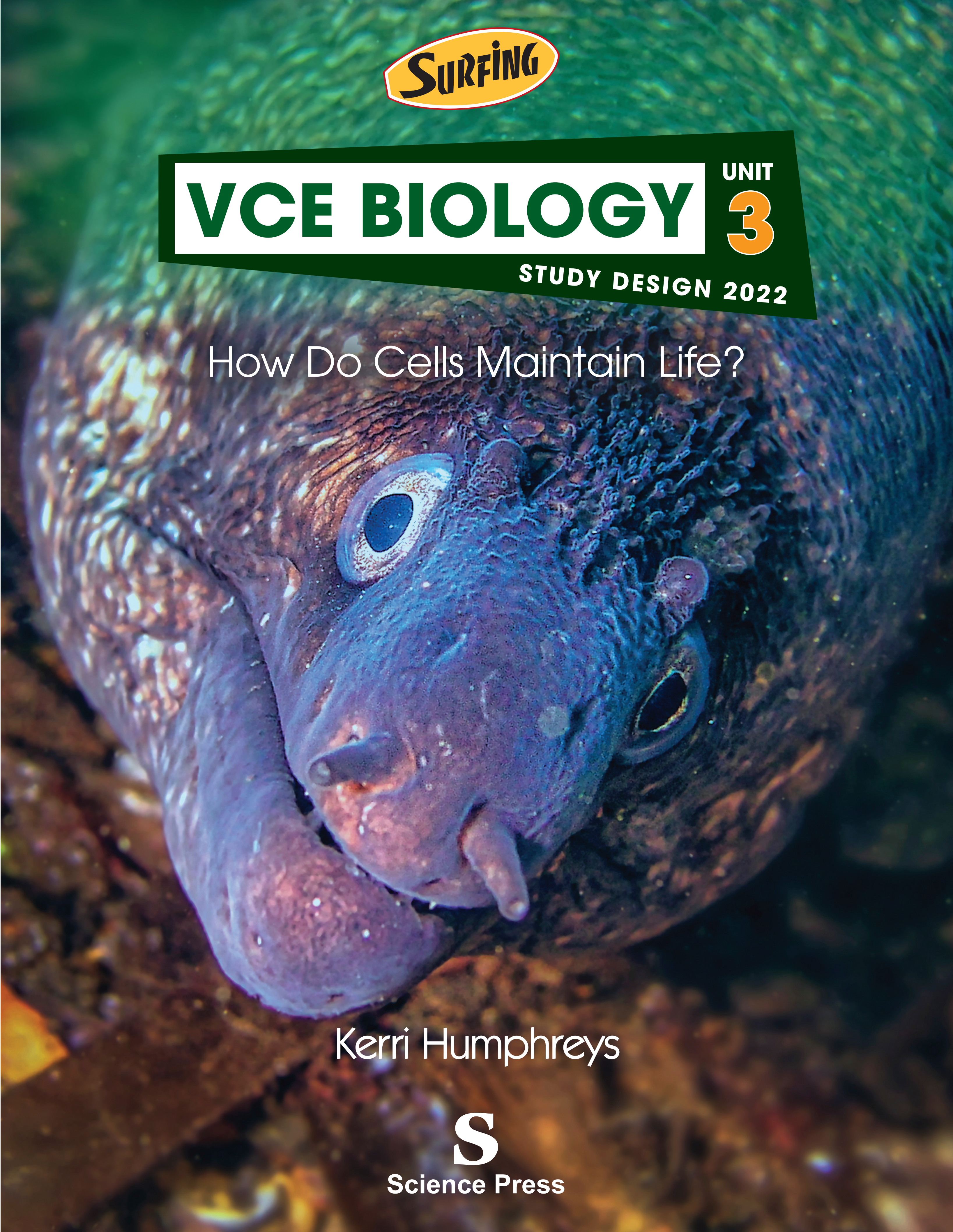
Surfing

VCE BIOLOGY UNIT 3

STUDY DESIGN 2022

How Do Cells Maintain Life?

Kerri Humphreys



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Surfing

VCE BIOLOGY

UNIT 3

STUDY DESIGN 2022

Area Of Study 1

What Is the Role Of Nucleic Acids and Proteins In Maintaining Life?

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1 Assumed Knowledge

QUESTIONS

1. Identify the four main classes of macromolecules found in living organisms.
2. The diagram shows a type of macromolecule.

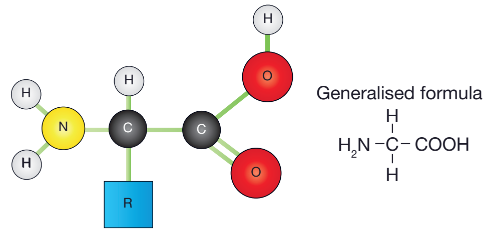

Figure 1.1 Macromolecule.

What is the name of this type of macromolecule?

3. What is an amino acid?
4. Distinguish between hydrophobic and hydrophilic.
5. What does DNA stand for?
6. The diagram shows the structure of the DNA molecule.

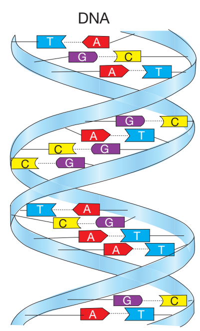

Figure 1.2 Structure of DNA molecule.

Identify the shape of the DNA molecule.

7. What does RNA stand for?
8. Distinguish between exocytosis and endocytosis.
9. Define a gene.
10. What is a chromosome?
11. Define an allele.
12. What is an enzyme?
13. Distinguish between a protein and a polypeptide.
14. The diagram shows nucleotides found in DNA.

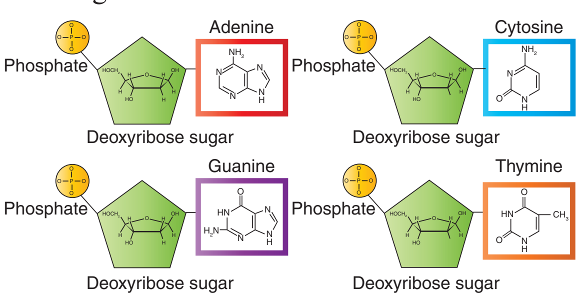

Figure 1.3 Nucleotides found in DNA.

What is the structure of a DNA nucleotide?

15. Describe a chloroplast.
16. Define photosynthesis.
17. Which group of organisms can photosynthesise?
18. Identify the materials required by multicellular organisms for photosynthesis.
19. Why is photosynthesis an important process in ecosystems?
20. What are inorganic compounds?
21. Define respiration.
22. The diagram shows the structure of ATP.

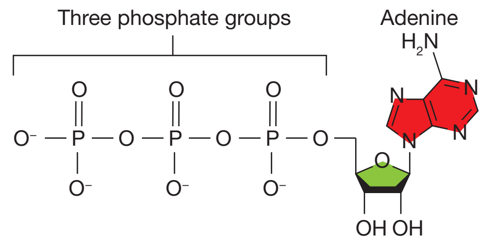

Figure 1.4 Structure of ATP.

Outline the importance of ATP.

23. The diagram shows an experiment investigating photosynthesis.

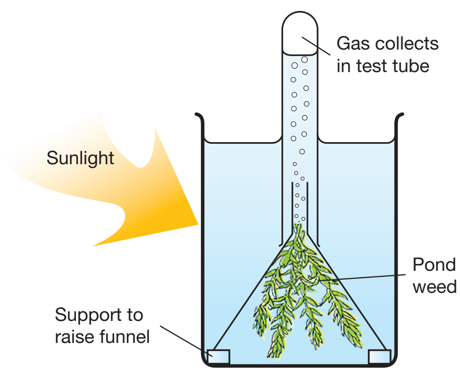

Figure 1.5 Photosynthesis experiment.

What gas is collecting in the test tube?

24. The diagram shows the results of Engelmann's experiment with the concentration of aerobic bacteria along a filament of *Spirogyra*.

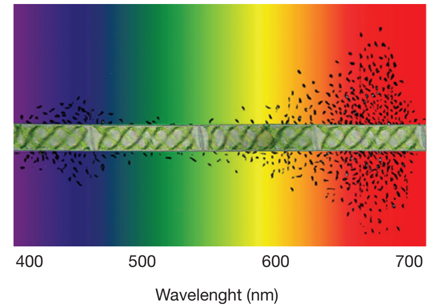

Figure 1.6 Engelmann's experiment.

What does this show about the wavelength(s) of light used in photosynthesis?

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6. The diagram shows the *trp* operon.

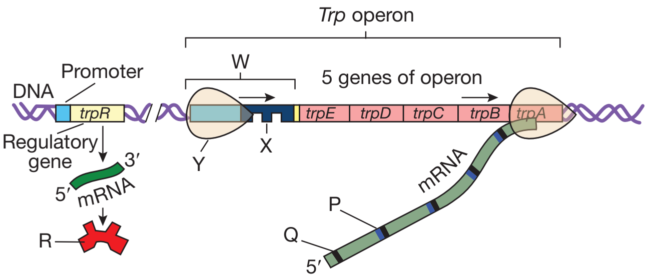


Figure 12.3 *Trp* operon to label.

(a) Identify parts P, Q, R, W, X, Y and Z.
(b) What is the function of R?

7. What are the products after transcription and translation of the *trp* operon?
8. Why are stop and start codons needed in the mRNA?
9. What is the bacterial action if tryptophan is available in the environment?
10. The diagram shows a section of DNA that has an operon.

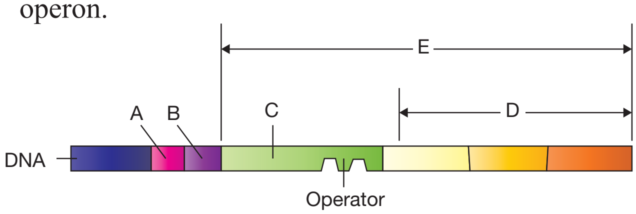


Figure 12.4 DNA with an operon.

(a) Identify parts A, B, C, D and E.
(b) In this diagram, how many genes are present?
(c) Outline the function of part C.

11. What is the function of the operator within the *trp* operon?
12. Compare the number of genes in the *trp* operon and the *lac* operon.
13. Explain why the *trp* operon is an example of a repressible system.
14. Explain why the *lac* operon is an example of negative gene regulation.
15. Name each gene and the inducible enzyme of the lactose pathway for which it encodes.
16. Outline the function of *lac*Z in the lactose pathway.
17. Outline the function of *lac*Y in the lactose pathway.
18. Which scientist(s) are most noted for their investigation of the *lac* operon?
    (A) Watson and Crick.
    (B) Beadle and Tatum.
    (C) Jacob and Monod.
    (D) TH Morgan.
19. What are the structural genes in the *lac* operon?
    (A) *lac*I, *lac*Z and *lac*Y.
    (B) *lac*I, *lac*Y and *lac*A.
    (C) *lac*I, *lac*Z and *lac*A.
    (D) *lac*Z, *lac*Y and *lac*A.

Use the diagram for the next TWO questions.

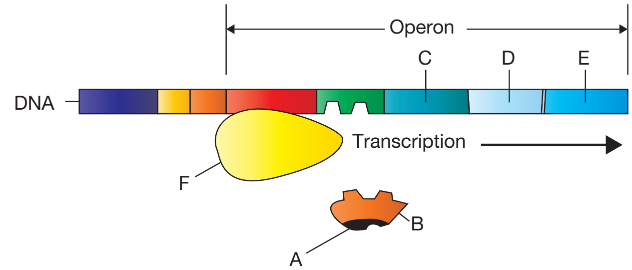
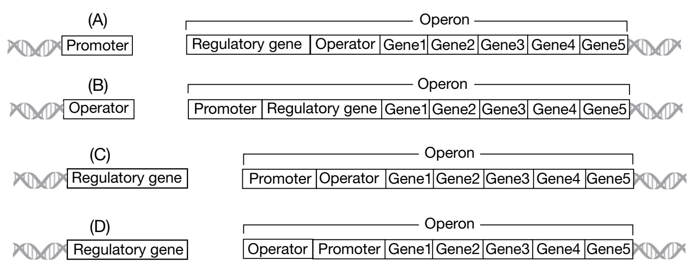


Figure 12.5 *Lac* operon.

20. What is represented by part C?
    (A) Structural gene.
    (B) Regulatory gene.
    (C) Inducible enzyme.
    (D) Operator.
21. What is the best explanation of what is happening in this diagram?
    (A) The operator is blocked allowing transcription to proceed.
    (B) An inducer is bound to the repressor allowing transcription to proceed.
    (C) The promoter is bound to a repressor blocking transcription.
    (D) The repressor gene binds to RNA polymerase.
22. Which of the following shows the correct format of the *trp* operon?



23. The diagram shows the products of the *trp* operon.

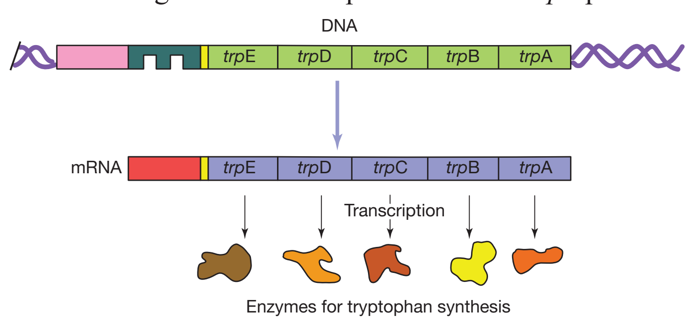


Figure 12.6 Products of the trp operon.

What is *incorrect* about this diagram?
(A) There should only be three genes.
(B) Gene expression forms tryptophan not enzymes.
(C) Labels for transcription and translation are wrong.
(D) The operator should be after the genes.

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13 Protein Structure

Proteins are long complex polymers built from linear sequences of amino acids joined together by peptide bonds in polypeptide chains.

Amino acids contain an amino group (–NH_2) which is basic and an acid group (–COOH) which is acidic. Most amino acids in proteins have the two functional groups on the same carbon atom – called the alpha carbon atom. There are 20 naturally occurring alpha amino acids. There are a variety of side chains that combine, with peptide bonds to form proteins.

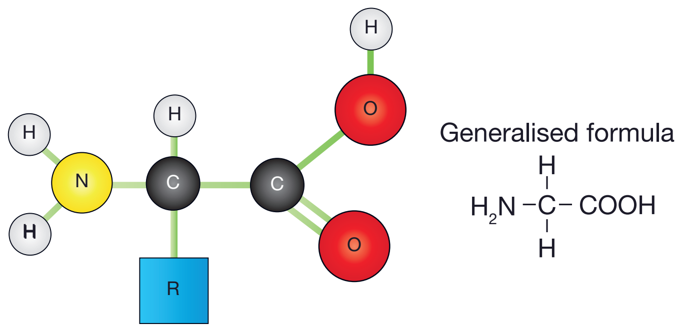

Figure 13.1 Generalised formula for an amino acid.

