Additional higher level topics

Essential idea: Analyses of protein activity and concentration are key areas of biochemical research.

B.7 Proteins and enzymes

Nature of science:

Theories can be superseded—"lock and key" hypothesis to "induced fit" model for enzymes. (1.9)

Collaboration and ethical considerations—scientists collaborate to synthesize new enzymes and to control desired reactions (ie waste control). (4.5)

Understandings:

- Inhibitors play an important role in regulating the activities of enzymes.
- Amino acids and proteins can act as buffers in solution.
- Protein assays commonly use UV-vis spectroscopy and a calibration curve based on known standards.

Applications and skills:

- Determination of the maximum rate of reaction ($V_{max)}$ and the value of the Michaelis constant ($K_{m)}$ for an enzyme by graphical means, and explanation of its significance.
- Comparison of competitive and non-competitive inhibition of enzymes with reference to protein structure, the active site and allosteric site.
- Explanation of the concept of product inhibition in metabolic pathways.
- Calculation of the pH of buffer solutions, such as those used in protein analysis and in reactions involving amino acids in solution.
- Determination of the concentration of a protein in solution from a calibration curve using the Beer–Lambert law.

International-mindedness:

- Technologies based on enzyme activity go back to ancient times in many parts of the world. Brewing and cheese-making are often associated with particular place names.

Theory of knowledge:

- The term "lock-and-key" is an effective metaphor but the "induced fit" model is a better model. How are metaphors and models used in the construction of knowledge?

Utilization:

- Enzymes are widely used in industrial and domestic applications. Examples include biological detergents, textiles, foods and beverages, and biodegradable plastics. Advances in protein engineering have led to the synthesis of enzymes that are effective in a wide range of conditions.

Syllabus and cross-curricular links:
Topic 6.1—chemical kinetics
Topics 8.1, 8.3 and 8.4—the pH scale and conjugate acids and bases
Topics 18.2 and 18.3—acid–base calculations and pH curves

B.7 Proteins and enzymes	
Guidance: • The effects of competitive and non-competitive inhibitors on K_m and V_{max} values should be covered. • The Henderson–Hasselbalch equation is given in the data booklet in section 1. • For UV-vis spectroscopy, knowledge of particular reagents and wavelengths is not required.	**Aims:** • **Aim 6**: Experiments could include measuring enzyme activity with changing conditions of temperature, pH and heavy metal ion concentration. • **Aim 7**: Data-logging experiments with temperature or pH probes to investigate enzyme activity under different conditions; or computer modelling of enzyme–substrate interactions. • **Aim 8**: Many enzyme technologies help mitigate damaging environmental effects of chemicals, such as from leather, paper and oil industries.

Essential idea: DNA is the genetic material that expresses itself by controlling the synthesis of proteins by the cell.

B.8 Nucleic acids

Nature of science:

Scientific method—the discovery of the structure of DNA is a good example of different approaches to solving the same problem. Scientists used models and diffraction experiments to develop the structure of DNA. (1.3)

Developments in scientific research follow improvements in apparatus—double helix from X-ray diffraction provides explanation for known functions of DNA. (3.7)

Understandings:

- Nucleotides are the condensation products of a pentose sugar, phosphoric acid and a nitrogenous base—adenine (A), guanine (G), cytosine (C), thymine (T) or uracil (U).
- Polynucleotides form by condensation reactions.
- DNA is a double helix of two polynucleotide strands held together by hydrogen bonds.
- RNA is usually a single polynucleotide chain that contains uracil in place of thymine, and a sugar ribose in place of deoxyribose.
- The sequence of bases in DNA determines the primary structure of proteins synthesized by the cell using a triplet code, known as the genetic code, which is universal.
- Genetically modified organisms have genetic material that has been altered by genetic engineering techniques, involving transferring DNA between species.

Applications and skills:

- Explanation of the stability of DNA in terms of the interactions between its hydrophilic and hydrophobic components.
- Explanation of the origin of the negative charge on DNA and its association with basic proteins (histones) in chromosomes.
- Deduction of the nucleotide sequence in a complementary strand of DNA or a molecule of RNA from a given polynucleotide sequence.

