 3.1.1 Nucleic Acids

Nucleic acids are information molecules that encode instructions for the synthesis of proteins: the structure of DNA, the three main forms of RNA (mRNA, rRNA and tRNA) and a comparison of their respective nucleotides.



Living things rely on precise instructions to build and maintain the complex cellular structures and functions necessary for life. These instructions are encoded in **nucleic acids**, a class of macromolecules in cells that store, transmit, and regulate genetic information. Two key types of nucleic acids, **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**, work together to direct the synthesis of proteins, which are essential for cellular structure and function.

## Nucleic Acids

Nucleic acids are polymers known as **polynucleotides**, which consist of repeating subunits called **nucleotides** (Figure 3.01). A nucleotide is composed of three fundamental components: a **sugar**, a **nitrogenous base**, and a **phosphate group** (Figure 3.01). There are two main categories of nitrogenous bases: **pyrimidines** and **purines**. Pyrimidines have a single six-membered ring composed of carbon and nitrogen atoms. The three pyrimidine bases are **cytosine (C)**, **thymine (T)**, and **uracil (U)**. Purines, in contrast, are larger and consist of a six-membered ring fused to a five-membered ring. The two purines are **adenine (A)** and **guanine (G)**. Adenine, guanine, and cytosine are found in both DNA and RNA, while thymine is exclusive to DNA, and uracil is unique to RNA. The nitrogenous bases are covalently bonded to a sugar molecule. In DNA, the sugar is **deoxyribose**, whereas in RNA, it is **ribose** (Figure 3.01). The sugar contains five carbon atoms, numbered 1' to 5' (pronounced "one-prime" to "five-prime"). The 5' carbon is covalently bonded to a phosphate group within the same nucleotide. In contrast, the 3' carbon is covalently bonded with the phosphate group of the next nucleotide, creating the **sugar-phosphate backbone** of the polynucleotide strand.

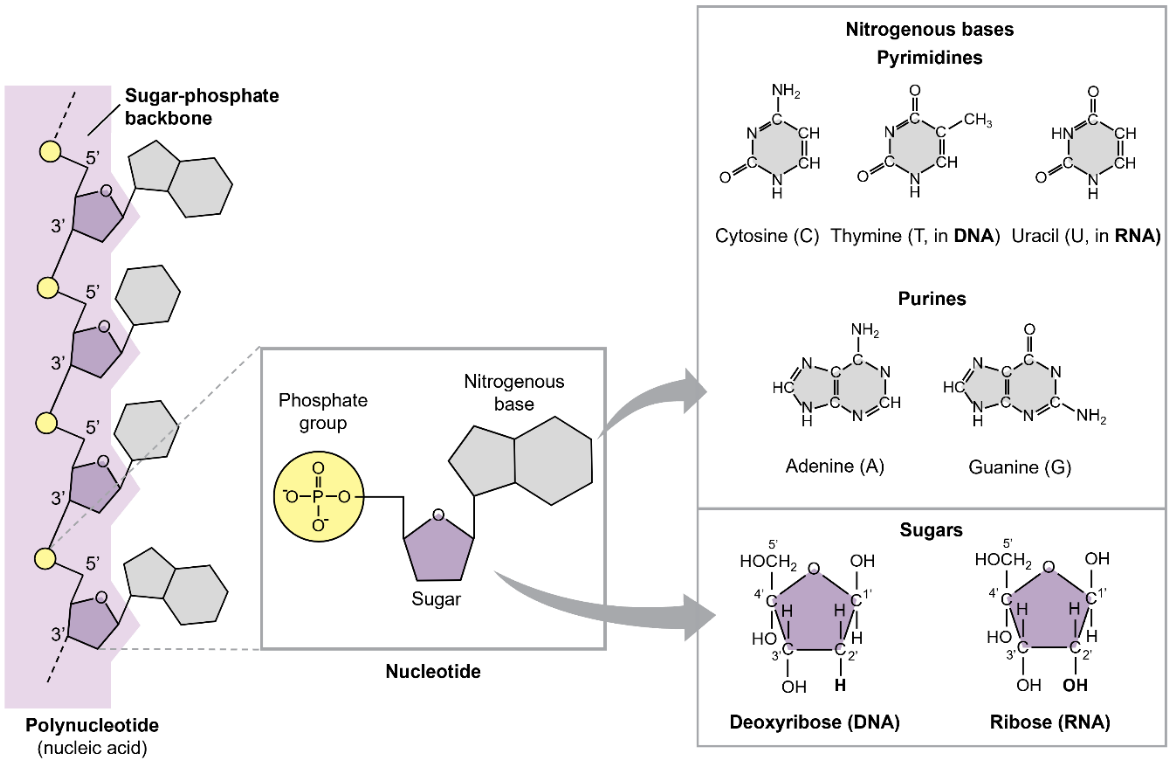



**Figure 3.01**: Components of Nucleic Acids

## The Structures of DNA and RNA Molecules

A DNA molecule consists of two polynucleotide strands that coil around an imaginary axis, forming a double helix (**Figure 3.02**). The sugar-phosphate backbones of each strand run in opposite 5' → 3' directions, a structural arrangement known as **antiparallel**. In the double helix, the sugar-phosphate backbones are positioned on the outside, while the nitrogenous bases are aligned in the interior, where they pair through weak electrical forces of attraction called **hydrogen bonds** (**Figure 3.02**). Each DNA strand is complementary to the other due to specific base-pairing rules: Adenine (A) always pairs with thymine (T), and Guanine (G) always pairs with cytosine (C). This complementarity ensures if one strand has the sequence 5'-AGGTCCG-3', the opposing strand must have the sequence 3'-TCCAGGC-5'. Because each strand serves as a template for its counterpart, DNA can be accurately replicated before cell division, ensuring that genetic information is transmitted to daughter cells. This structural feature is fundamental to DNA's role in heredity.

