Core topics

Essential idea: Metabolic reactions involve a complex interplay between many different components in highly controlled environments.

B.1 Introduction to biochemistry

Nature of science:

Use of data—biochemical systems have a large number of different reactions occurring in the same place at the same time. As technologies have developed, more data has been collected leading to the discovery of patterns of reactions in metabolism. (3.1)

Understandings:

- The diverse functions of biological molecules depend on their structures and shapes.
- Metabolic reactions take place in highly controlled aqueous environments.
- Reactions of breakdown are called catabolism and reactions of synthesis are called anabolism.
- Biopolymers form by condensation reactions and are broken down by hydrolysis reactions.
- Photosynthesis is the synthesis of energy-rich molecules from carbon dioxide and water using light energy.
- Respiration is a complex set of metabolic processes providing energy for cells.

Applications and skills :

- Explanation of the difference between condensation and hydrolysis reactions.
- The use of summary equations of photosynthesis and respiration to explain the potential balancing of oxygen and carbon dioxide in the atmosphere.

Guidance:

- Intermediates of aerobic respiration and photosynthesis are not required.

International-mindedness:

- Metabolic reactions in the human body are dependent on the supply of nutrients through a regular balanced diet. Globally there are significant differences in the availability of nutritious food, which have major and diverse impacts on human health.

Utilization:

- Biochemistry is fundamental to the study of many other subjects, including genetics, immunology, pharmacology, nutrition and agriculture.

Syllabus and cross-curricular links:
Topic 10.2—S_N reactions (condensation and hydrolysis)
Topic 13.2 and Option B.9—metal complexes and light absorption
Option C.8—electronic conjugation and light absorption

Essential idea: Proteins are the most diverse of the biopolymers responsible for metabolism and structural integrity of living organisms.

B.2 Proteins and enzymes

Nature of science:

Collaboration and peer review—several different experiments on several continents led to the conclusion that DNA, and not protein as originally thought, carried the information for inheritance. (4.4)

Understandings:

- Proteins are polymers of 2-amino acids, joined by amide links (also known as peptide bonds).
- Amino acids are amphoteric and can exist as zwitterions, cations and anions.
- Protein structures are diverse and are described at the primary, secondary, tertiary and quaternary levels.
- A protein's three-dimensional shape determines its role in structural components or in metabolic processes.
- Most enzymes are proteins that act as catalysts by binding specifically to a substrate at the active site.
- As enzyme activity depends on the conformation, it is sensitive to changes in temperature and pH and the presence of heavy metal ions.
- Chromatography separation is based on different physical and chemical principles.

Applications and skills:

- Deduction of the structural formulas of reactants and products in condensation reactions of amino acids, and hydrolysis reactions of peptides.
- Explanation of the solubilities and melting points of amino acids in terms of zwitterions.
- Application of the relationships between charge, pH and isoelectric point for amino acids and proteins.

International-mindedness:

- The Universal Protein Resource (UniProt) is a consortium of bioinformatics institutes. Its mission is to act as a resource for the scientific community by providing comprehensive, high-quality and freely accessible data on protein sequence and functional information.

Utilization:

- Many synthetic materials are polyamides. Examples include nylon and Kevlar®.
- Electrophoresis is used in some medical diagnostics to identify patterns of unusual protein content in blood serum or urine.
- The first protein to be sequenced was insulin by Frederick Sanger in 1951, in a process that took over ten years. Today, protein sequencing is a routine and very efficient process, and is a major part of the study known as proteomics.

Syllabus and cross-curricular links:
Topics 8.3 and 18.2—pH and pK_a and pK_b values
Topic 20.3—stereoisomerism
Option A.9—condensation polymers
Option B.9—chromatography
Biology topics 2.4, 2.5 and 8.1—proteins and enzymes

Aims:

- **Aim 6**: Experiments could involve hydrolysis of a protein, separation and identification of amino acid mixtures by paper chromatography, or gel electrophoresis of proteins and DNA.
- **Aim 7**: Data logging experiments involving absorption/concentration studies for protein content using the Biuret reagent.