International-mindedness:

- The Human Genome Project was an international research programme whose goal was to complete the mapping and sequencing of all the genes in the human genome.
- The policies on the labelling of genetically modified (GM) foods vary greatly in different countries.
- Most of the genetically modified organisms are protected by international patents. What effect does this have on the global economy and scientific community?

Theory of knowledge:

- DNA stores information but not knowledge.
- What are the differences between information and knowledge?
- The Nobel Prize in Physiology or Medicine 1962 was awarded jointly to Crick, Watson and Wilkins "for their discoveries concerning the molecular structure of nucleic acids and its significance for information transfer in living material". What is the role of collaboration in advancing knowledge?
- The existence of DNA databases opens up questions of individual privacy and the extent to which government has the right of access to personal information. Who has the right to access knowledge of an individual's DNA?

B.8 Nucleic acids	
• Explanation of how the complementary pairing between bases enables DNA to replicate itself exactly. • Discussion of the benefits and concerns of using genetically modified foods. **Guidance:** • Structures of the nitrogenous bases and ribose and deoxyribose sugars are given in the data booklet in section 34. • Knowledge of the different forms of RNA is not required. • Details of the process of DNA replication are not required. • Limit expression of DNA to the concept of a four-unit base code determining a twenty-unit amino acid sequence. Details of transcription and translation are not required.	**Utilization:** • Knowledge of DNA sequencing has transformed several aspects of legal enquiry, including forensics and paternity cases. It is also widely used in studies of ancestry and human migration. • DNA sequencing is an important aspect of the study of biochemical evolution. Syllabus and cross-curricular links: Topic 4.4—hydrogen bonding, intermolecular interactions Topic 8.1—acid–base interactions Biology topics 2.6 and 7.1—DNA and RNA structure **Aims:** • **Aim 5**: The story of the rivalry between the different teams involved in the elucidation of DNA structure in the 1950s is an example of a failure of effective collaboration and communication during scientific activities. • **Aim 6**: Experiments could include DNA extraction from cells and investigation of its physical properties, and model building exercises of DNA structure, including the specific base pairings between a purine and a pyrimidine. • **Aim 7**: Databases exist of genetic sequences from different organisms. • **Aim 8**: Many ethical questions are raised by our knowledge of the human genome, including cloning, genetic engineering, gene therapy, and so on.

Essential idea: Biological pigments include a variety of chemical structures with diverse functions which absorb specific wavelengths of light.

B.9 Biological pigments

Nature of science:

Use of data—quantitative measurements of absorbance are a reliable means of communicating data based on colour, which was previously subjective and difficult to replicate. (3.1)

Understandings:

- Biological pigments are coloured compounds produced by metabolism.
- The colour of pigments is due to highly conjugated systems with delocalized electrons, which have intense absorption bands in the visible region.
- Porphyrin compounds, such as hemoglobin, myoglobin, chlorophyll and many cytochromes are chelates of metals with large nitrogen-containing macrocyclic ligands.
- Hemoglobin and myoglobin contain heme groups with the porphyrin group bound to an iron(II) ion.
- Cytochromes contain heme groups in which the iron ion interconverts between iron(II) and iron(III) during redox reactions.
- Anthocyanins are aromatic, water-soluble pigments widely distributed in plants. Their specific colour depends on metal ions and pH.
- Carotenoids are lipid-soluble pigments, and are involved in harvesting light in photosynthesis. They are susceptible to oxidation, catalysed by light.

Applications and skills:

- Explanation of the sigmoidal shape of hemoglobin's oxygen dissociation curve in terms of the cooperative binding of hemoglobin to oxygen.
- Discussion of the factors that influence oxygen saturation of hemoglobin, including temperature, pH and carbon dioxide.
- Description of the greater affinity of oxygen for foetal hemoglobin.

International-mindedness:

- Artificial colours are commonly added during the commercial preparation and processing of food. The list of approved food colours varies greatly by country, which raises questions for international trade.