Unlike DNA, RNA molecules are usually comprised of a single polynucleotide strand. However, complementary base pairing can still occur, either between two RNA molecules or within different regions of the same molecule. This internal base pairing allows RNA to fold into complex three-dimensional structures, which are crucial for its function. For example, transfer RNA (tRNA), a type of RNA involved in protein synthesis, is about 80 nucleotides long and adopts a specific three-dimensional shape due to internal base pairing (**Figure 3.02**). Another key difference between RNA and DNA is in base pairing: adenine (A) pairs with uracil (U) in RNA, replacing thymine (T), which is exclusive to DNA. Furthermore, DNA molecules have a double helix structure, while RNA molecules are highly variable in structure.

RNA molecules play diverse and essential roles in cells, with **messenger RNA (mRNA)**, **transfer RNA (tRNA)**, and **ribosomal RNA (rRNA)** being the three main types involved in protein synthesis. mRNA serves as the intermediate between DNA and protein synthesis. It is transcribed from DNA and carries genetic instructions to the ribosome, where it directs the assembly of amino acids into a polypeptide chain. tRNA ensures the correct sequence of amino acids in the growing protein. rRNA is a key component of ribosomes, the cell's protein factories. It helps catalyse peptide bond formation and provides structural support to the ribosome. Together, these RNA types ensure the accurate synthesis of proteins, which are vital for cellular function and life.

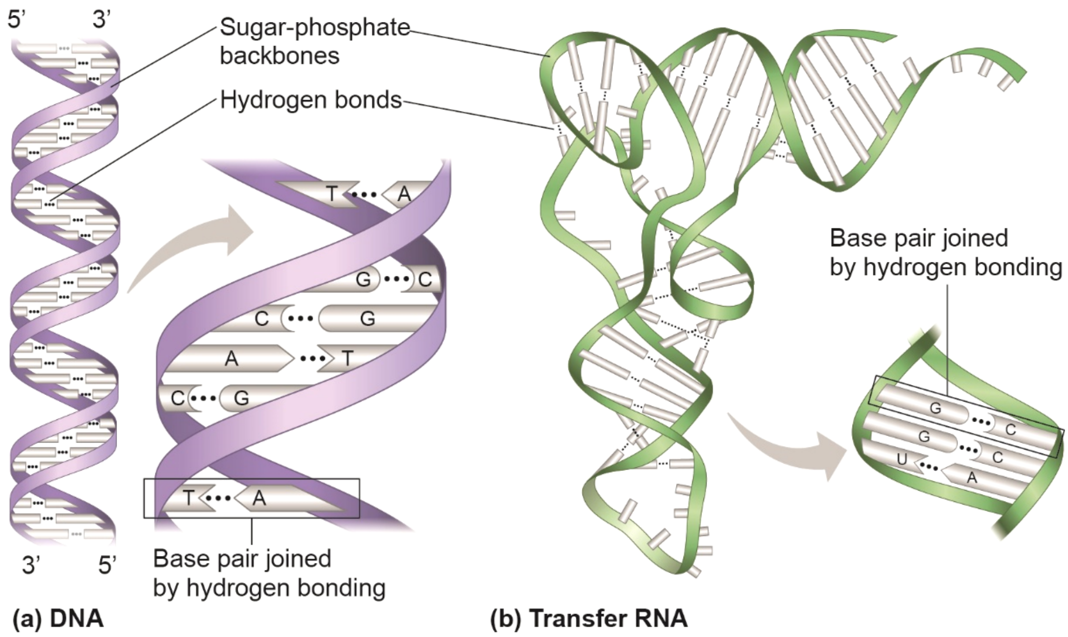



**Figure 3.02**: Hydrogen bonding in nucleic acids

## Chromosomes

Most DNA molecules are very long, containing thousands or even millions of base pairs. For this reason, cells arrange DNA molecules into one or more **chromosomes**, highly condensed structures composed of a single DNA molecule and associated proteins. In eukaryotes, each cell contains two or more linear chromosomes housed in the cell nucleus. Each eukaryotic chromosome contains **chromatin**, a mixture containing one long DNA molecule bound to proteins (**Figure 3.03**). Among the proteins bound to DNA in eukaryotes are **histones** (**Figure 3.03**), small round proteins that help coil the DNA molecule, reducing its length and allowing it to fit into the nucleus. When a eukaryotic cell is not dividing, the chromatin is relaxed, and the chromosomes are observed under an optical microscope as a spread-out mass, indistinguishable from one another. However, as a cell prepares to divide, the chromatin condenses, and the chromosomes become thick enough to be distinguished from one another under an optical microscope. In addition, each eukaryotic species has a characteristic number of chromosomes. For example, a typical human body cell has 46 chromosomes in its nucleus, whereas a fruit fly body cell has only eight chromosomes.

In contrast, prokaryotes each contain a single circular chromosome located in the **cytosol**, the fluid which fills the cell's cytoplasm. Prokaryotic chromosomes are composed of a single DNA molecule, but each is unbound and is not associated with proteins that regulate its length (**Figure 3.04**). In addition, the mitochondria and chloroplasts of eukaryotes also contain a single circular chromosome, a reflection of their evolutionary past as free-living prokaryotes.

When a cell reproduces by dividing, its one or more chromosomes are copied and passed along from one generation of cells to the next, making them genetically identical. The transmission of genetic information from parent to daughter cells depends on the structure and replication of DNA.