The number of amino acids in a protein can vary from about 50 amino acids to over 50 000 amino acids. Proteins can be classified by structure or by composition and a single protein may have varying structure and more than one function. Computer programs are used to predict the folding patterns and shape of a protein when the amino acid sequence has been determined. Different possible combinations of folding patterns are possible.

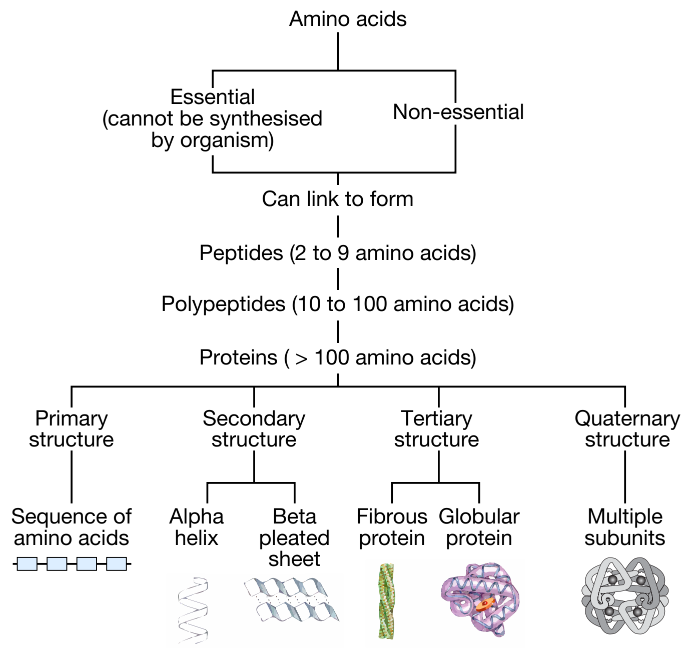

Figure 13.2 Protein structure.

Organisms make their own proteins from the amino acids in their cytoplasm. Mammals obtain amino acids mainly through the digestion of dietary protein. Humans can synthesise 12 of the 20 amino acids they need. Plants make their own amino acids using nitrates taken in through the roots.

Vertebrates do not store amino acids. Excess amino acids are deaminated with the nitrogenous waste being excreted and the remainder molecule oxidised and used in respiration.

Primary structure

The primary structure is the linear sequence of amino acids in the molecule. There are 20 different amino acids which can link together in a vast number of combinations, e.g. the primary structure of thyrotropin releasing hormone is glutamic acid-histidine-proline. The order of amino acids is determined by the DNA code in a gene.

A change in the code can change the amino acid and the functioning of the protein, e.g. a substitution in the code for haemoglobin in the beta chain with valine (uncharged side chain) substituted for glutamic acid (charged side chain) causes sickle cell disease and this affects the solubility of the haemoglobin and changes the shape of the red blood cell. The arrangement of polar R groups and non-polar R groups of the amino acids causes attraction and repulsion points. The sequence of amino acids is extremely important as it influences higher levels of organisation in the protein and its biological function.

Secondary structure

Secondary structures are coils or folds caused by hydrogen bonds between repeating CO and NH groups. Secondary structure gives the spatial arrangement of the amino acids in the chain. Secondary structures include the alpha helix and beta pleated sheet. Pleated sheets make up the basis of many globular proteins and fibrous proteins, e.g. keratin a fibrous protein consists mainly of alpha helices while silk protein is also a fibrous protein but is mainly beta sheet form. The spatial arrangement is determined by the angle of the bond between adjacent amino acids and is stabilised by the hydrogen bonding between different parts of the molecule.

Tertiary structure

Tertiary structure is formed by folding of the secondary structure into a complex and compacted shape giving the molecule a three-dimensional form. The shape is determined by interactions between the R groups of the amino acids, hydrophobic interactions, hydrophilic interactions and hydrogen bonding. Disulfide bridges are strong covalent links, e.g. between neighbouring cysteine amino acids and can stabilise the structure. The folding of tertiary structures can provide structural strength, e.g. microtubules are globular proteins, or can produce an 'active site', e.g. enzymes are globular proteins.

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Quaternary structure

Quaternary structure involves the interaction between several polypeptide chains. The individual subunits are held together by hydrogen bonds rather than covalent linkages, though disulfide bonds occur. Conjugated proteins contain non-protein material and the non-protein part is called the **prosthetic group**. Many important proteins use quaternary structure to carry out a large variety of biological functions, e.g. collagen fibres and haemoglobin. Conjugated proteins include chlorophyll and many enzymes in the electron transport chain. Haemoglobin consists of four haem groups within the molecule with two identical alpha chains and two identical beta chains.

Bonding in proteins

Hydrogen bonding between oxygen and hydrogen atoms helps to stabilise the tertiary structure of the protein and leads to the uniform backbone of the polypeptide chain in the secondary structure.

Ionic attraction bonds the R groups with positive charges to the R groups with negative charges.

Hydrophobic interactions occur when non-polar groups associate in the interior of a globular structure away from the surrounding water.

Covalent **disulfide bonds** link the sulfur atoms of two cysteine subunits which can be two parts of the same polypeptide chain or joining two different polypeptide chains.

Changes in protein shape

A change in the three-dimensional shape of a protein changes its functionality. If a protein is heated or treated with certain chemicals the bonds break and the structure unravels. The loss of shape makes it biologically inactive. This is called **denaturing**. Denaturation can occur with extreme temperature, extreme pH or extreme salt concentration. In most instances denaturation cannot be reversed although some proteins under some conditions can return to their original shape.

QUESTIONS

1. Define a protein.
2. Write the generalised formula for an amino acid.
3. What is meant by the alpha carbon of an amino acid?
4. Compare the synthesis of amino acids in plants and in mammals.
5. Outline what happens to excess amino acids.
6. Construct a table to summarise the four hierarchal levels of protein structure.
7. Construct a table to summarise the significance of the four hierarchal levels of protein structure.
8. Outline what happens when a protein denatures.
9. The diagram shows the structure of insulin. Insulin was one of the first proteins to be sequenced.

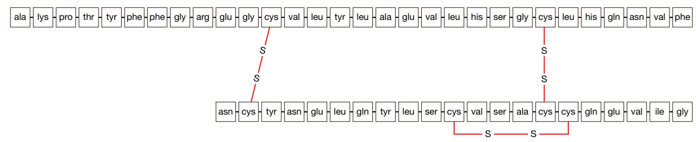

Figure 13.3 The hormone cattle insulin.

(a) Which level of structure is shown in this diagram?
(b) What does insulin consist of?
(c) Between which amino acids do disulfide bonds form?

10. The diagram shows the different types of bonds in proteins.

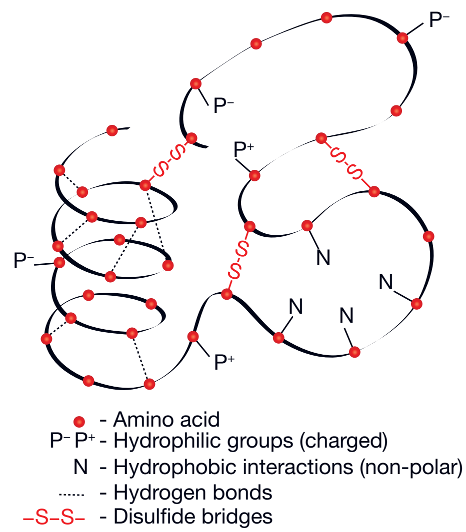

Figure 13.4 Bonds in proteins.

Identify the bonds that help to stabilise the tertiary structure of a protein molecule.

11. The diagram shows a hierarchal level of protein structure.

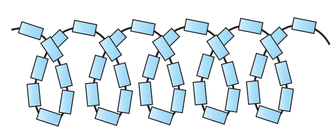

Figure 13.5 Level of protein structure.

What is this level?
(A) Primary structure.
(B) Secondary structure.
(C) Tertiary structure.
(D) Quaternary structure.

12. What is the name of the process when a protein loses its correct shape and become biologically inactive?
(A) Depolarisation. (B) Dehydration.
(C) Condensation. (D) Denaturation.

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15 Polar and Non-Polar Amino Acids

Amino acids consist of an amino group (–NH_2), a carboxyl group (–COOH) and a side chain (–R). The amino group is basic and the carboxyl group is acidic. An **amphoteric** substance is both acidic and basic.

The two functional groups of the amino acid (the amino group and the carboxyl group) in most amino acids are attached to the same carbon atom which is called the alpha carbon. Amino acids vary in the composition of the side chain. The chemical and physical properties of the side chain determine the particular features of each amino acid.

If the amino acid has one amino group and one carboxyl group it will be **neutral**. If the amino acid has additional amino groups it will be a **basic amino acid** while additional carboxyl groups will make it an **acidic amino acid**.

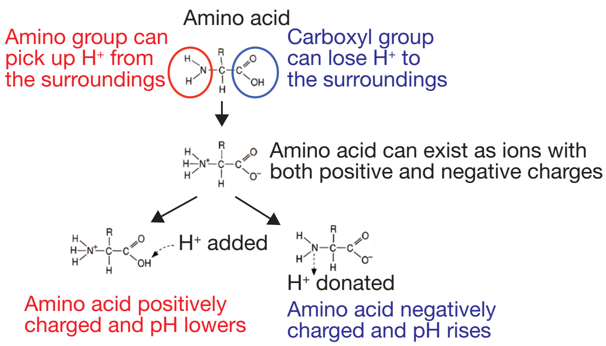

Figure 15.1 Amino acids can be amphoteric.

In an acid solution the amino acid picks up H^+ ions and becomes positively charged. In an alkaline solution the amino acid donates H^+ ions to the surroundings and becomes negatively charged. This means that the presence of amino acids in a solution stabilises the pH of the solution and amino acids act as **buffers**. Proteins are important in stabilising the pH of cells and body fluids.

Polar amino acids

Amino acids with a polar side chain (R) are hydrophilic. Hydrophilic molecules have an affinity for water and are usually ionic or polar substances. Soluble proteins have a large number of polar amino acids.

Non-polar amino acids

Amino acids with a non-polar side chain (R) are hydrophobic. Hydrophobic substances do not have an affinity for water and can even seem to repel water. Hydrophobic substances are non-ionic and non-polar substances. Integral proteins in the lipid bilayer of the cell membrane have an arrangement of polar and non-polar amino acids to anchor them in the membrane.

The distribution of polar, non-polar and electrically charged amino acids in a protein determines the tertiary structure and the quaternary structure of the protein. This in turn determines the properties of the protein and its biological function.

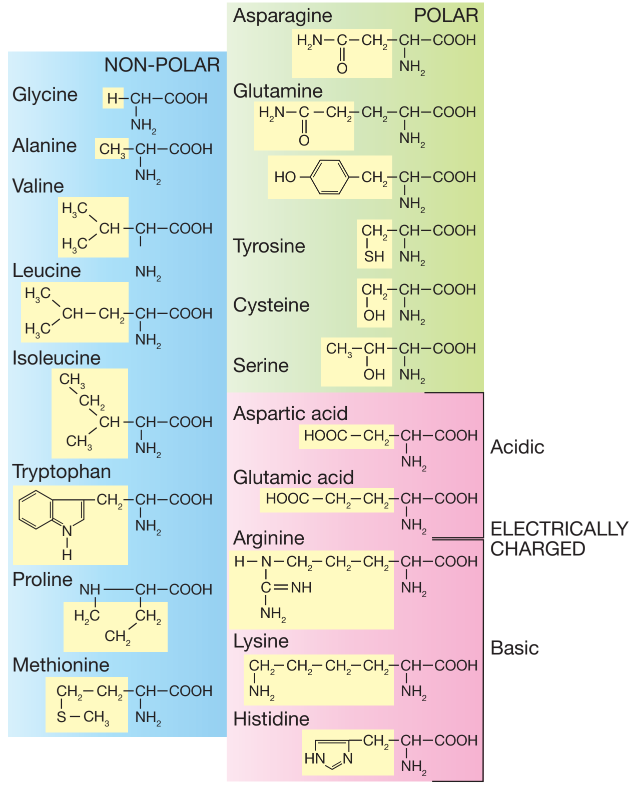

Figure 15.2 Polar, non-polar and electrically charged amino acids.

QUESTIONS

1. What are the components of an amino acid?
2. Which part of the amino acid is:
   (a) Basic? (b) Acidic?
3. What is meant by an amphoteric substance?
4. When describing amino acids, organic chemists talk about the functional groups present in the molecule. What are the functional groups of amino acids?
5. All amino acids, except for proline and hydroxyproline, have an alpha carbon atom. What is an alpha carbon atom?
6. What molecule composition leads to a neutral amino acid, a basic amino acid and an acidic amino acid?
7. Explain why proteins can act as buffers and stabilise the pH of cells and body fluids.
8. Which amino acids are likely to be hydrophilic and which are likely to be hydrophobic?
9. Which proteins are most likely to be soluble?
   (A) Those with a large number of polar amino acids.
   (B) Those with a large number of non-polar amino acids.
   (C) Those containing over 150 amino acids.
   (D) Those with a high number of nucleotides containing adenine.

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Receptor proteins

Cell membrane proteins detect chemical signals and recognise particular signal molecules, e.g. identifying hormones such as adrenaline (also called epinephrine). Adrenaline will cause a faster heart rate and increases blood flow to the muscles. Receptor proteins also have important roles in embryonic development and sensory reception. G protein linked receptors work with the help of a G protein with different G protein linked receptors being stimulated by different signal molecules and for recognising different G proteins inside the cell.

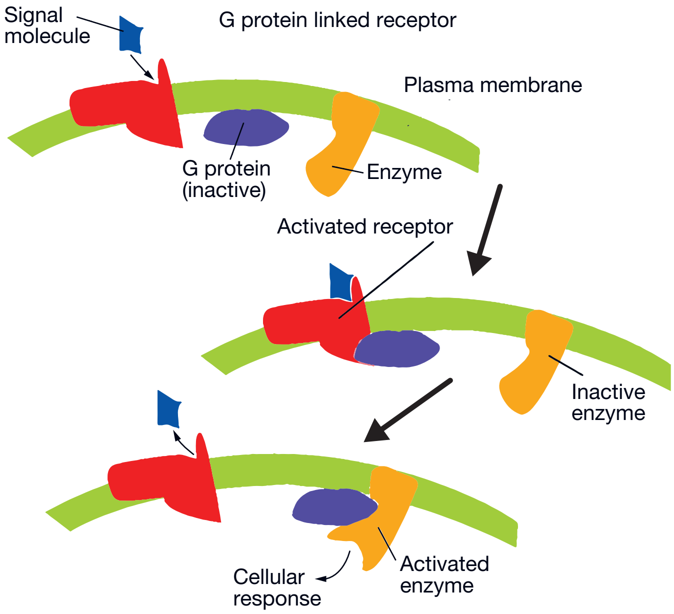

Figure 16.3 G protein linked receptor.