B.2 Proteins and enzymes	
• Description of the four levels of protein structure, including the origin and types of bonds and interactions involved. • Deduction and interpretation of graphs of enzyme activity involving changes in substrate concentration, pH and temperature. • Explanation of the processes of paper chromatography and gel electrophoresis in amino acid and protein separation and identification. **Guidance:** • The names and structural formulas of the amino acids are given in the data booklet in section 33. • Reference should be made to alpha helix and beta pleated sheet, and to fibrous and globular proteins with examples of each. • In paper chromatography the use of R_f values and locating agents should be covered. • In enzyme kinetics K_m and V_{max} are not required.	• **Aim 7**: Simulations can be used for gel electrophoresis.

Essential idea: Lipids are a broad group of biomolecules that are largely non-polar and therefore insoluble in water.

B.3 Lipids

Nature of science:

Significance of science explanations to the public—long-term studies have led to knowledge of the negative effects of diets high in saturated fat, cholesterol, and *trans*-fat. This has led to new food products. (5.2)

Understandings:

- Fats are more reduced than carbohydrates and so yield more energy when oxidized.
- Triglycerides are produced by condensation of glycerol with three fatty acids and contain ester links. Fatty acids can be saturated, monounsaturated or polyunsaturated.
- Phospholipids are derivatives of triglycerides.
- Hydrolysis of triglycerides and phospholipids can occur using enzymes or in alkaline or acidic conditions.
- Steroids have a characteristic fused ring structure, known as a steroidal backbone.
- Lipids act as structural components of cell membranes, in energy storage, thermal and electrical insulation, as transporters of lipid soluble vitamins and as hormones.

Applications and skills:

- Deduction of the structural formulas of reactants and products in condensation and hydrolysis reactions between glycerol and fatty acids and/or phosphate.
- Prediction of the relative melting points of fats and oils from their structures.
- Comparison of the processes of hydrolytic and oxidative rancidity in fats with respect to the site of reactivity in the molecules and the conditions that favour the reaction.

International-mindedness:

- There are large global and cultural differences in the dietary sources of lipids and methods used to prevent rancidity.

Theory of knowledge:

- Different countries have very different standards towards food labelling. Is access to information a human right? What knowledge should be universally available?
- What are the different responsibilities of government, industry, the medical profession and the individual in making healthy choices about diet? Public bodies can protect the individual but also limit their freedom. How do we know what is best for society and the individual?

Utilization:

- Alkaline hydrolysis of fats is used in the process of soap-making, known as saponification.
- Steroid abuse, especially in sports, and methods for detection.

Syllabus and cross-curricular links:
Topics 10.1 and 10.2—functional groups, hydrogenation of alkenes
Topic 10.2—free radical mechanisms
Topic 20.3—configurational isomerism
Biology topic 2.3—lipids

B.3 Lipids	
• Application of the concept of iodine number to determine the unsaturation of a fat. • Comparison of carbohydrates and lipids as energy storage molecules with respect to their solubility and energy density. • Discussion of the impact of lipids on health, including the roles of dietary high-density lipoprotein (HDL) and low-density lipoprotein (LDL) cholesterol, saturated, unsaturated and *trans*-fat and the use and abuse of steroids. **Guidance:** • The structures of some fatty acids are given in the data booklet in section 34. • Specific named examples of fats and oils do not have to be learned. • The structural differences between *cis*- and *trans*-fats are not required.	**Aims:** • **Aim 6**: Experiments could include the calculation of the iodine number of fats to measure degree of unsaturation, calorimetric experiments on different fats and oils, or the separation of lipids from common food sources using different solvents and a separating funnel.

Essential idea: Carbohydrates are oxygen-rich biomolecules, which play a central role in metabolic reactions of energy transfer.