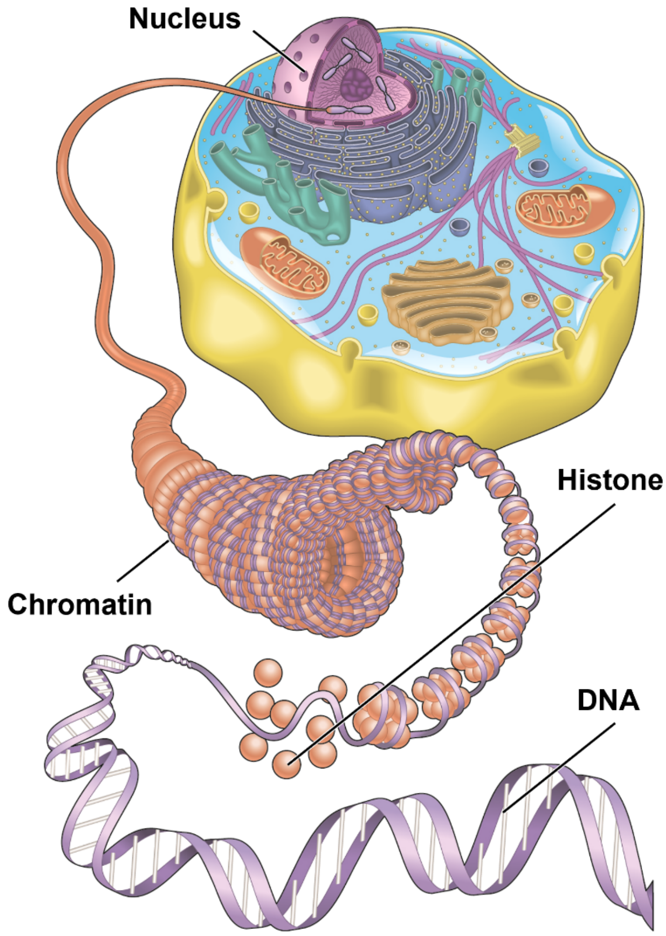



**Figure 3.03:** Chromosome structure eukaryotes

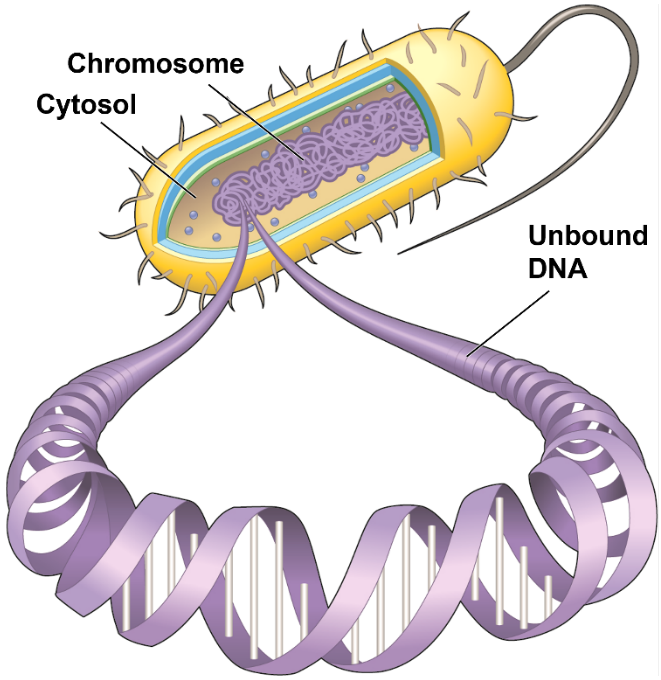



**Figure 3.04:** Chromosome structure prokaryotes

## DNA Replication

DNA is the genetic material that organisms inherit from their parents. When a cell reproduces, its one or more DNA molecules are copied and passed along from one generation of cells, called parent cells, to the next, called daughter cells, making them genetically identical. The transmission of genetic information from parent to daughter cells depends on the structure and replication of DNA.

Before a parent cell divides, its one or more chromosomes are copied, so the daughter cells each have a complete set of genetic information that programs a cell's activities. The process by which the chromosomes are copied is called **DNA replication**, a chemical reaction in which the two strands of a **parent DNA molecule** are separated, and free DNA nucleotides are used to construct complementary strands, forming two **daughter DNA molecules**, as in Figure 3.05. First, the two polynucleotide strands in the parent DNA molecule are separated, allowing each parent strand to serve as a template for synthesising one new strand. In living things, this separation is facilitated by the enzyme helicase, which breaks the weak hydrogen bonds between the base pairs in the parent strands. Next, the enzyme DNA polymerase binds free DNA nucleotides and attaches them to their complementary base pair on the exposed parent strands. Finally, DNA polymerase connects the nucleotides, forming the sugar-phosphate backbones of the daughter molecules.

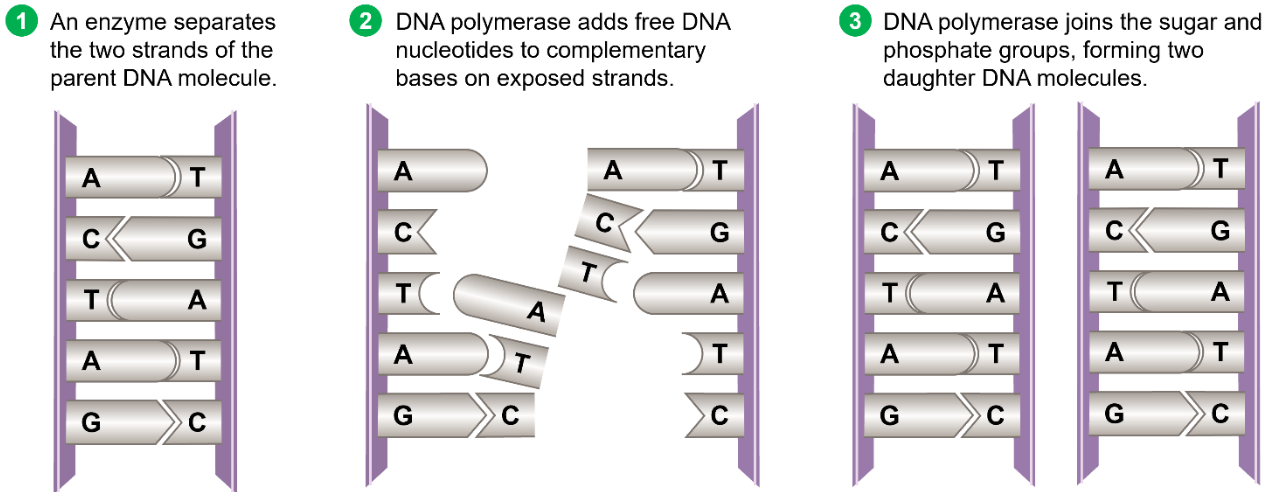



Figure 3.05: DNA replication process.

During DNA replication, the two strands of the parent molecule separate, and each functions as a template for synthesising a complementary strand. In this way, DNA replication is a **semi-conservative process** as when a double helix replicates, each of the daughter molecules has one old strand from the parent molecule and one new strand from DNA replication, as in Figure 3.06.