Gene regulatory proteins

Gene regulatory proteins bind to specific regulatory sequences of DNA and act to switch a gene on and off and thus control the transcription of genes.

Defence proteins

Defence proteins help organisms fight infection, heal damaged tissue and evade predators.

Immunoglobulins (Ig) are large Y shaped proteins that are made by plasma B cells and function as antibodies. They are divided into five classes that differ in their distribution in the body and the way they act against the antigen. Immunoglobulin A (IgA) is produced by mucosal linings and is found in tears, saliva and sweat.

Fibrin proteins form blood clots and scabs at a wound side.

Threonine deaminase (TD) is an enzyme made by plants, e.g. tomato plants to deter herbivores, e.g. leaf-eating caterpillars. TD disrupts the digestion of the caterpillar as it degrades the threonine before the herbivore can absorb it starving the herbivore of an essential amino acid.

Conjugated proteins

Conjugated proteins are protein molecules combined with another kind of molecule. **Lipoproteins** are proteins combined with lipids and are mainly found in plasma membranes or carry hydrophobic molecules in the blood, e.g. carrying cholesterol in low density lipoproteins (LDL). **Glycoproteins** are proteins combined with carbohydrates and are important in plasma membranes, e.g. where a carbohydrate section is found on the external surface of the cell forming hydrogen bonds with water and other molecules in the extracellular fluid.

QUESTIONS

1. Define proteomics.
2. What is functional proteomics?
3. Define the proteome.
4. Outline the importance of proteins in living things.
5. Identify the main component of proteins.
6. Outline the relationship between DNA and the proteome.
7. What is an enzyme?
8. The diagram shows a reaction involving an enzyme.

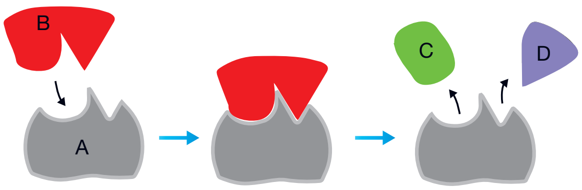

Figure 16.4 Reaction involving an enzyme.

   (a) Identify the enzyme in this reaction and explain its function.
   (b) Identify the reactants and the products.
   (c) What type of reaction is shown in this diagram?
9. What is a hormone?
10. Outline the action of a specific hormone.
11. Distinguish between fibrous proteins and globular proteins.
12. What are transport proteins?
13. Use an example to describe the function of a protein receptor.
14. Outline the function of gene regulatory proteins.
15. Use an example to describe the function of a defence protein.
16. What are conjugated proteins?
17. Construct a table to show the functional diversity of proteins.
18. What is the best description of the proteome?
   (A) A three-dimensional polymer constructed of different amino acid monomers.
   (B) The complete complement of genes in an organism's genetic material.
   (C) The study of the structure and function of proteins.
   (D) The entire complement of proteins that is or can be expressed.

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The cytoplasm of the cell contains many free nucleotides which are used during DNA replication. DNA polymerase proofreads each nucleotide against its template removing incorrect nucleotides or catalysing the formation of bonds to join the correct nucleotide to the DNA strand. If DNA polymerase while proofreading misses a set of mismatched nucleotides other repair enzymes can remove and replace the incorrect pair.

The significance of DNA replication is that large amounts of coded information can be copied and passed onto the next generation, providing continuity of a species. The method also allows for some changes and for mutations when the code is incorrectly copied.

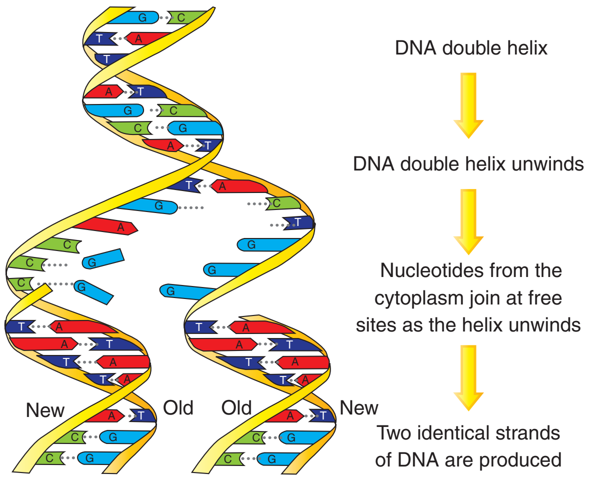

Figure 30.4 DNA replication.

QUESTIONS

1. Which model of DNA replication was proposed by Watson and Crick?
2. Construct a table to summarise the three models of DNA replication that were proposed in the early 1950s.
3. Describe the experiment that eventually showed how DNA replicated.
4. The diagram shows a simple summary of the process of DNA replication.

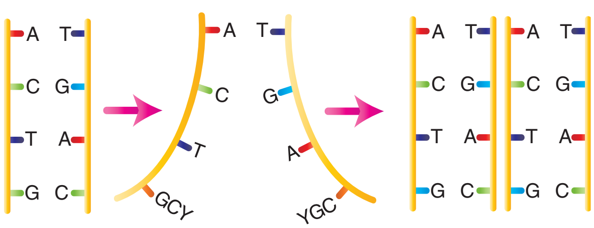

Figure 30.5 Simple summary of DNA replication.

Briefly explain what is happening in this diagram.

5. What is an origin of replication site?
6. What is a replication 'bubble'?
7. Outline the function of helicase enzymes.
8. (a) What is a primer?
   (b) What is the function of RNA primase?
9. Outline the function of DNA polymerase enzymes.
10. Distinguish between the leading strand and the lagging strand in DNA replication.
11. What are Okazaki fragments?
12. Outline the function of DNA ligase enzymes.
13. Explain the significance of DNA replication.
14. The diagram shows several stages of DNA replication.

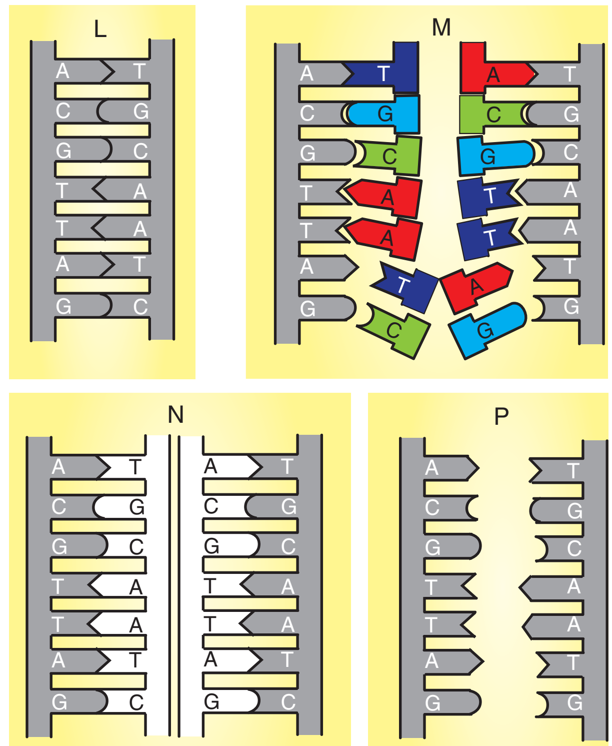

Figure 30.6 Stages of DNA replication.

Identify the correct sequential order.

(A) L, P, N, M (B) L, M, N, P
(C) N, P, M, L (D) L, P, M, N

15. The diagram shows a DNA replication bubble.

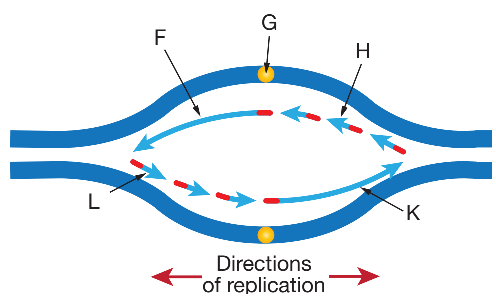

Figure 30.7 DNA replication bubble.

Which arrow(s) point to the leading strand in DNA replication?

(A) F only. (B) H only.
(C) H and L. (D) F and K.

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36 Activity – Gel Electrophoresis

Gel electrophoresis separates substances on the basis of their size and electrical charge by measuring their rate of movement through an electrical field in a gel. Anions (negatively charged particles) travel to the positive electrode (anode). Since DNA has a slight negative charge fragments of DNA move towards the anode in gel electrophoresis.

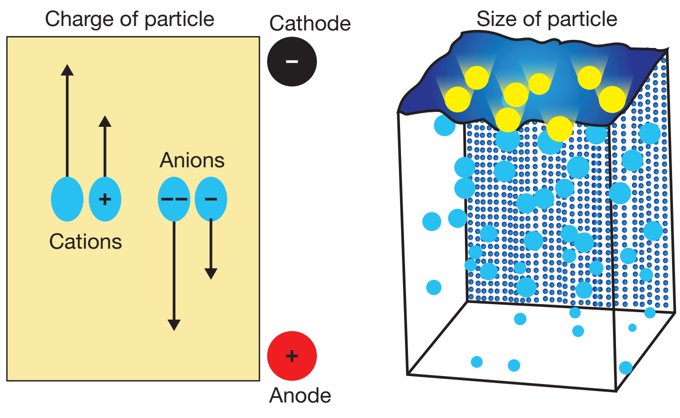

Figure 36.1 Movement in gel depends on charge and particle size.

Equipment

To investigate the movement of substances in gel electrophoresis some senior biology students used coloured dyes on agar trays. Dyes were used instead of DNA as dyes do not need to be stained making the process quicker and the gel can be agar instead of agarose making the investigation less expensive with cheaper reagents. The students used 0.1% sodium hydrogen carbonate solution as the buffer solution, 1% plain agar solution, 40% sucrose solution, micropipette, gel electrophoresis assembly and a selection of dyes.

Method

1. The agar trays were poured and the comb was placed in the notches on the edge of the casting tray.
2. The comb was removed from the gel by gently wiggling to overcome the suction when pulling upwards.

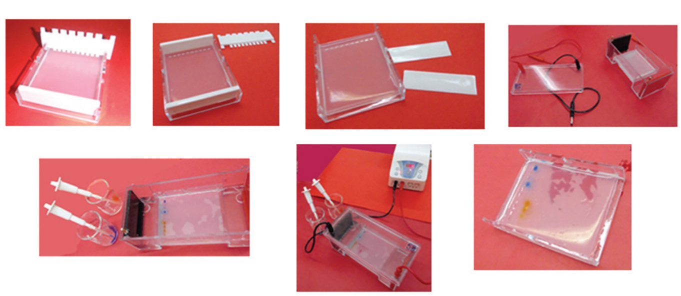

Figure 36.2 Gel electrophoresis investigation.

3. The end plates were removed and the casting tray with agar was positioned in the chamber.
4. The buffer solution was poured into the chamber until it just covered the agar tray.
5. Samples of coloured dyes were injected into the wells in the gel using a micropipette.
6. The chamber lid was attached and the leads connected to the power supply.

Results

The students quickly recorded the distances travelled by each dye in the gel before the dye spots dispersed through the gel.

QUESTIONS

1. What is gel electrophoresis?
2. Distinguish between an anion and a cation.
3. Which way do anions move in gel electrophoresis?
4. Identify the two properties that lead to separation of substances in a mixture in gel electrophoresis.
5. Explain why DNA moves to the anode in gel electrophoresis.
6. Explain why the students used dyes rather than DNA fragments in their experiment.
7. In the experiment when would the dyes have started to move in the gel?
8. Explain why the students had to immediately record the distances travelled by the dyes once the power was turned off.
9. The diagram shows a band pattern for three dyes used by the students in their experiment.

Figure 36.3 Gel electrophoresis with three coloured dyes.

What conclusion could the students draw from these results?

10. Which of the following DNA fragments would move the least in gel electrophoresis?
(A) ATCGGGC
(B) ATCCGGCCATCG
(C) ATCCGGCCATCGCG
(D) ATCCGGCCATCGCGAATTC

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SURFING

VCE BIOLOGY UNIT 3

STUDY DESIGN 2022

Area Of Study 2

How Are Biochemical Pathways Regulated?

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44 Metabolism

Metabolism refers to the sum of all chemical reactions in an organism. **Metabolic pathways** are series of chemical reactions that either build complex macromolecules or break down complex molecules into simpler molecules.

A **catabolic pathway** is a series of reactions that release energy by breaking down complex molecules into simpler molecules, e.g. cellular respiration. Catabolic reactions are often called 'downhill' reactions as energy is released.

An **anabolic pathway** is a series of reactions that build complex macromolecules from simpler molecules, e.g. synthesis of proteins from amino acids. Anabolic reactions are often called 'uphill' reactions as energy is needed to drive the reaction.

Enzyme control

Each step in a metabolic pathway is controlled by a specific enzyme. An **enzyme** is an organic catalyst that controls the rate of a specific chemical reaction.

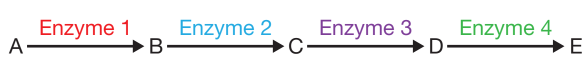

Figure 44.1 Metabolic pathway.

Enzymes lower the activation energy of the chemical reactions that they catalyse.

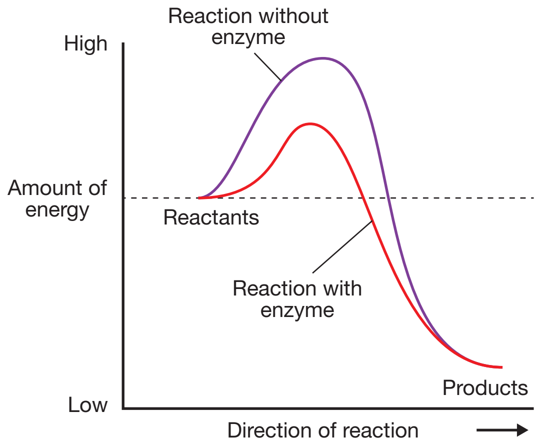

Figure 44.2 Activation energy.

The graph in Figure 44.2 shows exothermic reactions (releases energy by light or heat) – energy is released with the energy levels of the reactants higher than the energy level of the products. The energy required for the reaction to proceed without an enzyme is higher than with an enzyme present.

Each enzyme has an optimal temperature and an optimal pH at which it is most active.

Types of cellular work

There are three main types of work done by cells.