B.4 Carbohydrates

Nature of science:

Construct models/visualizations—understanding the stereochemistry of carbohydrates is essential to understanding their structural roles in cells. Haworth projections help focus on the nature and position of attached groups by making carbon and hydrogen implicit. (1.10)

Obtaining evidence for scientific theories—consider the structural role of carbohydrates. (1.8)

Understandings:

- Carbohydrates have the general formula $C_x(H_2O)_y$.
- Haworth projections represent the cyclic structures of monosaccharides.
- Monosaccharides contain either an aldehyde group (aldose) or a ketone group (ketose) and several –OH groups.
- Straight chain forms of sugars cyclize in solution to form ring structures containing an ether linkage.
- Glycosidic bonds form between monosaccharides forming disaccharides and polysaccharides.
- Carbohydrates are used as energy sources and energy reserves.

Applications and skills:

- Deduction of the structural formulas of disaccharides and polysaccharides from given monosaccharides.
- Relationship of the properties and functions of monosaccharides and polysaccharides to their chemical structures.

International-mindedness:

- Sugar is a major international commodity and is produced in about 130 different countries. Approximately three-quarters of production comes from sugar cane in tropical and subtropical regions and the remainder comes from sugar beet which is cultivated in temperate climates.
- Diabetes is a chronic disease that occurs when the body cannot effectively regulate blood sugar, due to a failure in the production or functioning of insulin. The World Health Organization projects that deaths from diabetes will double between 2005 and 2030.
- Lactose intolerance is a condition in which the individual is not able to digest lactose, the sugar found in milk and dairy products. It is due to a failure to produce sufficient levels of lactase, the enzyme that hydrolyses lactose into glucose and galactose. Globally lactose intolerance is the norm. It is an example of a Western perspective invading science.

Theory of knowledge:

- The use of aspartame as an artificial sweetener has been controversial for many years as the side effects are not fully investigated. Should scientists be held morally responsible for the adverse consequences of their work?

B.4 Carbohydrates	
Guidance: • The straight chain and α-ring forms of glucose and fructose are given in the data booklet in section 34. • The component monosaccharides of specific disaccharides and the linkage details of polysaccharides are not required. • The distinction between α- and β- forms and the structure of cellulose are not required.	**Utilization:** • Carbohydrates are used in the pharmaceutical industry to bind preparations into tablets. • Ethanol is produced as a biofuel from the fermentation of carbohydrates in crops such as corn or sugar cane. Syllabus and cross-curricular links: Topics 10.1 and 10.2—organic functional groups Topic 20.1—organic reactions Topic 20.3—stereoisomerism Option C.4—biofuels Biology topic 2.3—carbohydrates **Aims:** • **Aim 6**: Experiments could include using Benedict's or Fehling's solution tests to distinguish between reducing sugars and non-reducing sugars or using iodine solution to test for the presence of starch. • **Aim 8**: The production of biofuels from crops raises many questions about related issues such as deforestation, soil erosion and sustainability. The "food vs fuel" debate refers to the controversies arising from developments that divert agricultural crops into biofuel production.

Essential idea: Vitamins are organic micronutrients with diverse functions that must be obtained from the diet.

B.5 Vitamins

Nature of science:

Making observations and evaluating claims—the discovery of vitamins (*vital amines*) is an example of scientists seeking a cause for specific observations. This resulted in the explanation of deficiency diseases (eg scurvy and beriberi). (1.8)

Understandings:

- Vitamins are organic micronutrients which (mostly) cannot be synthesized by the body but must be obtained from suitable food sources.
- The solubility (water or fat) of a vitamin can be predicted from its structure.
- Most vitamins are sensitive to heat.
- Vitamin deficiencies in the diet cause particular diseases and affect millions of people worldwide.

Applications and skills:

- Comparison of the structures of vitamins A, C and D.
- Discussion of the causes and effects of vitamin deficiencies in different countries and suggestion of solutions.