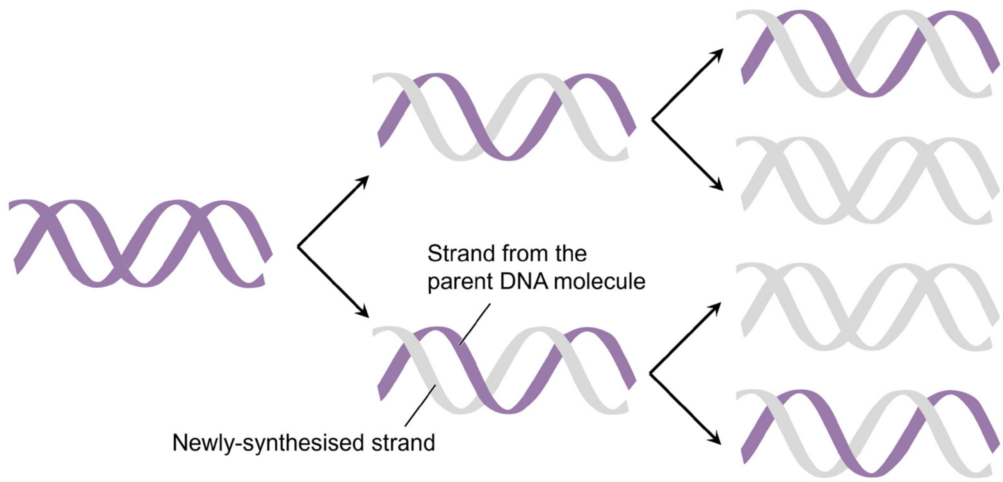



Figure 3.06: The semi-conservative model of DNA replication

## DNA Replication and Inheritance

DNA replication ensures the faithful transmission of genetic information from a parent cell to its daughter cells, guaranteeing that each inherits a complete set of chromosomes. These chromosomes contain the genetic instructions necessary for cellular function, survival, and reproduction.

In eukaryotic cells, inheritance begins with DNA replication. Before replication, the cell contains **unduplicated chromosomes**, each a DNA molecule bound to histones in a highly condensed, linear structure. During replication, each chromosome is copied, resulting in a **duplicated chromosome**, where two identical DNA molecules—known as **sister chromatids**—are held together along their length by cohesin proteins, forming the characteristic X-shaped structure.

During cell division, the sister chromatids are separated, with each becoming an unduplicated chromosome that is distributed into a different daughter cell, as shown in Figure 3.07. In eukaryotes, DNA replication occurs during the S phase of the cell cycle, with its duration varying across species. In humans, the S phase lasts approximately 8 hours, during which 46 chromosomes are replicated.

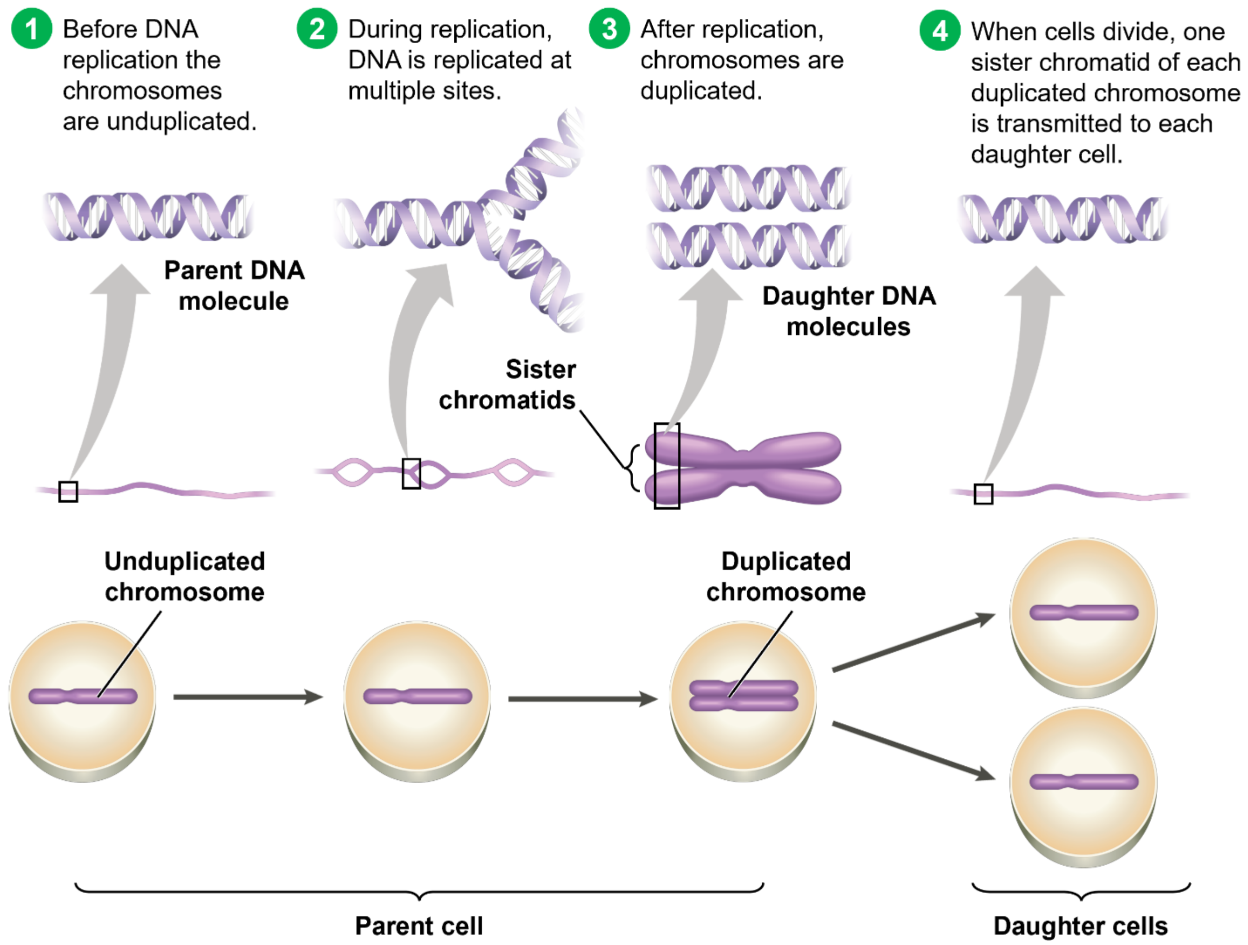
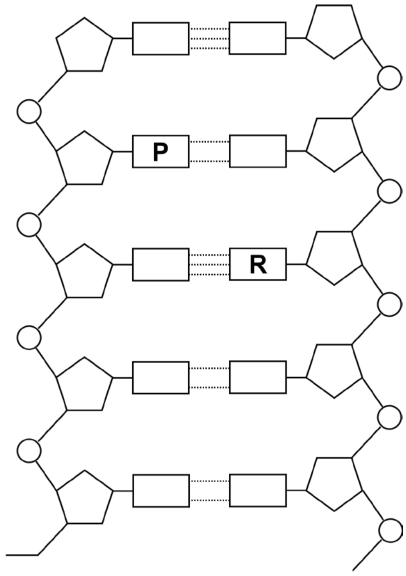