Transport work – substances are moved across a membrane by active transport against the concentration gradient.

Chemical work – energy is used to drive specific chemical reactions, e.g. biosynthesis of macromolecules.

Mechanical work – involving the transfer of energy, e.g. beating of cilia, muscle cells change shape in contraction, chromosomes move in mitosis.

Adenosine triphosphate (ATP)

ATP is the 'energy currency' of a cell. It is used to drive transport and mechanical work.

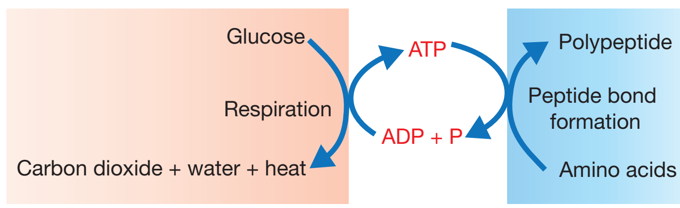

Figure 44.3 ATP/ADP cycle.

QUESTIONS

1. Define metabolism.
2. What is meant by a metabolic pathway?
3. Define a catabolic pathway.
4. Define an anabolic pathway.
5. Explain why catabolic and anabolic reactions are often called 'downhill' and 'uphill' reactions respectively.
6. Define an enzyme.
7. Explain how enzymes affect the activation energy of a reaction.
8. Define an exothermic reaction.
9. Construct a table to summarise the three types of work done by cells.
10. How is ATP involved in metabolism?
11. Draw a word equation to show the linking of ATP formation and respiration.
12. Study the following linked reactions.

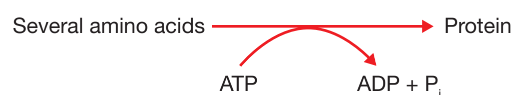

Figure 44.4 Linked reactions.

What is shown in this diagram?
(A) ADP becomes a part of protein structure.
(B) ATP becomes a part of protein structure.
(C) ADP provides energy in protein synthesis.
(D) ATP provides energy in protein synthesis.

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45 Photosynthesis Review

Photosynthesis is a chemical process in which solar energy is captured and transformed to chemical energy by fixing carbon to produce a carbohydrate and releasing oxygen as a by-product.

$$\text{Carbon dioxide} + \text{water} \xrightarrow{\text{light, chlorophyll}} \text{glucose} + \text{oxygen}$$

$$6CO_2 + 6H_2O \xrightarrow{\text{light, chlorophyll}} C_6H_{12}O_6 + 6O_2$$

Figure 45.1 Equations for photosynthesis.

Photosynthesis is needed to sustain and maintain most of the complex ecosystems on Earth. Photosynthesis is not only used by photoautotrophs to start food webs but it removes carbon dioxide from the atmosphere and releases gaseous oxygen into the atmosphere which is important in the carbon/oxygen cycle and the maintenance of the ozone layer around the Earth. Oxygen gas and glucose are needed for aerobic respiration in all living things.

$$3O_2 \xrightarrow{\text{UV light}} 2O_3$$

Figure 45.2 Equation for formation of ozone.

Photoautotrophs are organisms that harness light energy to synthesise organic compounds from carbon dioxide. Photoautotrophs include green plants, cyanobacteria, phytoplankton, *Euglena* and algae. Only about 1% to 2% of solar energy is captured by photosynthesis.

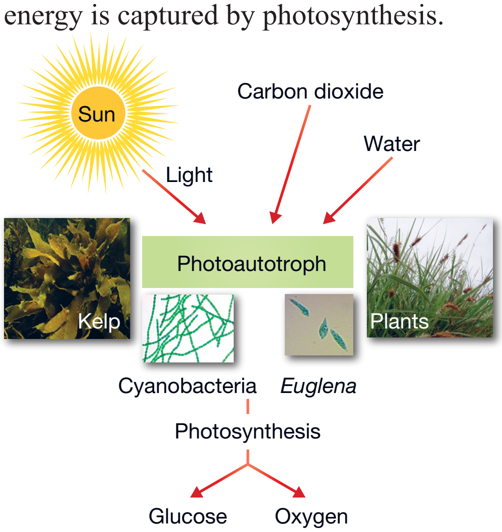

Figure 45.3 Photoautotrophs and photosynthesis.

Main steps in photosynthesis

There are two main steps in photosynthesis in eukaryotes – the light dependent reaction and the light independent reaction. The **light dependent reaction** occurs in the grana of chloroplasts and splits water into hydrogen and oxygen. The light independent reaction occurs in the stroma of chloroplasts and involves the joining of the hydrogen to carbon dioxide to form a glucose molecule.

Factors affecting the rate of photosynthesis

The rate of photosynthesis is affected by light intensity, carbon dioxide concentration and temperature.

If there is sufficient water and carbon dioxide increasing the **light intensity** will increase the rate of photosynthesis until other limiting factors restrict the rate of photosynthesis.

If there is sufficient light and water increasing the **carbon dioxide concentration** will increase the rate of photosynthesis until other limiting factors restrict the rate of photosynthesis.

At **very low temperatures** and **very high temperatures** the rate of photosynthesis is restricted.

Importance of photosynthesis

Besides harvesting solar energy and starting food chains and food webs, photosynthesis is important as the ultimate source of many **raw materials** used by humans. Plants provide materials for clothing, e.g. cotton, for footwear, e.g. latex rubber, for construction, e.g. timber, for paper and for making solvents, e.g. alcohol.

Many synthetic materials such as **synthetic polymers** come from fossil fuels such as natural gas and crude oil and to a lesser extent coal and are used to make fabrics and containers depending on their properties. The petrochemicals are non-renewable which means it is important to recycle these synthetic polymers.

Photosynthesis is important as plant biomass from photosynthetic plants can be used instead of fossil fuels to produce ethanol which can be used as a fuel and plant biomass can also be used to produce biodegradable plastics such as polyesters, e.g. polylactic acid (PLA) and polyhydroxybutyrate (PHB) or cellulose fibres such as rayon.

Scientists are investigating artificial photosynthesis using solar energy to form chemical bonds in solar fuels. This shows the importance of photosynthesis as a chemical process and human reliance on its products. For example, researchers are developing an '**artificial leaf**' using solar energy to split water into hydrogen and oxygen with the hydrogen to be used as a fuel, e.g. for vehicles or to be stored for use in generating electricity. Since only a small amount of solar energy is captured by natural photosynthesis processes, the development of new technologies could increase the efficiency rate of converting light energy to chemical energy to aid the world's energy supply problem.

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Development of knowledge

In 1634 **Jan Baptist van Helmont** investigated the growth of plants and became the first person to study photosynthesis scientifically. He grew a willow tree and measured the amount of soil, the weight of the tree and the water added and argued that the increase in weight of the tree was due to the water alone as the soil weighed approximately the same amount at the end of five years as at the beginning of his experiment.

In 1864, **Julius von Sachs** studied starch grains being formed in leaves exposed to light and showed that chlorophyll is not distributed randomly throughout the plant but is found in specific bodies, later called chloroplasts. Sachs found that this site is where glucose is produced and that glucose is usually stored as starch.

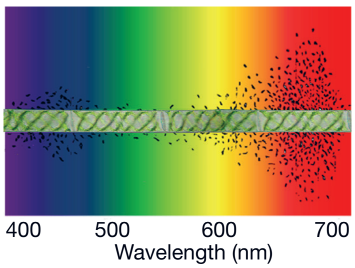

Figure 45.4 Results of Engelmann's experiment.

In 1883, **Theodor Wilhelm Engelmann** performed his classic experiment showing that photosynthesis uses red and blue light. He shone thin rays of light on *Spirogyra*, a filamentous alga that has a spiral chloroplast, and *Pseudomonas*, a motile bacterium that is very sensitive to oxygen concentrations. He found that the bacteria clustered near the chloroplast that was exposed to the violet and red wavelengths of the spectrum. From this Engelmann produced an action spectrum showing the region in which chlorophyll absorbs light. An **action spectrum** is a graph that shows the effectiveness of different wavelengths of radiation in driving a particular process.

In 1894 Engelmann showed that the bacteria migrate to areas where the *Spirogyra* was green or where there were chloroplasts.

Later research showed that the action spectrum of photosynthesis does not match the spectrum produced by Engelmann for chlorophyll as other pigments, e.g. the yellow and orange carotenoids and phycobilins absorb light in other wavelengths, e.g. wavelengths reflected by chlorophyll and these pigments pass the energy on to chlorophyll. These accessory pigments increase the range of wavelengths that can be used for photosynthesis.

QUESTIONS

1. What is photosynthesis?
2. Identify the products of photosynthesis.
3. Outline the importance of photosynthesis.
4. Define a photoautotroph and give some examples.
5. Outline the two main steps in photosynthesis.
6. List the main abiotic factors that limit the rate of photosynthesis.
7. Explain the advantages of a farmer burning paraffin lamps inside a greenhouse.
8. Outline a relationship between photosynthesis and the ozone layer.
9. Explain the significance of photosynthesis for ecosystems.
10. Explain how photosynthesis could be used to help solve a named environmental issue.
11. Outline the contribution of Jan Baptist van Helmont to our understanding of photosynthesis.
12. Outline the contribution of Julius von Sachs to our understanding of photosynthesis.
13. Outline the contribution of Theodor Engelmann to our understanding of photosynthesis.
14. Use an example to show how our understanding of the process of photosynthesis can lead to new technologies that could help address climate change problems.
15. What is meant by an action spectrum?
16. Why is the action spectrum of chlorophyll produced by Engelmann different to the action spectrum for photosynthesis?
17. The graph shows the effect of an abiotic factor on the rate of photosynthesis.

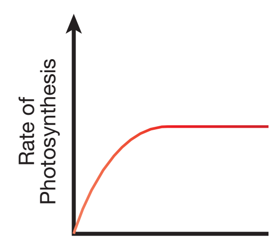

Figure 45.5 Rate of photosynthesis changes with an abiotic factor.

Which of the following is the most likely abiotic factor represented in this graph?
(A) Carbon dioxide concentration.
(B) Oxygen concentration.
(C) Wavelength of light.
(D) Temperature.

18. What is the correct word equation for photosynthesis?
(A) Water + glucose → carbon dioxide + oxygen
(B) Water + carbon dioxide → glucose + oxygen
(C) Glucose + oxygen → carbon dioxide + water
(D) Carbon dioxide + glucose → oxygen + water
19. Which group only contains photoautotrophs?
(A) Protists, fungi, bacteria.
(B) Bacteria, *Euglena*, algae.
(C) Fungi, plants, cyanobacteria.
(D) Plants, algae, cyanobacteria.

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50 Reactions In Photosynthesis

Photosynthesis is a series of reactions that occur in two main steps – the light dependent reactions and the light independent reactions.

Light dependent reactions

The light dependent reactions convert solar energy to the chemical energy of ATP and NADPH. Chlorophyll absorbs light energy and water is split to produce hydrogen ions (H^+), electrons and oxygen gas is released as a by-product. In plants the light reactions occur in the membranes of the thylakoids in chloroplasts. In the thylakoid membranes there are **light harvesting complexes** that contain pigment molecules, e.g. chlorophyll *a* (blue-green), chlorophyll *b* (yellow-green) and carotenoids (yellow or orange pigments). The type of pigment molecules and the number of pigment molecules determine the amount of light that can be trapped.

The pigment molecules absorb a photon of energy and pass the energy to the reaction centre complex. The **reaction centre complex** is a series of proteins linked with a primary electron acceptor and a pair of chlorophyll *a* molecules. The reaction centre complex is excited by light energy and triggers the light reaction of photosynthesis.

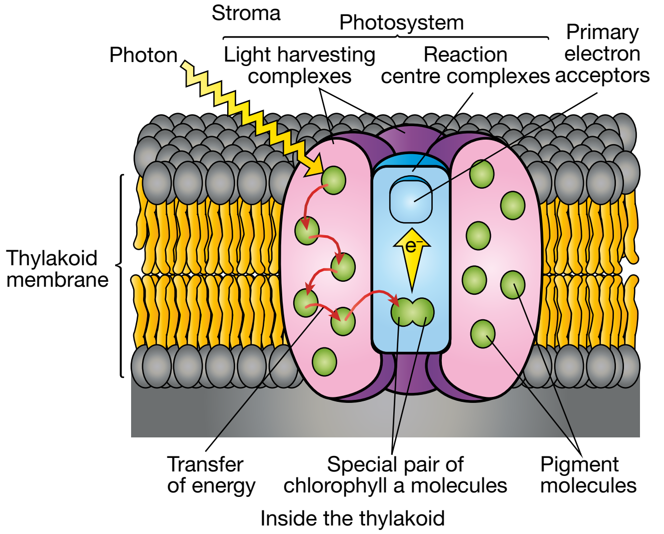

Figure 50.1 Reaction centre complex.

There are two types of photosystems in the thylakoid membranes. A **photosystem** is a light capturing unit that contains a reaction centre complex surrounded by several light harvesting complexes. There are two types of photosystems – photosystem I (PS I) has two molecules of P700 chlorophyll *a* at its reaction centre and photosystem II (PS II) has two molecules of P680 chlorophyll *a* at its reaction centre. PS II acts first and absorbs light with a wavelength of 680 nm (red light). It was discovered after PS I and thus was named second. PS I absorbs light with a wavelength of 700 nm (far red).

The photoactivation of a photosystem occurs when light strikes a pigment molecule, is absorbed and electrons move away from the nucleus of the atom to higher energy levels. PS II can elevate electrons to a moderate level while PS I can elevate electrons to a high level and its electrons are replaced by electrons from PS II. The electron flow from carrier to carrier in redox reactions pushes electrons from water where they have low potential energy to be taken up by $NADP^+$ to form NADPH where they are stored in a high state of potential energy. The electron current also generates ATP when hydrogen ions diffuse from inside the thylakoid back into the stroma through an ATP synthase complex and ATP forms on the stroma side of the membrane. **Photophosphorylation** occurs when the light energy is used to generate ATP by adding a phosphate group to ADP.

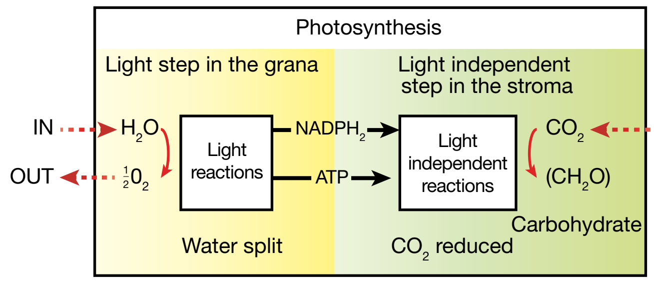

Figure 50.2 The two steps of photosynthesis.