Theory of knowledge:

- Experiments show that our appreciation of food is based on an interaction between our senses. How do the different senses interact in giving us empirical knowledge about the world?

Utilization:

- Different tones of skin, eye and hair colour are the result of differences in the concentration of the pigment melanin.
- People whose ancestors have lived at high altitude for many generations have developed hemoglobin with a higher affinity for oxygen.
- The purplish-red colour of meat is largely due to the presence of myoglobin. The change in colour to brown on cooking occurs as the iron ion becomes oxidized to Fe^{3+}.
- Anthocyanins and carotenoids provide visible signals for plants to attract insects and birds for pollination and seed dispersal. They also protect plants from damage caused by UV light.

Syllabus and cross-curricular links:
Topic 8.2—indicators
Topic 13.2—complex ions
Option C.8—electronic conjugation and dye-sensitized solar cells

B.9 Biological pigments	
• Explanation of the action of carbon monoxide as a competitive inhibitor of oxygen binding. • Outline of the factors that affect the stabilities of anthocyanins, carotenoids and chlorophyll in relation to their structures. • Explanation of the ability of anthocyanins to act as indicators based on their sensitivity to pH. • Description of the function of photosynthetic pigments in trapping light energy during photosynthesis. • Investigation of pigments through paper and thin layer chromatography. **Guidance:** • The structures of chlorophyll, heme B and specific examples of anthocyanins and carotenoids are given in the data booklet in section 35; details of other pigment names and structures are not required. • Explanation of cooperative binding in hemoglobin should be limited to conformational changes occurring in one polypeptide when it becomes oxygenated. • Knowledge of specific colour changes with changing conditions is not required.	**Aims:** • **Aim 6**: Experiments could include the extraction and isolation of pigments from plant sources using solvents and separating funnel or the use of anthocyanins as pH indicators. • **Aim 7**: Use of data loggers for collecting absorption data.

Essential idea: Most biochemical processes are stereospecific and involve only molecules with certain configuration of chiral carbon atoms.

B.10 Stereochemistry in biomolecules

Nature of science:

Theories used to explain natural phenomena/evaluate claims—biochemistry involves many chiral molecules with biological activity specific to one enantiomer. Chemical reactions in a chiral environment act as a guiding distinction between living and non-living matter. (2.2)

Understandings:

- With one exception, amino acids are chiral, and only the L-configuration is found in proteins.
- Naturally occurring unsaturated fat is mostly in the *cis* form, but food processing can convert it into the *trans* form.
- D and L stereoisomers of sugars refer to the configuration of the chiral carbon atom furthest from the aldehyde or ketone group, and D forms occur most frequently in nature.
- Ring forms of sugars have isomers, known as α and β, depending on whether the position of the hydroxyl group at carbon 1 (glucose) or carbon 2 (fructose) lies below the plane of the ring (α) or above the plane of the ring (β).
- Vision chemistry involves the light activated interconversion of *cis*- and *trans*-isomers of retinal.

Applications and skills:

- Description of the hydrogenation and partial hydrogenation of unsaturated fats, including the production of *trans*-fats, and a discussion of the advantages and disadvantages of these processes.
- Explanation of the structure and properties of cellulose, and comparison with starch.
- Discussion of the importance of cellulose as a structural material and in the diet.
- Outline of the role of vitamin A in vision, including the roles of opsin, rhodopsin

International-mindedness:

- Different countries have very different standards of food labelling with respect to its chemical content, including the type of fats present.

Utilization:

Syllabus and cross-curricular links:
Topic 10.1—organic functional groups
Topic 20.1—organic reactions
Topic 20.3—stereoisomerism
Option A.4—intermolecular/London forces

Aims:

- **Aim 8**: Ethical questions arise through the use of saturated and *trans*-fats, particularly in the fast-food industry.

B.10 Stereochemistry in biomolecules	
and *cis*- and *trans*-retinal. **Guidance:** • Names of the enzymes involved in the visual cycle are not required. • Relative melting points of saturated and *cis*-/*trans*-unsaturated fats should be covered.	