Figure 3.07: DNA replication and the transmission of genetic material.

In prokaryotes, DNA replication is more rapid as the single circular chromosome is much shorter in length than most eukaryotic chromosomes. In favourable environments, some bacteria can replicate their DNA in less than 15 minutes. Biologists have studied the processes of DNA replication extensively in prokaryotes and eukaryotes and concluded that most of the processes are fundamentally similar, indicating that DNA replication methods are universal.

## Question 1

The diagram below shows part of a DNA double helix.




The double helix is 24% **P**. The percentage of **R** is

- A 24%
- B 48%
- C 26%
- D 52%

(1 mark)

## Question 2

The production of proteins involves molecules of tRNA.

Which row in the table describes the structure of tRNA?

| | ***Bases*** | ***Number of strands*** | ***Type of sugar*** |
|---|---|---|---|
| A | A, C, G, U | One | deoxyribose |
| B | A, C, G, U | One | ribose |
| C | A, C, G, T | Two | deoxyribose |
| D | A, C, G, T | Two | ribose |

(1 mark)

## Question 3

In DNA, the number of

- A phosphate groups equals the number of nitrogen bases.
- B guanine nucleotides equals the number of uracil nucleotides.
- C adenine nucleotides equals the number of cytosine nucleotides.
- D phosphate groups equals twice the number of sugar molecules.

## Question 4

The following nucleotide sequence forms part of a DNA strand.

TGGATGACA

Which base is present at the fourth position on the complementary DNA strand?

- ◯ A C
- ◯ B G
- ◯ C T
- ◯ D U

(1 mark)

## Question 5

In a polynucleotide strand:

- ◯ A The 5'carbon of the sugar bonds with the phosphate of the previous nucleotide.
- ◯ B The 3' carbon of the sugar bonds with the base on the same nucleotide.
- ◯ C The 5' carbon of the sugar bonds with the base on the next nucleotide.
- ◯ D The 3' carbon on the sugar bonds with the phosphate group on the next nucleotide.

(1 mark)

## Question 6

Cells in plant leaves have several organelles containing DNA.

Which one of the following combinations correctly identifies the location, shape, and number of chromosomes in a plant leaf cell?

| | | ***Location*** | ***Shape*** | ***Number*** |
|---|---|---|---|---|
| ◯ | A | Nucleus | Linear | One |
| ◯ | B | Nucleus | Circular | Multiple |
| ◯ | C | Chloroplast | Linear | Multiple |
| ◯ | D | Chloroplast | Circular | One |

(1 mark)

## Question 7

Which of the following statements about mRNA are correct?

I. mRNA can form base pairs.
II. mRNA can form hydrogen bonds.
III. mRNA is single-stranded.

- ◯ A I, II and III
- ◯ B Only I and II
- ◯ C Only II and III
- ◯ D Only I and III

(1 mark)

## Question 8

All living things contain DNA molecules, some of which are arranged into chromosomes.

Which of the following statements about DNA and chromosomes in living things is *incorrect*?

- ◯ A Eukaryotes contain multiple DNA molecules, each associated with proteins.
- ◯ B Prokaryotes have a single circular chromosome.
- ◯ C Eukaryotes and their organelles contain multiple linear chromosomes.
- ◯ D Prokaryotes have one DNA molecule that is not bound to proteins.

(1 mark)

## Question 9

Which of the following statements is/are evidence that DNA replication is semi-conservative?

I. After one replication, the number of adenine nucleotides is equal to the number of guanine nucleotides.
II. After two replications, two DNA molecules have one original and one new strand, and two DNA molecules have two new strands.
III. After three replications, there are eight DNA molecules, only two of which have strands from the original DNA.

- ◯ A I, II and III
- ◯ B Only II and III
- ◯ C Only I and II
- ◯ D Only I

(1 mark)

## Question 10

The table below refers to the shape and location of a chromosome in a non-dividing plant cell, and whether or not it is bound to histone proteins.

| | ***Shape*** | ***Location*** | ***Bound to histone proteins*** |
|---|---|---|---|
| A | linear | nucleus | yes |
| B | circular | nucleus | no |
| C | circular | cytosol | no |
| D | linear | cytosol | yes |

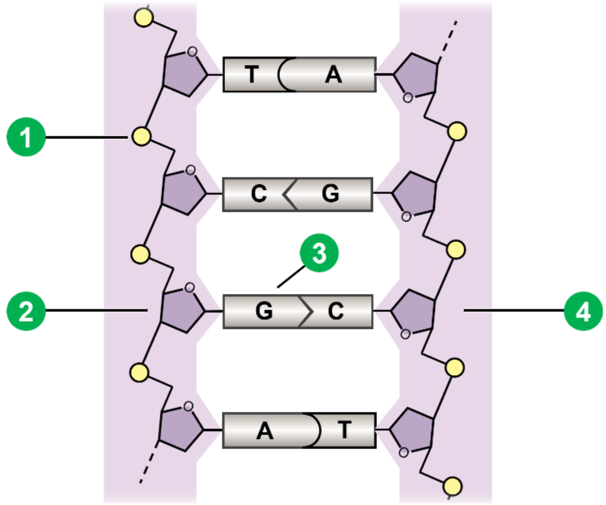
For a chromosome in a non-dividing plant cell, the combination in the table that correctly describes its shape, location, and whether or not it is bound to histone proteins is

- ◯ A
- ◯ B
- ◯ C
- ◯ D

(1 mark)

## Question 11

The diagram below shows a short section of DNA.