Light independent reactions

At first these reactions were called the 'dark' stage as they do not directly need light but this name is misleading as the reactions do not need darkness to occur. The reactions are now called the light independent stage or the synthetic stage. Melvin Calvin led the team that worked out the chemical pathway which incorporates carbon dioxide from the air into carbohydrates and the pathway is known as the **Calvin cycle**. The first step is **carbon fixation**. The Calvin cycle then reduces the fixed carbon to carbohydrate by the addition of electrons.

The end product of the Calvin cycle is a three carbon sugar – G3P (glyceraldehyde-3-phosphate) – a triose phosphate which requires the cycle to occur three times to fix three molecules of carbon dioxide. The G3P molecule is the raw material for the production of glucose, fatty acids, amino acids, nucleotides and other organic molecules that are needed by the plant. In many instances G3P is immediately converted into glucose phosphate and then starch. The starch grains accumulate in the stroma of chloroplasts and are broken down during night time as a source of energy or raw material for metabolic reactions in the plant.

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The need for chlorophyll in photosynthesis can be shown by using variegated leaves which have areas of white-cream-yellow on the leaf where there is no chlorophyll. When tested for starch these areas will show a negative test result.

Figure 51.5 Variegated leaf.

QUESTIONS

1. Define photosynthesis.
2. What is the range of wavelengths of visible light?
3. Name the colours in white light.
4. How can you show the need for light in photosynthesis?
5. Explain why chlorophyll appears green.
6. How would you 'destarch' the leaves of a potted plant?
7. What is chlorophyll?
8. Name the three pigments found in chlorophyll in the chloroplasts of plants.
9. What is the absorption spectrum of a pigment?
10. What does the absorption spectrum of chlorophyll *a* show?
11. Outline the function of a spectrophotometer.
12. What are the action spectra of photosynthesis?
13. How would you measure the action spectra of photosynthesis?
14. Explain why the action spectra of photosynthesis are not a perfect match for the absorption spectrum of chlorophyll *a*.
15. A group of biology students set up the following experiment.

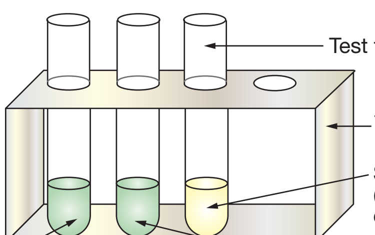

Figure 51.6 Student experiment.

The students stirred the contents of each test tube and then left them in sunlight for six hours. Each test tube was then tested for the presence of sugar.

(a) Name the biochemical process that was being tested in this experiment.
(b) Predict the result of the test for sugar.
(c) Give one reason for your prediction.

16. Chlorophyll *a* is blue-green while chlorophyll *b* is yellow-green. How is this difference in appearance shown by the absorption spectra?
17. Explain why plants need accessory pigments besides chlorophyll *a*.
18. In 1883 the German botanist Theodor W Engelmann performed an experiment to measure the rates of photosynthesis in *Spirogyra*, a green filamentous algae. He shone white light through a prism so that different sections of the algae were illuminated in different wavelengths of light. He used aerobic bacteria to show where oxygen was being produced.

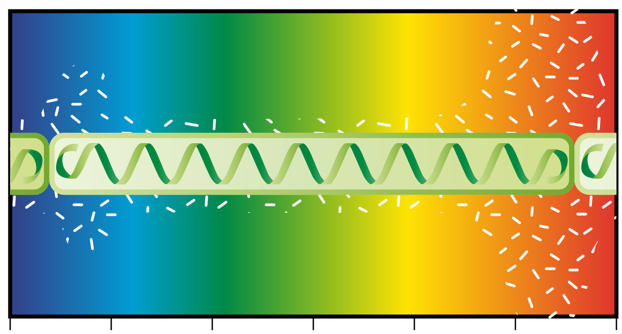

Figure 51.7 Engelmann's experiment.

The diagram shows the results of Engelmann's experiment and the concentration of aerobic bacteria along the filament of *Spirogyra*.
What conclusion could Engelmann draw from this experiment?

(A) *Spirogyra* only photosynthesises when bacteria are present.
(B) Bacteria have a symbiotic relationship with *Spirogyra.*
(C) *Spirogyra* mainly uses green light in photosynthesis.
(D) *Spirogyra* uses red and blue light in photosynthesis.

19. What do you call a graph that shows the rate of photosynthesis for different wavelengths of light?
(A) Absorption spectrum.
(B) Action spectrum.
(C) Electromagnetic spectrum.
(D) Dispersion of light.

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54 Radioisotopes and Photosynthesis

Increasing our knowledge of biochemical pathways is difficult as the substances cannot be viewed under a microscope and there are usually many intermediate steps in the pathway.

Isotopes are different forms of the same element with the same number of protons and electrons but a different number of neutrons in the nucleus and thus have a different mass number.

Radioisotopes are unstable forms that will decay and emit radiation. The half-life of a radioisotope is the time for 50% of the radioactive atoms to decay – half the radioactive mass is gone. Radioisotopes can be used in biochemistry and those with short half-lives are useful for investigations and treatments for living organisms.

There is a range of isotopes that have been used in studying photosynthesis. The radioactive tracers are incorporated into plants in a labelled substance and stopping the reaction at different times means that the pathway being taken by the labelled atoms can be followed. The radioactive tracers do not affect the plant metabolism and can be used in living material.

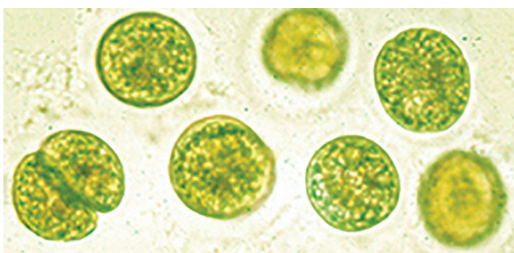

Figure 54.1 *Chlorella*, a single cell green alga.

Ruben's experiment

In 1939 Samuel Ruben and Martin Kamen began using the radioactive isotope ^{11}C to trace the carbon atoms in photosynthesis. However, ^{11}C has a short half-life (approximately 20 minutes) which meant it decayed too quickly to be of significant use.

In 1941 Samuel Ruben used heavy oxygen ^{18}O to investigate the pathway of oxygen in photosynthesis. He placed his experimental green algae, *Chlorella* in water containing ^{18}O but since this is not a radioactive isotope of the most common form of oxygen (^{16}O) he used a mass spectrometer to follow the metabolic path of the ^{18}O. The only oxygen released was ^{18}O and he concluded that the oxygen from the water became the oxygen released as a gas (O_2) in photosynthesis and the oxygen from water was not incorporated into the glucose ($C_6H_{12}O_6$).

The Calvin cycle

Between 1948 and 1957 A Benson and M Calvin investigated the steps in photosynthesis using radioactive carbon dioxide ($^{14}CO_2$). Labelled carbon dioxide was given to the green algae *Chlorella* that was exposed to light. He immersed the algae after a few seconds in boiling alcohol killing the cells and inactivating the enzymes involved in the reactions. By changing the number of seconds before stopping the reaction, the number of intermediates could be controlled and the steps in the reaction could be determined, e.g. the intermediate compounds were separated out using paper chromatography. The carbon-14 is radioactive and the paper chromatogram can be placed on unexposed photographic film. The location of the carbon-14 will show up as spots on the developed film (autoradiograph). The spots can then be cut out and chemically analysed to confirm their identity. This work led to our understanding of the Calvin cycle (light independent reactions) in photosynthesis.

Table 54.1 Isotopes used to study photosynthesis.

Isotope	Half-life	Why it is used
Hydrogen (^{3}H)	12.1 years	Tracks the movement of hydrogen ions (H^+) across the thylakoid membranes
Carbon (^{14}C)	5700 years	Tracks carbon in carbon dioxide (CO_2) gas to glucose
Oxygen (^{18}O)	Not radioactive and measured in mass spectrometer	Determining pathway of oxygen atoms in raw products water (H_2O) and carbon dioxide (CO_2)
Phosphorus (^{32}P)	14.3 days	Tracking the phosphate groups in the ADP/ATP cycle

QUESTIONS

1. What is an isotope?
2. What is a radioisotope?
3. Explain why radioisotopes are useful in investigating biochemical pathways such as photosynthesis.
4. Explain why ^{11}C was not suitable as a radioactive tracer for many experiments discovering the stages and process of photosynthesis.
5. Explain why ^{18}O cannot be used a s radioactive tracer.
6. Outline the contribution of Samuel Ruben to our understanding of photosynthesis.
7. How did radioisotopes reveal the Calvin cycle?
8. Why is chlorella useful as an experimental organism?
9. Which radioisotope would be most suitable for investigating carbon in the Calvin cycle?
   (A) Carbon-11
   (B) Carbon-12
   (C) Carbon-14
   (D) Carbon-18

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The Krebs cycle

The Krebs cycle was worked out in the 1930s by Sir Hans Krebs. It is also known as the citric acid cycle or the tricarboxylic acid (TCA) cycle. It is a series of reactions that occur in the mitochondria with each step catalysed by a specific enzyme. The enzymes for the Krebs cycle are in the matrix of the mitochondria.

Pyruvate formed by glycolysis enters the mitochondrion by active transport and is converted into acetyl coenzyme A (**acetyl CoA**). The acetyl CoA is then degraded to carbon dioxide and water with the release of ATP. Since the breakdown of one glucose molecule produces two acetyl CoA molecules the cycle must turn twice to process each glucose molecule. The Krebs cycle also forms NADH and $FADH_2$ which will donate electrons to the electron transport chain.

NAD^+ (nicotinamide adenine dinucleotide) is an electron acceptor that acts as an oxidising agent in respiration and is reduced to NADH. Each NADH formed in respiration has stored energy that can be used by the electron transport chain.

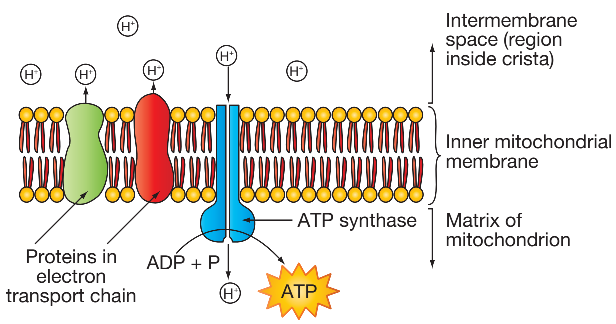

Figure 62.3 Electron transport chain.

Electron transport pathway

The electron transport chain is a series of electron carrier molecules (e.g. membrane proteins) that move electrons during redox reactions. The enzymes and carriers of the electron transport chain are attached to the inner membrane of the mitochondria.

Energy released in the electron transport chain is used to make ATP – at certain steps in the electron transport chain the movement of the electrons causes hydrogen ions (H^+) to be moved from the mitochondrial matrix into the intermembrane space. This creates a H^+ (proton) gradient storing energy as a proton motive force. The hydrogen ions will move back into the matrix through ATP synthase causing the phosphorylation of ADP to form ATP.

NADH and $FADH_2$ formed in the Krebs cycle transfer electrons to the electron transport chain with the electrons moving from one electron acceptor molecule to the next losing energy in the energy-releasing steps. The final electron acceptor is molecular oxygen to produce water as a by-product.

Chemiosmosis is an energy coupling mechanism that uses stored energy in the form of a H^+/proton gradient across a membrane to power cellular activities. In cellular respiration the synthesis of ATP is by chemiosmosis.

QUESTIONS

1. Distinguish between oxidation and reduction in chemical reactions.
2. Compare the energy of an oxidised substance and a reduced substance.
3. Would a glucose molecule ($C_6H_{12}O_6$) have more or less energy than a methane molecule (CH_4)? Explain your reasoning.
4. Would a molecule of methane (CH_4) have more or less energy than a molecule of carbon dioxide (CO_2)? Explain your reasoning.
5. Name the three main steps in cellular respiration.
6. What is the meaning of the word 'glycolysis'?
7. What happens in glycolysis?
8. Explain why glycolysis can occur in both aerobic and anaerobic conditions.
9. How much ATP is synthesised per glucose molecule in glycolysis?
10. What is phosphorylation?
11. Where does the Krebs cycle occur?
12. What is chemiosmosis?
13. In a mitochondrion, what reactions occur:
    (a) On the inner membrane?
    (b) In the matrix?
14. In which step of cellular respiration is glucose broken down into two pyruvate molecules?
    (A) Glycolysis.
    (B) Krebs cycle.
    (C) Electron transport chain.
    (D) Chemiosmosis.
15. Which molecule is the main 'energy currency' of a cell?
    (A) Adenosine diphosphate.
    (B) Adenosine triphosphate.
    (C) Adenine.
    (D) Acetyl CoA.
16. What happens during phosphorylation?
    (A) Phosphate is broken down into phosphorus and oxygen.
    (B) Phospholipids are broken down with a phosphate being removed.
    (C) A phosphate is added to a molecule.
    (D) Hydrogen is added to a phosphate.
17. Which of the following can act as an electron acceptor?
    (A) CO_2 (B) $C_6H_{12}O_6$
    (C) NADH (D) NAD^+

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SURFING

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Topic Test

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11. The diagram shows a cross-section of a leaf.

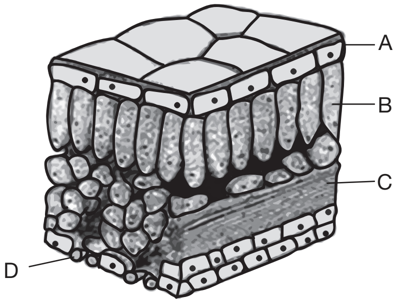

Figure TT.3 Leaf cross-section.

In which cells is most oxygen produced?

(A) A
(B) B
(C) C
(D) D

Use the following diagram for the next THREE questions.

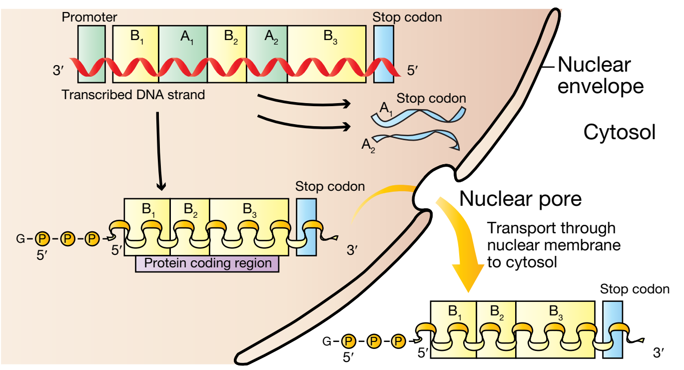

Figure TT.4 Process involving DNA.