Guidance:

- The structures of vitamins A, C and D are provided in the data booklet section 35.
- Specific food sources of vitamins or names of deficiency diseases do not have to be learned.

International-mindedness:

- The food supplements industry, especially the sale of vitamin pills, has become very lucrative in many countries.
- Vitamin D deficiency is increasing, partly as a result of greater protection of the skin from sunlight.

Theory of knowledge:

- What are the ethical considerations in adding supplements to commonly consumed foods, such as fluoride to water or iodine to salt? Public bodies can protect the individual but also limit their freedom. How do we know what is best for society and the individual?
- Linus Pauling is the only man to win two individual Nobel Prizes. His claim that vitamin C supplements could prevent diseases such as the common cold led to their widespread use. What is the role of authority in communicating scientific knowledge to the public?

Utilization:

Syllabus and cross-curricular links:
Topics 4.1, 4.2 and 4.3—structure and physical properties
Topic 10.1—organic functional groups
Topic 20.3—configurational isomerism
Biology option D.2—human nutrition and health

Aims:

- **Aim 6**: Experiments could include the DCPIP determination of vitamin C levels in foods.

Essential idea: Our increasing knowledge of biochemistry has led to several environmental problems, while also helping to solve others.

B.6 Biochemistry and the environment

Nature of science:

Risk assessment, collaboration, ethical considerations—it is the responsibility of scientists to consider the ways in which products of their research and findings negatively impact the environment, and to find ways to counter this. For example, the use of enzymes in biological detergents and to break up oil spills, and green chemistry in general. (4.8)

Understandings:

- Xenobiotics refer to chemicals that are found in an organism that are not normally present there.
- Biodegradable/compostable plastics can be consumed or broken down by bacteria or other living organisms.
- Host–guest chemistry involves the creation of synthetic host molecules that mimic some of the actions performed by enzymes in cells, by selectively binding to specific guest species, such as toxic materials in the environment.
- Enzymes have been developed to help in the breakdown of oil spills and other industrial wastes.
- Enzymes in biological detergents can improve energy efficiency by enabling effective cleaning at lower temperatures.
- Biomagnification is the increase in concentration of a substance in a food chain.
- Green chemistry, also called sustainable chemistry, is an approach to chemical research and engineering that seeks to minimize the production and release to the environment of hazardous substances.

Applications and skills:

- Discussion of the increasing problem of xenobiotics such as antibiotics in sewage treatment plants.
- Description of the role of starch in biodegradable plastics.

International-mindedness:

- The term green chemistry was first coined in 1991, and acceptance of its philosophy has led to developments in education and legislation in many countries.
- Use of the pesticide DDT is banned in most countries due to its toxic effects and biomagnification. Its use continues, however, in countries where malaria remains a major public health challenge.

Utilization:

Syllabus and cross-curricular links:
Topic 4.4—intermolecular forces
Topic 10.1—natural and synthetic organic compounds
Options A.5 and A.7—environmental impact of plastics
Option D.2—antibiotics

Aims:

- **Aim 6**: Experiments could include the comparison of the breakdown of biodegradable and non-biodegradable plastics in the environment.
- **Aim 6**: Risk assessment, including the risks to the environment, is an essential part of all experimental work.
- **Aim 8**: The development of the science of green chemistry has raised awareness of the environmental and ethical implications of using science and technology.

B.6 Biochemistry and the environment	
• Application of host–guest chemistry to the removal of a specific pollutant in the environment. • Description of an example of biomagnification, including the chemical source of the substance. Examples could include heavy metals or pesticides. • Discussion of the challenges and criteria in assessing the "greenness" of a substance used in biochemical research, including the atom economy. **Guidance:** • Specific names of "green chemicals" such as solvents are not expected. • The emphasis in explanations of host–guest chemistry should be on non-covalent bonding within the supramolecule.	