(a) Name the components **1–4**.

(4 marks)

(b) Describe the structure of a DNA molecule.

(3 marks)

## Question 12

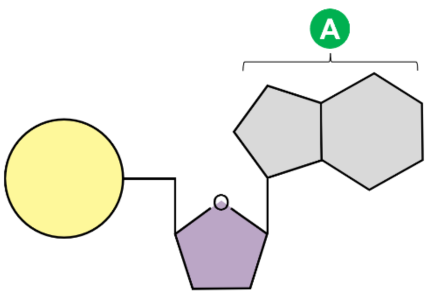
DNA is a macromolecule in the cells of all living things.

(a) State the name of this type of macromolecule.

(1 mark)

(b) DNA molecules are composed of nucleotides, like the one shown below.

(1) Name the component of the nucleotide labelled A in the diagram.



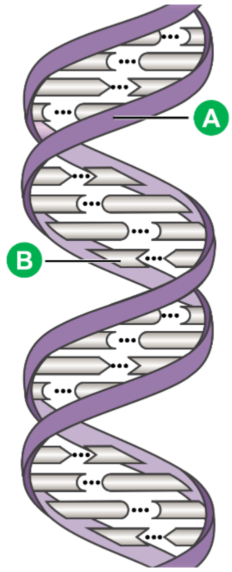

(1 mark)

(2) Describe how the structural units in the diagram are arranged in DNA molecules.

(3 marks)

## Question 13

The diagram opposite shows the DNA double helix.




The double helix may be described as a coiled ladder.

(a) State the composition of the uprights of the ladder, labelled **A**.

(1 mark)

(b) The rungs of the ladder are made by pairing components labelled **B**. Name the components and their specific pairs.

(2 marks)

## Question 14

The diagram opposite is a coloured transmission electron micrograph (TEM) of the bacterium *Escherichia coli*.

The cell has burst, and the chromosome has leaked out.

(a) Describe the structure and composition of the bacterial chromosome.

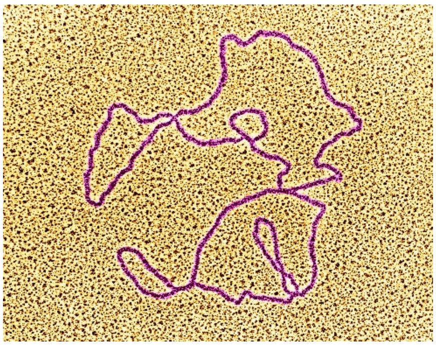
(2 marks)

(b) State the location of the chromosome before it leaked out of the cell.

(1 mark)

## Question 15

The diagram opposite is a coloured TEM of mitochondrial DNA.



(a) Describe the structure of mitochondrial DNA using evidence from the diagram.

(2 marks)

(b) Mitochondrial DNA has a similar structure to DNA in prokaryotes. Give one reason for this.

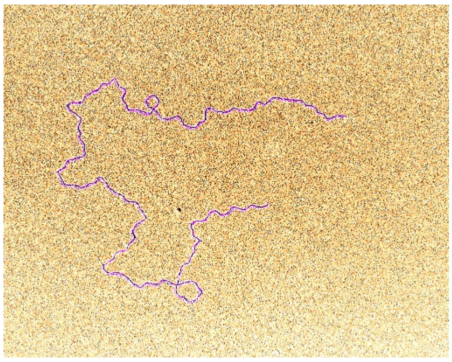
(1 mark)

(c) Mitochondria are one type of organelle containing DNA. Name two other organelles that contain DNA.

(2 marks)

## Question 16

The diagram below is a coloured TEM of a DNA molecule from the nucleus of a eukaryotic cell.



(a) State the evidence from the diagram showing this DNA molecule is from a eukaryotic cell.

(1 mark)

(b) The DNA molecule shown is one of twelve chromosomes in this cell. Describe the structure of the twelve chromosomes in this eukaryotic cell.

(3 marks)

(c) The DNA molecule in the diagram is from the nucleus of a mesophyll cell in *Vicia faba*, the broad bean plant.

Mesophyll cells contain up to 60 chloroplasts, each containing DNA.

State two differences between the DNA in the nucleus and chloroplasts in *Vicia faba*.

(2 marks)

## Question 17

The table below shows the relative percentages of the bases in DNA from various species.

| | Percentage of each nucleotide | | | |
|---|---|---|---|---|
| **Source cell** | Adenine | Guanine | Thymine | Cytosine |
| Wheat | 27.3 | 22.7 | 27.1 | 22.8 |
| Sea urchin | 32.8 | 17.7 | 32.1 | 17.3 |
| Human | 30.9 | 19.9 | 29.4 | 19.8 |

(a) DNA is a double-stranded molecule.

Explain how the data in the table supports the concept of complementary base-pairing.

(2 marks)

(b) Sea urchins and humans are very different species with similar percentages of each base in their DNA.

Use your knowledge of DNA structure and function to explain how this is possible.

(2 marks)

## Question 18

A section of a DNA molecule has 74 base pairs.

The two strands of the DNA, one and two, were analysed to find the number of each nucleotide base.

Some of the results are shown in the table.

| Strand | Number of nucleotides: Adenine | Guanine | Thymine | Cytosine |
|---|---|---|---|---|
| One | | | | 26 |
| Two | 9 | | | 19 |

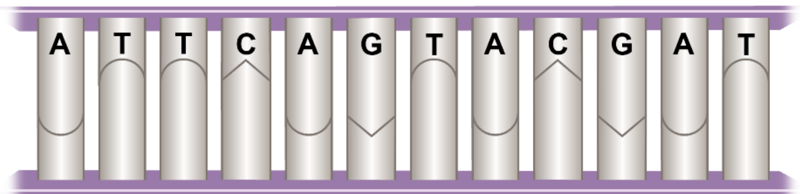
Complete the table by writing in the missing values. (2 marks)

## Question 19

The table below shows the bases guanine and cytosine as percentages of the total nucleotides present in three different pathogens.

| Pathogen | Nucleotide composition (%): Guanine | Cytosine |
|---|---|---|
| Bacterium | 36.0 | 35.7 |
| Fungus | 18.7 | 17.1 |
| Virus | 42.0 | 13.9 |

(a) The diagram shows a section of DNA from the bacterium.