12. In this process what is represented by parts A_1 and A_2 and parts B_1, B_2, B_3?

	A_1 A_2	B_1 B_2 B_3
(A)	Exons	Introns
(B)	Introns	Exons
(C)	DNA	RNA
(D)	Histones	Nucleotides

13. What is shown in this process?

(A) Translocation.
(B) Differentiation.
(C) Translation.
(D) Transcription and RNA processing.

14. During this process the following section was added to the strand.

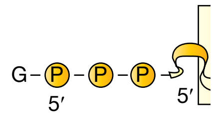

Figure TT.5 Section added to strand.

What happens in this process?

(A) A cap of a modified base is added to the 5′ end of mRNA chain.
(B) A cap of a modified base is added to the 3′ end of mRNA chain.
(C) A poly-A tail is added to the 3′ end.
(D) A poly-A tail is added to the 5′ end.

15. Which of the following would *not* be considered a biofuel?

(A) Fermentation of sugar to form ethanol.
(B) Transesterification of vegetable fats into diesel.
(C) Saponification of algae to extract oil.
(D) Fractional distillation of crude oil.

16. Certain chemicals are known to inhibit the action of specific enzymes, e.g. penicillin prevents bacteria making their cell walls. Which of the following offers the best explanation for this inhibition?

(A) Penicillin is made of cellulose in a form which cannot be used by bacteria.
(B) Penicillin reacts with cellulose so there is no substrate to make cell walls.
(C) Penicillin blocks the active site of an enzyme involved in making the cell wall.
(D) Penicillin changes the pH increasing the acidity so enzymes cannot function.

17. Which of the following best represents the formation of ATP during aerobic respiration?

(A) Glucose + oxygen → carbon dioxide + water + 2ATP.
(B) Glucose + oxygen → carbon dioxide + water + 46ATP.
(C) Glucose → carbon dioxide + water + 2ATP + lactic acid.
(D) Glucose + oxygen → carbon dioxide + water + 38ATP.

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33. Some students investigated the transformation of milk into cheese using a bacterial starter culture. They kept the fermentation trials at room temperature and varied the pH. Their results are shown in the graph.

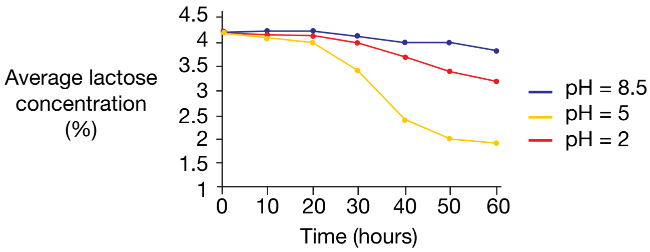

Figure TT.12 Effect of pH on lactose concentration in cheese making.

From these results how does pH affect the fermentation of lactose to lactic acid?

(A) The greatest conversion of lactose to lactic acid occurs in slightly acidic conditions.
(B) The greatest conversion of lactose to lactic acid occurs in highly acidic conditions.
(C) The greatest conversion of lactose to lactic acid occurs in slightly alkaline conditions.
(D) The greatest conversion of lactose to lactic acid occurs in pH neutral conditions.

34. The diagram shows a cellular process.

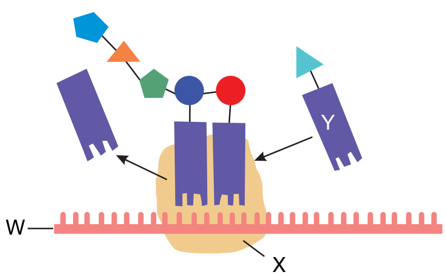

Figure TT.13 Cellular process.

Identify parts W, X and Y.

	W	X	Y
(A)	mRNA	tRNA	Ribosome
(B)	mRNA	Ribosome	tRNA
(C)	tRNA	Ribosome	mRNA
(D)	tRNA	mRNA	Ribosome

35. In which type of plant cell does the Calvin cycle occur in C4 plants?
(A) Bundle sheath cells.
(B) Palisade mesophyll cells.
(C) Spongy mesophyll cells.
(D) Epidermal cells.

36. Which of the following identifies two isotopes that have been useful in studying photosynthesis?
(A) Carbon-14 (^{14}C) and sulfur-34 (^{34}S).
(B) Carbon-14 (^{14}C) and oxygen-18 (^{18}O).
(C) Sulfur-34 (^{34}S) and oxygen-18 (^{18}O).
(D) Nitrogen-15 (^{15}N) and sulfur-34 (^{34}S).

37. What is the function of photosystem I?
(A) Provides electrons and traps energy to generate ATP.
(B) Causes the oxidation of water.
(C) Generates a strong reducing agent to reduce $NADP^+$ to NADPH.
(D) Traps light energy in grana of thylakoids.

38. If an enzyme is heated and its active site is permanently altered, the enzyme is said to be:
(A) Denatured.
(B) Distorted.
(C) Compromised.
(D) Inhibited.

39. A student carried out a first-hand investigation on the effect of pH on an enzyme. Which of the following identifies the independent and dependent variable?

	Independent variable	Dependent variable
(A)	pH	Substrate concentration
(B)	pH	Enzyme activity
(C)	Enzyme activity	pH
(D)	Amount of enzyme	Substrate concentration

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40. The graphs show the absorption spectrum of chlorophyll *a* and action spectrum of a particular plant.

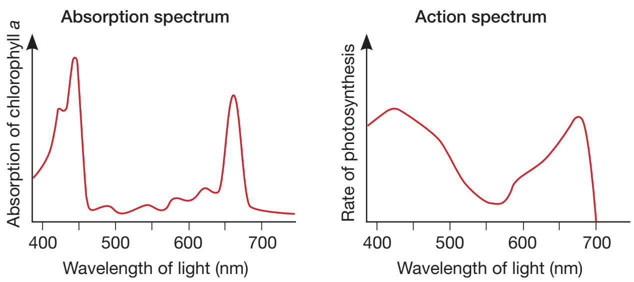

Figure TT.14 Absorption spectrum and action spectrum.

What difference is present in the wavelength range of each peak of the action spectrum compared to the absorption spectrum of chlorophyll *a*?

(A) The action spectrum peaks are more in the green wavelengths than the peaks of the absorption spectrum of chlorophyll *a*.
(B) The action spectrum peaks more clearly define particular wavelengths than the peaks of the absorption spectrum of chlorophyll *a*.
(C) The action spectrum peaks are narrower than the peaks of the absorption spectrum of chlorophyll *a*.
(D) The action spectrum peaks are broader than the peaks of the absorption spectrum of chlorophyll *a*.

Section B – Written Response (60 marks)

41. What is meant by the universality of the genetic code? (1 mark)

42. The diagram shows an organelle.

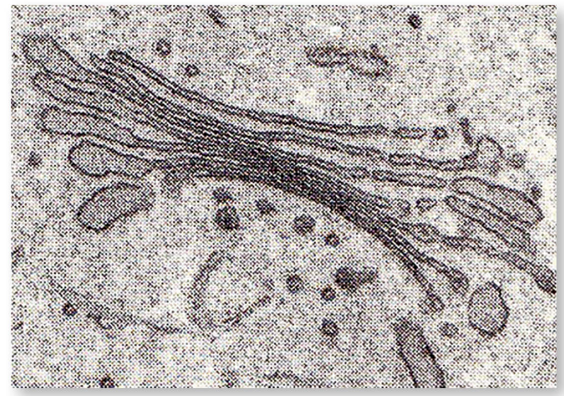

Figure TT.15 Organelle.

Identify this organelle and explain its function in the export of a protein product from the cell through exocytosis. (4 marks)

43. (a) Define a proteome. (1 mark)
(b) Outline the relationship between DNA and the proteome. (3 marks)

44. (a) Write the word and chemical equation for anaerobic fermentation in yeast. (2 marks)
(b) What is an advantage of aerobic respiration over anaerobic respiration? (1 mark)

45. The diagram shows the three main forms of RNA.

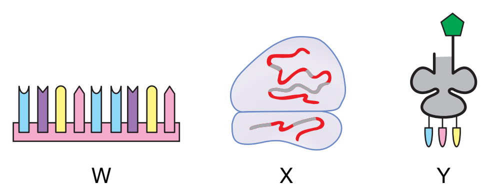

Figure TT.16 Three main types of RNA.

Identify each type of RNA and compare their features. (4 marks)

46. (a) Define an operon. (1 mark)
(b) Outline why the *trp* operon is often used as the classic example of prokaryotic gene regulation. (2 marks)
(c) Explain why the *trp* operon is an example of repressible negative regulation of gene expression. (3 marks)

47. Construct a table to compare structural genes and regulatory genes giving examples and how they work. (6 marks)

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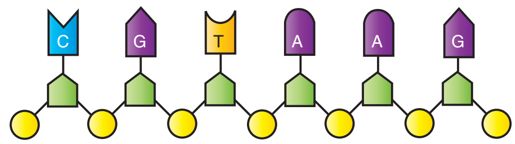
Answers

1 Assumed Knowledge

1. Four main classes of macromolecules are carbohydrates, lipids, proteins and nucleic acids.
2. Generalised formula and structure of proteins.
3. Amino acids have an amino group (NH_3), a carboxyl group (COOH) and a side chain R.
4. Hydrophobic means water hating and hydrophilic means water loving,
5. DNA stands for deoxyribose nucleic acid.
6. DNA has a double helix shape.
7. RNA stands for ribose nucleic acid.
8. Exocytosis is the process when vesicles inside the cell fuse with the cell membrane and the contents of the vesicle are secreted from the cell. Whereas endocytosis is a process where a cell takes in macromolecules by forming vesicles from the plasma membrane.
9. A gene is a distinct unit of hereditary information made up of a specific nucleotide sequence in DNA or RNA in some viruses.
10. A chromosome is one very long DNA molecule and associated proteins consisting of hundreds or thousands of genes arranged along its length. Chromosomes carry the genetic material.
11. An allele is an alternate form of gene that may produce distinguishable phenotypes.
12. An enzyme is a chemical made by living things and its function is to control the rate of a specific chemical reaction that occurs in the body.
13. Proteins are long complex polymers built from linear sequences of amino acids joined together by peptide bonds in polypeptide chains. Proteins can be one or more polypeptide chains.
14. DNA nucleotides consist of a deoxyribose sugar, a phosphate and a nitrogenous base either adenine, cytosine, guanine or thymine.
15. A chloroplast is a green organelle found in green tissues of plants that captures sunlight in photosynthesis to manufacture sugars from carbon dioxide and water.
16. Photosynthesis is a process where the energy of sunlight is used to convert carbon dioxide and water into sugars and oxygen.
17. Groups of organisms that can photosynthesise include plants, algae and photosynthetic bacteria.
18. Carbon dioxide and water are needed for photosynthesis using light energy and in the presence of chlorophyll.
19. Photosynthesis is important in ecosystems as it converts light energy into chemical energy to begin most food chains on Earth and also provides oxygen which is needed for respiration.
20. Inorganic compounds are molecules that do not contain carbon (excluding some carbonates and simple oxides of carbon).
21. Respiration is the chemical reactions in which cells obtain energy from food.
22. ATP is adenosine triphosphate which is a molecule composed of three phosphate groups and adenosine (ribose sugar combined with adenine). ATP releases free energy when its phosphate bonds are hydrolysed and is the main source of energy in cells.
23. The gas collecting in the test tube is oxygen.
24. The results show that plants mainly use red and blue light in photosynthesis.

2 The Structure Of DNA

1. A gene is a certain section of DNA in a chromosome that represents a particular characteristic.
2. DNA stands for deoxyribose nucleic acid.
3. A major advance in scientific understanding occurred when in 1944 Oswald Avery demonstrated that genes were made of DNA. This directed future biological research into the structure of DNA, leading to Rosalind Franklin, with Maurice Wilkins, using X-ray diffraction crystallography in 1952 to show that the DNA molecule was helical. This major advance then led to James Watson and Francis Crick proposing in 1953 that DNA molecules had a double helix structure. The work of each scientist built upon the work of another scientist to unravel the mystery of the structure of DNA.
4. DNA is a double helix or twisted ladder shape.
5. A nucleotide is the basic unit of DNA. It consists of a sugar, a phosphate and a nitrogenous base.
6. The phosphate group gives the nucleotide its acidic properties.
7. Adenine pairs with thymine and cytosine pairs with guanine.
8. (a) DNA is able to encode a large amount of information; (b) it is chemically stable; (c) it is able to make an accurate replication of itself; (d) it controls and directs protein synthesis; (e) occasional errors (mutations) occur.
9. Covalent bonds called phosphodiester linkages hold the sugar of one nucleotide to the phosphate group of the next nucleotide.
10. Hydrogen bonds hold the nitrogenous bases on the rungs of the ladder together.
11. The two stands of DNA are called antiparallel as one sugar phosphate backbone runs $5' \rightarrow 3'$ direction while the other strand runs $3' \rightarrow 5'$ direction.
12. The hydrogen bonds holding the nitrogenous bases together on the rungs of the ladder break during DNA replication.
13. Each gene is a certain section of a chromosome which means it is a certain length of the DNA molecule. The coding of the DNA molecule passes hereditary information from one generation to the next.
14. The significance of DNA replication is that large amounts of coded information can be copied and passed onto the next generation, providing continuity of a species. The method also allows for some changes (mutations).
15. (a) Part X is phosphate, part Y is sugar.
    (b)



    (c) The segment of DNA has the base code GCATTC. The messenger RNA uses the DNA as a template, with uracil replacing thymine, forming the code CGUAAG. mRNA moves from the nucleus to the cytoplasm and attaches to a ribosome. The sequence of codons along mRNA is translated into amino acids by tRNA, e.g. CGU forms one amino acid and AAG forms the next amino acid.
16. B
17. A
18. B
19. B
20. D
21. C
22. A

3 RNA

1. RNA is a single stranded nucleic acid that functions in protein synthesis in a cell. It is a polymer made of ribonucleotide subunits linked together by 5′–3′ bonds similar to those found in DNA.
2. The genetic code in both DNA and RNA is universal as living organisms, with a few rare and minor exceptions use the same genetic code.
3. The genetic code is degenerate with only 20 amino acids forming 64 codons. This means that more than one codon may code for the same amino acid allowing for silent mutations where a change in the nucleotide sequence does not affect the amino acid sequence in the polypeptide.
4. The pentose sugar in RNA is ribose.
5. The nitrogenous bases found in RNA are adenine, uracil, cytosine and guanine.
6. The genetic code is a triplet code with every three nucleotides giving a specific instruction.