Write the letters corresponding to the complementary bases on the other strand.

(1 mark)

(b) The viral DNA is different to that of other pathogens in the table.

Use the information in the table to identify and explain the difference.

(2 marks)

(c) The host cell makes a complementary strand to the viral DNA when the virus infects a host.

The complementary strand is made the same way as a new complementary strand during semi-conservative replication in human cells.

Describe how the complementary strand of viral DNA is made.

(2 marks)

| Question | Part | Author's response | Marks |
|---|---|---|---|
| 1 | | C | 1 |
| 2 | | B | 1 |
| 3 | | A | 1 |
| 4 | | C | 1 |
| 5 | | D | 1 |
| 6 | | D | 1 |
| 7 | | C | 1 |
| 8 | | C | 1 |
| 9 | | B | 1 |
| 10 | | A | 1 |
| 11 | (a) | 1: Phosphate 2: Sugar/deoxyribose | 1+1 |
| | | 3: Nitrogenous base/base 4: Sugar-phosphate backbone | 1+1 |
| | (b) | Two polynucleotide strands form a double helix. | 1 |
| | | The strands are composed of repeating nucleotides. | 1 |
| | | The strands are joined by hydrogen bonds between the nitrogenous bases. | 1 |
| 12 | (a) | Nucleic acid | 1 |
| | (b) (1) | Nitrogenous base/ base | 1 |
| | (b) (2) | The nucleotides are bonded together by chemical bonds between the sugar and phosphate groups, forming the sugar-phosphate backbone. | 1 |
| | | The nitrogenous bases connected to the sugar-phosphate backbone face inwards, forming hydrogen bonds that connect the two polynucleotide strands in the DNA molecule. | 1 |
| 13 | (a) | The uprights are composed of the sugar and phosphate groups of adjacent nucleotides. | 1 |
| | (b) | Nitrogenous bases/bases | 1 |
| | | A pairs with T, and G pairs with C. | 1 |
| 14 | (a) | The bacterial chromosome is a single unbound DNA molecule. | 1 |
| | | The DNA molecule forms a closed loop. | 1 |
| | (b) | Cytosol/cytoplasm | 1 |
| 15 | (a) | The diagram shows a single loop of DNA. | 1 |
| | | This is evidence that mitochondrial DNA is a single, circular DNA molecule. | 1 |
| | (b) | Mitochondria were once free-living prokaryotes. | 1 |
| | (c) | Nucleus and chloroplasts. | 1+1 |

## Review Test 1

### Questions 1 to 10

Questions 1 to 10 are **multiple-choice questions.** For each multiple-choice question, indicate the best answer to the question by shading in the bubble [O] beside it.

**1.** Plant cells have DNA in their nucleus, mitochondria, and chloroplasts.

Which of the following describes chloroplast DNA?

◯ **A** multiple linear chromosomes
◯ **B** a single linear chromosome
◯ **C** multiple circular chromosomes
◯ **D** a single circular chromosome

(1 mark)

**2.** In a DNA molecule, 17% of the nucleotide bases were cytosine.

What percentage of the nucleotide bases were adenine?

◯ **A** 17%
◯ **B** 33%
◯ **C** 66%
◯ **D** 83%

(1 mark)

**3.** The table shows mRNA codons and their amino acids.

| mRNA codon | Amino acid |
|---|---|
| ACC | Threonine |
| AUU | Isoleucine |
| CUU | Leucine |
| UCC | Serine |

A tRNA has the anticodon AGG.

Which one of the following amino acids does this tRNA bring to the ribosome?

◯ **A** Leucine
◯ **B** Isoleucine
◯ **C** Serine
◯ **D** Threonine

(1 mark)

**4.** A segment of one DNA strand in a target gene contains the nucleotide sequence below.

AACGAGGACCTGGCG

Which one of the following sequences could be used as an RNA probe to locate this segment?

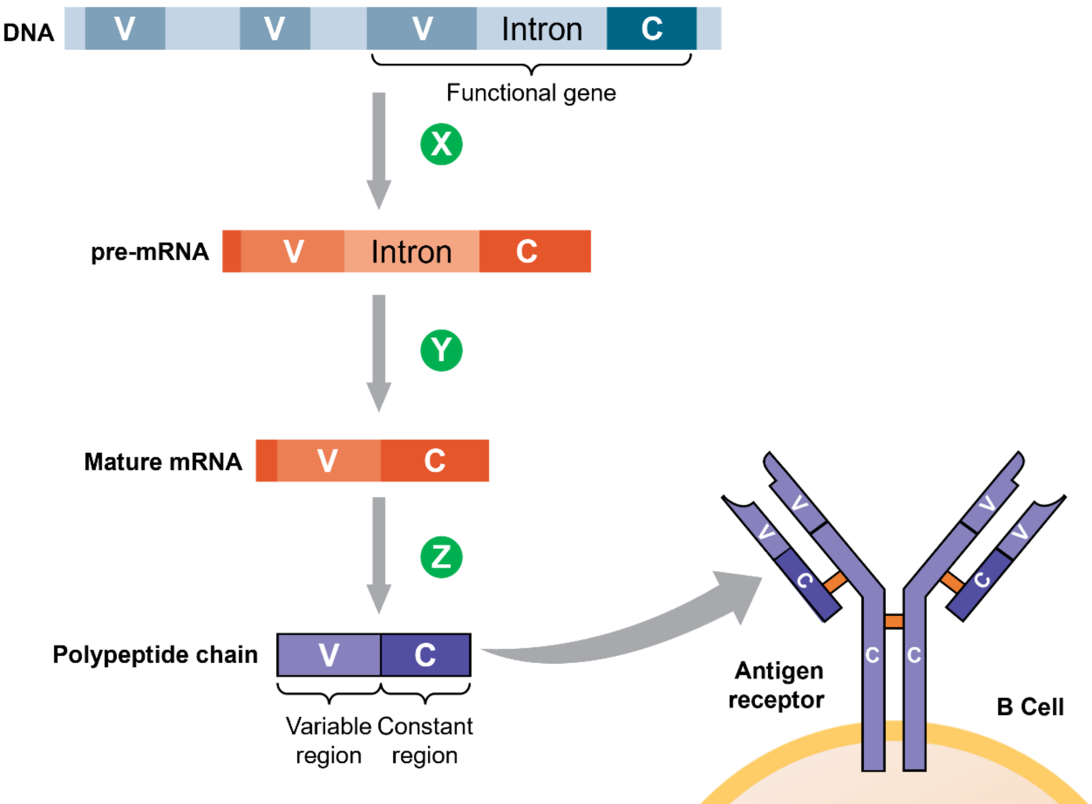
◯ **A** UCCUGGAC
◯ **B** TTGCTCCT
◯ **C** UUGCTCCT
◯ **D** GCUGGUCC