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11. Less than 10% of the human genome is involved in actual coding for protein synthesis even though it is a critical function of the coding.
12. B
13. B
14. D
15. A
16. D
17. B
18. C

6 Polypeptide Synthesis – Translation

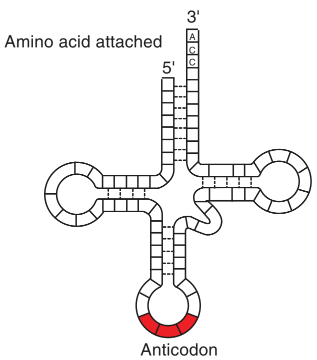
1. (a) Translation is a cellular process that uses the genetic code on mRNA to synthesise a polypeptide.
   (b) Translation occurs in the cytoplasm on ribosomes.
   (c) The translator is tRNA (transfer ribonucleic acid).
2. (a) The three main stages of translation are initiation, elongation and termination.
   (b)

Stage of translation	What happens
Initiation	In initiation the mRNA, tRNA with the first amino acid of the polypeptide that is to be formed and the two subunits of a ribosome are brought together to form the initiation complex.
Elongation	In elongation the amino acids are brought to the mRNA and added to the growing polypeptide chain.
Termination	In termination a stop codon (e.g. UAG, UAA, UGA) in the mRNA is recognised by a protein release factor causing the polypeptide to be completed and released and the translation assembly comes apart.

3.

DNA code	mRNA code	Amino acid
GAC	CUG	Leucine
TCT	AGA	Arginine
GTA	CAU	Histidine
CCA	GGU	Glycine
TTA	AAU	Asparagine
GTC	CAG	Glutamine

4. (a) tRNA has a distinctive shape which looks like a three-leaf clover leaf when flattened to draw in two dimensions. One end of the tRNA has a nucleotide triplet called the anticodon which is complementary to the mRNA code. The other end of the tRNA carries the amino acid and takes it to the ribosome for translation.
   (b)



5. In eukaryotes, tRNA is formed in the nucleus.
6. There are 20 different synthetase enzymes that relate to the 20 different amino acids. In translation the synthetase enzymes link the correct amino acid to the tRNA with the correct anticodon. Once a tRNA has delivered its amino acid at the ribosome, the synthetase enzyme can link another amino acid to the t RNA thus allowing a tRNA to be used many times.
7.

(a) mRNA	(b) tRNA	(c) Ribosomes
mRNA carries the code from the DNA that will be translated into an amino acid sequence.	tRNA has an anticodon at one end to connect to the mRNA and an amino acid on the other end which will become part of the sequence in the protein.	Ribosomes have grooves where the mRNA strand can fit. They provide the environment for attachment. The ribosome moves along the mRNA strand, binding the correct tRNA to the mRNA to form the correct amino acid sequence for the protein.

8. Ribosomes are made up of two subunits which consist of proteins and ribosomal RNA (rRNA) with about two thirds of the mass of a ribosome consisting of rRNA.
9. Ribosomes consist of two subunits. The large subunit binds with tRNA and the smaller subunit binds with mRNA.
10. A ribosome has three binding sites for tRNA – 1. P site holds the tRNA with the growing chain. 2. A site holds the tRNA carrying the amino acid about to be added to the chain. 3. E site has the exiting tRNA that has delivered its amino acid and is about to leave the ribosome. There is also the binding site for mRNA.
11. Translation occurs in the $5' \rightarrow 3'$ direction.
12. Codes for stop codons include UAG, UAA and UGA.
13. (a) A polysome is a cluster of ribosomes bound to one mRNA.
    (b) The formation of a polysome means that multiple copies of a polypeptide can be quickly synthesised. Thus increasing the efficiency of polypeptide production.
14. DNA molecule unwinds → mRNA forms using DNA template → mRNA moves from nucleus to cytoplasm → mRNA binds to ribosome → tRNA with amino acid is drawn to ribosome → tRNA adds amino acid to chain, then leaves → line-up of amino acids leads to the synthesis of a polypeptide.
15. C
16. A
17. B

7 Activity – Making a Model Of Protein Synthesis

1. (a) Transcription is a process that copies the information from DNA onto mRNA.
   (b) During transcription the DNA unzips and the enzyme RNA polymerase binds to one of the DNA strands. The enzyme makes a long chain of RNA nucleotides that are complementary to the DNA nucleotides. This forms the messenger RNA (mRNA) which is released from the enzyme.
2. During translation the coding on the mRNA is used to make proteins. Translation occurs on ribosomes in the cytoplasm. The ribosome provides the structural site for the mRNA and a tRNA brings an amino acid to this site. The tRNA has a triplet code which is complementary to the code on the mRNA. The ribosome moves to the next triplet code and the amino acids are added to the growing peptide chain.
3. In eukaryotes transcription occurs in the nucleus while translation occurs in the cytoplasm on a ribosome.

4. Protein synthesis is a complex biological process in eukaryotes that involves transcribing the DNA code in the nucleus onto mRNA and the passage of the mRNA from the nucleus into the cytoplasm. The mRNA binds to a ribosome in the cytoplasm and tRNA delivers amino acids in an order that matches up the complementary base pairing between the mRNA and tRNA. A 3-D model of this complex sequence of events would be very hard to build, keep pieces together and show all details of base pairing. Other details, e.g. action of enzymes would be hard to attach which means some details would not be present. Thus all groups reached the same conclusion about not building a 3-D model.
5. Protein synthesis is a biological process that involves a complex sequence of steps that each need to be understood to comprehend how a DNA is taken from the nucleus of a eukaryote and used to produce a protein that will be used by the cell. The construction of a model means each step can be detailed and understood before moving to the next step. By working in a group there can be discussion about what is happening, why it is happening and how each step fits into the sequence. This aids understanding, learning and remembering. Thus group work to construct a group model will assist student understanding of this biological process.
6. An advantage of constructing a model as group work is that the model can be more efficiently constructed with each person in the group being given individual tasks. This can save time and effort with students pooling their resources to complete the project. A disadvantage that arises from each person carrying out only one section of the task and then everyone pooling resources is that some students may not take enough 'interest' in the work done by others in their group and thus may not understand and learn all the steps in protein synthesis. This will give these students a patchy and incomplete understanding of the biological process.
7. (a) The most favoured form of representing the process of protein synthesis was a PowerPoint slide show presentation.
   (b) PowerPoint slide show presentations allow each step in the process of protein synthesis to be on individual slides. Highly detailed and coloured diagrams can be inserted to show what is happening and animations can be used to label different features and indicate specific details. Thus PowerPoint slide show presentations were suitable for this task and were preferred by 2/5 groups.
8. Two types of RNA are mRNA and tRNA.
9. (a) Glycine, serine, valine.
   (b) Codons for isoleucine include AUC, AUU and AUA.
   (c) The new code on the mRNA would read GGUUCAAUG and this changes the code to read glycine, serine and methionine.
10. A codon is a triplet code of three bases that gives the genetic information in either a molecule of DNA or mRNA to specify a particular amino acid. An anticodon is a group of three bases on a tRNA molecule that pairs with the complementary codon on the mRNA.
11. In DNA there are four kinds of bases – adenine, thymine, guanine and cytosine. These bases form the 'rungs' of the 'ladder' of the double helix, always pairing adenine-thymine and cytosine-guanine. RNA is only a single strand of nucleic acid and has the bases adenine, cytosine and guanine, however, uracil replaces the thymine.
12. Both mRNA and tRNA are single strands of nucleic acid with the bases adenine, uracil, cytosine and guanine. They differ in that mRNA carries the codon sequence from the nucleus to the ribosomes in the cytoplasm, while tRNA gathers and assembles three amino acids in their correct order along the mRNA.
13.

Single strand DNA	Transcribed mRNA	Anticodon of tRNA	Amino acid
AAA	UUU	AAA	Phenylalanine
TAG	AUC	UAG	Isoleucine
TGG	ACC	UGG	Threonine
CCA	GGU	CCA	Glycine
AGC	UCG	AGC	Serine

14. Transcription begins when an enzyme, RNA polymerase binds to the DNA at the beginning of a gene and moves along to the end of the gene causing the formation of a RNA transcript which is released at the end of the gene.
15. There are several possible answers to this question. The following table shows two possibilities.

Amino acid	Arginine	Lysine	Glutamine	Cystine	Trypsin
DNA code 1	GCA	TTT	GTT	ACA	ACC
DNA code 2	GCT	TTC	GTC	ACG	ACC

16. To code 51 amino acids you would need 51 codons which is 153 bases, but you would also need a stop and start code, so the minimum number of bases is 159 bases. This number of bases relates to exons needed to code for the protein. Since genes have many areas of introns, the gene probably has a larger number of bases present.
17. The diagram shows translation. The ribosome is moving along the length of a mRNA strand 'reading' the codons. Two tRNAs are held at any one time on the ribosome and the anticodon matches up with the codon on the mRNA. The polypeptide chain is being assembled.
18. The students were required to make a model of protein synthesis. The group that added the additional information about free and bound ribosomes had researched further information about protein synthesis and found out that proteins synthesised on free ribosomes were mainly used within the cell while proteins synthesised on bound ribosomes were mainly secreted from the cell. This describes what happens at the end of protein synthesis and thus this group felt it was necessary to add the information to complete the story of protein synthesis.

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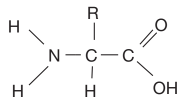
10. The bonds that stabilise the tertiary structure of a protein molecule are – 1. Hydrophobic interactions (between non-polar sections), 2. Hydrogen bonds between oxygen and hydrogen holding neighbouring strands together 3. Ionic attraction between the R groups with positive charges and the R groups with negative charges. 4. Disulfide bonds.
11. B
12. D

14 Amino Acids and Proteins

1. (a) Each amino acid has an amino group (NH_2), a carboxyl group (COOH) and a side chain (R).
   (b) 

2. The different chemical properties of different amino acids, e.g. polar (hydrophile) or non-polar (hyrodphobe) depend on the properties of R.
3. Glycine is the simplest amino acid with R = H.
4. A dipeptide is 2 amino acids joined together by a peptide bond. A tripeptide is 3 amino acids joined together by peptide bonds. A polypeptide is many amino acids joined together by peptide bonds.
5. (a) The distinguishing test for protein is the biuret test. Biuret solution (equal amounts of 1% copper sulfate solution and 5% potassium hydroxide solution) will turn from pale blue to purple in a positive test for protein.
   (b) The biuret test is actually detecting peptide linkage – which is the bond that holds amino acids together in a protein.
6. (a) The primary structure of a protein is the unique linear sequence of amino acids in its molecule and is determined by genetic information.
   (b) The secondary structure of a protein refers to the segments of the polypeptide chain that has coils or folds caused by hydrogen bonds between repeating CO and NH groups.
   (c) The tertiary structure of a protein is formed by the folding of the secondary structure into a complex and compacted shape.
   (d) The quaternary structure of a protein involves the interaction between several polypeptide chains that aggregate into one functional macromolecule.
7. The coils/folds of secondary structures of proteins are the helix and the beta pleated sheet.
8. (a) The diagram shows the primary structure of the protein as it shows the long chain of the polypeptide. However, it does not show the actual sequence of amino acids in the polypeptide which is what makes the precise primary structure of the protein. The diagram shows the secondary structure of the protein as it shows the segments of the polypeptide that are coiled or folded. The diagram shows the tertiary structure as it gives the overall globular shape of the polypeptide.
   (b) Structure X is a pleated sheet and structure Y is a helix coil.
9. D
10. A

15 Polar and Non-Polar Amino Acids

1. Amino acids consist of an amino group ($–NH_2$), a carboxyl group (–COOH) and a side chain (–R).
2. (a) The amino group is basic.
   (b) The carboxyl group is acidic.
3. An amphoteric substance is both acidic and basic.
4. The functional groups of amino acids are the amino group and the carboxyl group.
5. In an amino acid the alpha carbon atom is the carbon that has the two functional groups attached to it – the amino group and the carboxyl group are attached to this atom.
6. If the amino acid has one amino group and one carboxyl group it will be neutral. If the amino acid has additional amino groups it will be a basic amino acid while additional carboxyl groups will make it an acidic amino acid.
7. Buffers are substances that stabilise the pH of a solution. In an acid solution an amino acid will pick up H^+ ions and become positively charged. In an alkaline solution an amino acid donates H^+ ions to the surroundings and becomes negatively charged. Thus proteins which consist of many amino acids will act as buffers in cells and in body fluids.
8. Amino acids with polar side chains are likely to be hydrophilic while amino acids with non-polar side chains are likely to be hydrophobic.
9. A

16 Proteomics

1. Proteomics is the study of proteomes and their functions in large scale investigations of the biochemistry and genetics of gene products.
2. Functional proteomics looks at specific proteins to determine their significance and their DNA sequence providing information about how protein networks operate and how they produce particular cellular phenotypes.
3. The proteome is the entire complement of proteins that is or can be expressed by a genome, cell, tissue or organism.
4. Proteins are very important in living things. About two thirds of the total dry mass of many cells is protein and these proteins are vital for the structural components of cells, for growth and repair of cells, for regulating reactions in cells, for transport, for cellular communications and for defence against foreign substances.
5. Proteins consist of amino acid subunits joined to form polypeptide chains and the shape of the protein determines its function.
6. The sequence of nucleotides in DNA gives the order of amino acids found in a protein. This means that the coding in DNA is directly related to the proteome and the full range of proteins that can be expressed by a cell, tissue or organism.
7. An enzyme is an organic catalyst that controls the rate of metabolic reactions. They are involved in the breakdown of a substrate (catabolic enzyme) or the building of larger molecules from their substrate (anabolic enzyme).
8. (a) The enzyme is part A and its function is to speed up the reaction by aligning its active site with the substrate.
   (b) Part B is the reactant (substrate) and part C and part D are the products.
   (c) It is a catabolic reaction as it involves the breakdown of a large molecule.
9. Hormones are globular proteins that are secreted by endocrine cells directly into the interstitial fluid and act on specific target cells to change their functioning.
10. Insulin is a hormone that is produced in the pancreas in the beta cells of the islets of Langerhans. When blood sugar exceeds a certain level insulin is released and it causes the liver to take up glucose and store it as glycogen.
11. Structural proteins that are fibrous proteins form long fibres or sheets. They have a regular repeated sequence of amino acids and cross-links between the fibres produce properties to make the fibre tough, supple or elastic. Whereas structural proteins that are globular proteins are polypeptide chains tightly folded into a compact spherical shape.
12. Transport proteins are involved in transporting molecules across cell membranes and in the bloodstream, e.g. haemoglobin red blood cells transports oxygen in the bloodstream.
13. Cell membrane proteins detect chemical signals and recognise particular signal molecules, e.g. identifying hormones such as adrenaline. Adrenaline will cause a faster heart rate and increases blood flow to the muscles.
14. Gene regulatory proteins bind to specific regulatory sequences of DNA and act to switch a gene on and off and thus control the transcription of genes.
15. Defence proteins help organisms fight infection, heal damaged tissue and evade predators. Threonine deaminase (TD) is an enzyme made by plants, e.g. tomato plants to deter herbivores, e.g. leaf-eating caterpillars. TD disrupts the digestion of the caterpillar as it degrades the threonine before the herbivore can absorb it starving the herbivore of an essential amino acid.