(1 mark)

**5.** B cells are immune cells in humans that synthesise defensive proteins called antibodies and antigen receptors.

B cells have genes that code for the polypeptides that comprise an antigen receptor.

The diagram below shows the gene expression stages synthesising a polypeptide chain in the B cell antigen receptor.




Which of the following combinations correctly identifies processes X, Y and Z?

| | X | Y | Z |
|---|---|---|---|
| ◯ **A** | Translation | Transcription | RNA processing |
| ◯ **B** | Transcription | RNA processing | Translation |
| ◯ **C** | Translation | RNA processing | Transcription |
| ◯ **D** | Transcription | Translation | RNA processing |

(1 mark)

**6.** DNA polymerase is an enzyme that joins DNA nucleotides during DNA replication.

Which one of the following statements about DNA polymerase is ***not*** correct?

◯ **A** DNA polymerase lowers the activation energy for DNA replication.

◯ **B** DNA polymerase has an active site complementary to DNA nucleotides.

◯ **C** DNA nucleotides bind to the active site of DNA polymerase by induced fit.

◯ **D** DNA polymerase joins nucleotides more rapidly at higher temperatures.

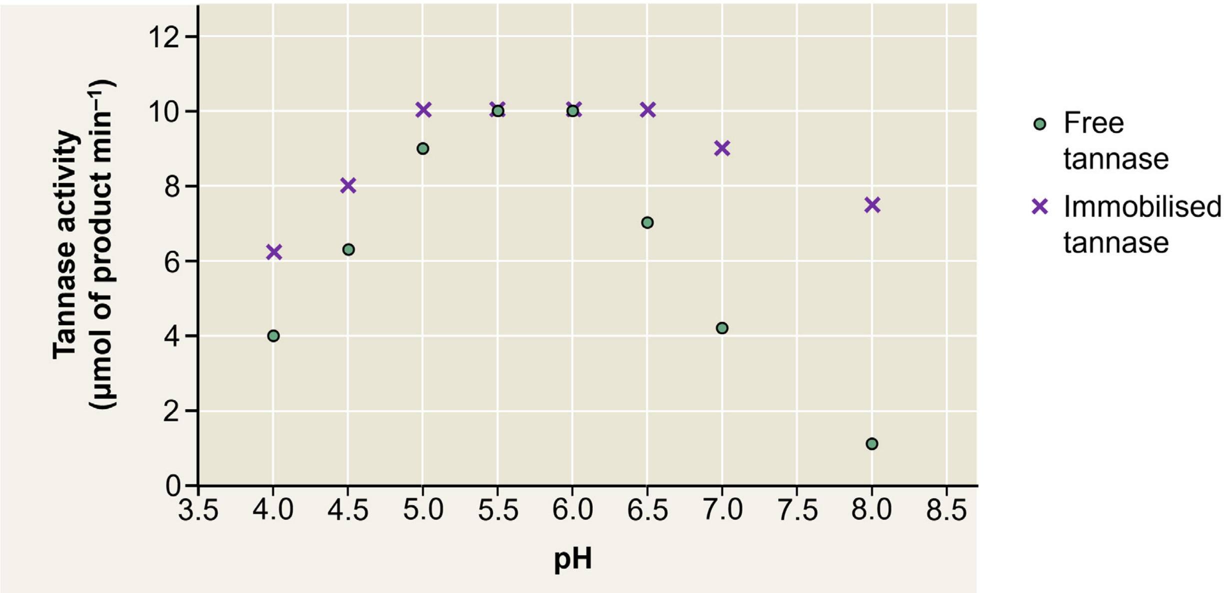
(1 mark)

## Question 13

Tannase is an enzyme used in the manufacture of tea.

Manufacturers can use free tannase enzymes derived from microorganisms, or they can design tannase proteins to bind to tiny beads and remain immobile.

An investigation was carried out to compare the activity of free tannase and immobilised tannase over a range of pH. The results are shown below.




(a) State the dependent variable in this investigation.

(1 mark)

(b) Identify one factor held constant in this investigation and explain the effect that this could have on the data.

(2 marks)

(c) Most teas have a pH in the range of 4 to 8.

State and explain whether tea manufacturers should use free or immobile tannase.

(3 marks)

(d) Explain how the reliability of the data from this investigation can be increased.

(2 marks)

## Question 15

African elephants are being poached for their ivory tusks at species-threatening rates.

One recent study found that elephant populations in Tanzania and Mozambique decreased by more than 50% between 2009 and 2014.

To combat the illegal ivory trade, scientists working in the USA produced DNA profiles for more than a thousand elephants from populations in 29 African countries, including Tanzania and Mozambique.

(a) Scientists obtain an elephant's DNA from its dung (faeces).

The DNA is isolated from dung, subject to PCR, digested into fragments with enzymes and separated with gel electrophoresis.

(1) State why elephant DNA can be obtained from dung.

(1 mark)

(2) State why PCR is required when DNA is obtained from dung.

(1 mark)

(3) Elephant dung contains DNA from digested plant leaves.

Explain why the plant DNA is not reproduced in PCR.

(2 marks)

(4) Describe and explain how DNA profiling thousands of elephants can help international law enforcement locate poachers.

(2 marks)