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4. Chlorophyll is found on the thylakoid membranes.
5. The thylakoids form stacks which increases the surface area available for light absorption and the separation of the stacks means that each stack has an opportunity to absorb sunlight. Increased light absorption means increased photosynthesis can occur.
6. The lamellae in the chloroplast link one granum to another and help maintain the shape of the chloroplast keeping the grana apart with no overlapping grana so each can receive sunlight for photosynthesis. There is also a continuous lumen between the grana and lamellae.
7. The stroma is the dense fluid within the chloroplast surrounding the thylakoid membranes and contains the enzymes, ribosomes and DNA. The stroma has a suitable pH for the light independent reaction, e.g. for Calvin cycle.
8. The cross-section of the Australian eucalypt leaf shows many chloroplasts in the mesophyll cells in the middle of the leaf. The leaf hangs vertically and has stomates on both sides of the leaf with tightly packed mesophyll cells so that the mesophyll cells can capture sunlight in the morning and in the afternoon for photosynthesis. In the middle of the day when the Sun is directly overhead the stomates can close to reduce water loss and there is reduced photosynthesis occurring in the leaf. There are also chloroplasts in the guard cells of the stomates.
9. D

47 Play – Inside Photosynthesis

Scene 1 – The Root

1. Water enters the plant by osmosis through a root hair.
2. Salts enter the plant by active transport through a root hair.
3. Osmosis is the movement of water across a semipermeable membrane to an area of low water concentration.
4. Soil → root hair → root cortex → xylem.
5. Bacteria are primitive as it is a prokaryote with no membrane bound organelles such as a nucleus.

Scene 2 – The Leaf

1. A leaf is green due to the presence of chloroplasts which contain the green pigment chlorophyll.
2. Water evaporates out of stomates on the underside of leaves.
3. A stomate is an opening for gas exchange.
4. Photosynthesis occurs in chloroplasts in the palisade mesophyll cells of a leaf.
5. Raw materials of photosynthesis are water and carbon dioxide.
6. In photosynthesis water is split into hydrogen and oxygen.
7. The light reaction occurs in the grana of a chloroplast.

Scene 3 – Photosynthesis

1. In the light independent reaction hydrogen joins with carbon dioxide in a process called carbon fixation.
2. The light independent reaction occurs in the stroma.
3. A radioactive tracer is a radioactive element that is used to trace the pathway of a particular element in chemical reactions.
4. The oxygen gas comes from the water and not from the carbon dioxide.
5. The source of the oxygen was shown by the use of radioactive tracers such as oxygen-18.
6. Sugar travels in the phloem.
7. Part A is a granum (stack of thylakoids) and part B is the stroma.
8. (a) Carbon dioxide enters the leaf by diffusion.
   (b) Water leaves the leaf by transpiration which is diffusion of water vapour out of the leaf through the stomate.
   (c) In a leaf vein there are xylem vessels, phloem sieve tubes and companion cells.
   (d) In a leaf the sugars move from a photosynthetic cell, e.g. palisade mesophyll cell into the phloem sieve tubes for transportation to other parts of the plant.
   (e) Chloroplasts are found in palisade mesophyll cells, spongy mesophyll cells and guard cells of stomates.
   (f) Xylem vessels transport water from the roots to the leaf.

Scene 4 – The Root

1. In respiration, oxygen combines with glucose to produce carbon dioxide and water and release energy.
2. In photosynthesis, carbon dioxide is a reactant and joins with water, while in respiration carbon dioxide is a product and is formed along with water.
3. When comparing photosynthesis and respiration they involve the same chemicals although they are not the forward and reverse of the same reaction, as each involves different enzymes and energy transfers.
   Photosynthesis:
   Carbon dioxide + water → glucose + oxygen
   Respiration:
   Glucose + oxygen → carbon dioxide + water
4. Nitrates enter by active transport.
5. Carbon and oxygen cycle using the processes of photosynthesis and respiration to change from gases in the atmosphere to components of living things.
6. Part A is a root hair. Part B is the xylem.

48 Experiment – Chromatography

1. Chromatography is a laboratory technique used to separate parts of a mixture by selective adsorption.
2. A chromatogram is the visible record showing the result of chromatography with separated components of a mixture.
3. Adsorption involves the adhesion of molecules or particles from a gas, liquid or dissolved solid to a surface. In the process a film of the adsorbate forms on the surface of the adsorbent, whereas in absorption the pores of a solid are filled.
4. Chlorophyll is located within the thylakoid membrane.
5. (a) Mikhail Tswett invented adsorption chromatography.
   (b) Tswett isolated plant pigments using chalk (calcium carbonate) as the column of adsorbent and carbon disulfide (CS_2) as the solvent.
   (c) Tswett concluded that there two types of chlorophyll and four types of xanthophylls (carotenoids), proving that the green colour in plants is caused by a mixture of pigments.
6. (a) The mobile phase flows through the stationary phase and carries the components of the mixture with it.
   (b) In the student investigation the mobile phase is the ethanol.
7. (a) The stationary phase is a solid or a liquid supported on a solid that holds the mobile phase.
   (b) In the student investigation the stationary phase is the chromatography paper.
8. D

49 Endosymbiont Theory

1. Symbiosis is an ecological relationship between organisms of two different species that live together in direct contact.
2. Endosymbiosis is a type of symbiotic relationship where one organism lives inside the other organism.
3. In the endosymbiont theory it is believed that mitochondria and chloroplasts were once free-living prokaryote cells. The theory proposes that large prokaryotes engulfed other prokaryotes, e.g. a large prokaryote engulfed a smaller prokaryote that was capable of aerobic respiration. The host cell and the engulfed cell then evolved into a single organism, e.g. the engulfed aerobe became a mitochondrion and the ancestral eukaryotic cell evolved.

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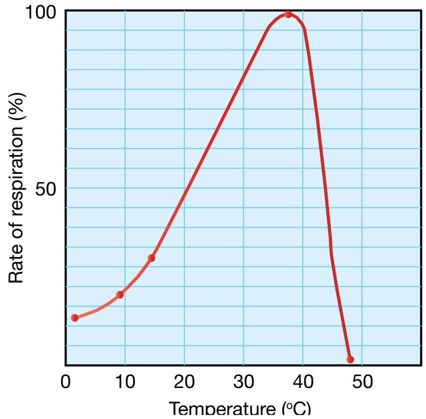
5. 

6. (a) In region Q oxygen is being consumed which means that the plant is respiring using an aerobic respiration pathway with more respiration occurring than photosynthesis.
   (b) In region R oxygen is being produced which means that the plant is photosythesising with the rate of oxygen production greater than the rate of oxygen being used in respiration.
   (c) Even though there is more light available after point S the rate of oxygen production (increased photosynthesis) cannot occur due to other limiting factors such as limited water availability or limited carbon dioxide availability.
7. A

65 Biotechnological Applications

1. There are many examples of industrial applications of genetic engineering – 1. Protein engineering production of vaccines for hepatitis B virus and supplies of insulin, growth factor, blood coagulating factor. 2. Metabolic engineering providing substances that change metabolic pathways' rate and distribution. 3. Biodegradable plastics industry using transgenes that code for particular enzymes which cause certain end products to form. 4. Cleaning up waste, e.g. bacteria that degrade crude oil, break down polluting wastes, convert biomass wastes such as sewage into useful products or transform toxic metals into a less toxic form. 5. Oil industry, e.g. to increase fatty acid quality and yield in certain plant seeds. 6. Biohydrometallurgy using bacteria, e.g. *Thiobacillus ferrooxidans* to extract metals from ores. 7. Biomineralisation using bacterial genes to aid metal deposition. 8. Fuel industry, e.g. to increase production of ethanol in alcohol fermentation.
2. (a) Biodegradable plastic means that living organisms can break down the plastic into small tiny pieces but still stay as very small pieces of plastic while compostable means the plastic will completely break down in soil and water and the resulting components are recycled in natural systems.
   (b) The plastics that break down into very tiny fragments (microplastics) and are biodegradable can be ingested or inhaled, e.g. by marine animals affecting the health of these animals and their ability to consume food. These microplastics are not compostable which means they stay in the ecosystem and studies suggest that non-compostable plastic bags should be banned from use and sale as a protective measure for conservation and preservation.
3. Polyhydroxybutyrate (PHB) is a polyester polymer produced by several different micro-organisms and is a compostable polymer that can be used to make biodegradable plastics. By genetic manipulation, e.g. altering a regulatory protein in cyanobacteria more PHB can be produced, harvested and used to make compostable plastics.
4. The development of 'suicidal genetically engineered micro-organisms' (SGEMs) is important as these organisms can carry out the bioremediation but will have a short survival time which will limit their dispersal ability and additional effects on the environment.
5. The oilseed industry is complex and diverse. The diagram shows the variety of plants that are used and have been developed for the oilseed industry, e.g. canola, cottonseed, soy, sunflower, peanut and linseed. Biotechnology has been very important in developing new strains, cultivars and varieties of these plants, e.g. to enable the plants to grow under specific environmental conditions, have higher yield, are disease resistant or produce particular nutritional components, e.g. Roundup Ready® is tolerant to the herbicide glyphosate. New genetic technologies give greater precision in altering genomes and can create new genetic combinations that are not possible using conventional breeding techniques. The oil products are used in cooking oil, spreads/shortening, prepared foods, cosmetics, lubricants, fuels and meal for livestock. These products are important economically, e.g. Australia is one of the world's largest exporters of canola seed. Thus the use of biotechnology has been important in the development and expansion of the oilseed industry.
6. The bacteria *Acidithiobacillus ferrooxidans* can oxidise metals and sulfur, e.g. iron in pyrite to produce ferric iron and sulfuric acid. Researchers are interested in the isolation and coding of sulfur-oxdising enzyme gene as this DNA section can be inserted into plants, e.g. *Arabidopsis thaliana* or tobacco plants so that these plants will accumulate toxic wastes, e.g. mercury accumulation.
7. Biofuels are derived immediately from living matter or organic material such as plant materials and animal waste. Industrialisation and the maintenance of modern technologies cause high energy demands which have mainly in the past been met by the combustion of fossil fuels which are non-renewable resources. Additionally the increasing amounts of carbon dioxide in the atmosphere means that alternative energy sources need to be developed. Thus biofuels, e.g. bioethanol produced by yeast in alcohol fermentation or microalgal biofuels need to be developed to help meet energy needs and to reduce carbon dioxide emissions.
8. C

Topic Test

Section A – Multiple Choice (40 marks)

1. D	2. C	3. C	4. D	5. B
6. B	7. B	8. A	9. C	10. D
11. B	12. B	13. D	14. C	15. D
16. C	17. D	18. A	19. A	20. B
21. C	22. D	23. A	24. D	25. B
26. C	27. D	28. C	29. A	30. B
31. D	32. C	33. A	34. B	35. A
36. B	37. C	38. A	39. B	40. D

Section B – Written Response (60 marks)

41. Marking Guidelines

Criteria	Marks
Correctly explains what is meant by the universality of the genetic code	1

Sample answer:
The genetic code in both DNA and RNA is universal as living organisms, with a few rare and minor exceptions use the same genetic code.

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. (b) Marking Guidelines

Criteria	Marks
Correctly relates expression of intact gene R/non-expression of split gene R AND visibility of recombinant plasmid	2
Correctly identifies one aspect	1

Sample answer:

If gene R is intact (non-recombinant) the bacteria will appear red. If gene H has been taken up and is in the middle of gene R (recombinant bacteria) then gene R will not be expressed and will not be red. This distinguishes between bacteria with/without gene H that are growing on the ampicillin plates.

52. (a) Marking Guidelines

Criteria	Marks
Correctly determines the sizes and number of the DNA fragments	2
Works out some correct elements	1

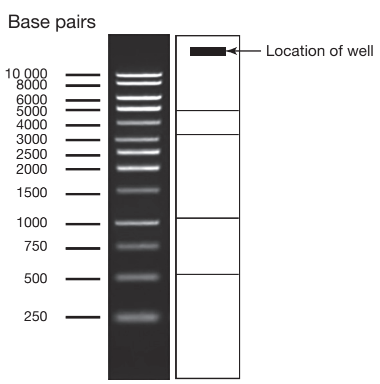
Sample answer:

The enzymes will cut the plasmid into 3 pieces, one fragment is 1050 bp, one is 550 bp and the remainder is 3400 bp.

(b) Marking Guidelines

Criteria	Marks
Correctly marks the location of the well AND draws the bands (given in part (a) – note systematic error) AND a band for an uncut plasmid	3
Correctly marks the location of the well AND/OR draws the bands (given in part (a) – note systematic error) AND/OR a band for the complete plasmid	1 to 2

Sample answer:



(c) Marking Guidelines

Criteria	Marks
Correctly explains the location of the well in gel electrophoresis	1

Sample answer:

The well is at the negatively charged end and the negatively charged DNA fragments move to the positive electrode. Smaller DNA fragments travel faster and further than larger DNA fragments.

53. Marking Guidelines

Criteria	Marks
Demonstrates a thorough knowledge and understanding of proteomics and the application of modern biotechnology in producing useful products for humans. Answer needs to demonstrate coherence and logical progression and includes correct use of scientific principles and ideas	8
Demonstrates some of the requirements in assessing the use of proteomics to produce proteins	1 to 7

Sample answer:

Proteomics is the study of the full sets of proteins encoded by genomes and knowledge of proteomics has many possible future benefits. Studies of human genomes have provided a large bank of information about the location and function of the gene(s) that produces particular proteins. Knowing the location means genetic engineering with gene splicing techniques can be used to extract the human gene(s) and insert it into a suitable new host, e.g. bacteria. Culturing these bacteria in fermenters means large quantities of these proteins can be produced for food, pharmaceutical use and other industries. Since it is likely that the number of proteins produced by humans is larger than the number of genes it is important to combine proteomics with genomics. Researchers in proteomics are making catalogues of the genes and proteins in humans and with the aid of computer science and mathematical analyses are determining the fine details of the structure and functions of each gene and protein and its relationship to other substances. Single nucleotide polymorphisms (SNPs) are single base pair variations in the genome and comparing SNPs of different humans will aid identifying disease genes. People with identified diseases may be able to begin treatment earlier with replacement proteins given before symptoms appear and cause disability. Thus proteomics and the production of proteins by cells cultured in fermenters has many possible future benefits.

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