Topic 2. Biological Molecules and Processes

SL: 14 hours
HL: 24 hours

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Objectives from the Biology Guide 2025, published by the IB

1.1 Carbohydrates and Lipids

Standard level and higher level: 4 hours

B1.1.1—Chemical properties of a carbon atom allowing for the formation of diverse compounds upon which life is based
Students should understand the nature of a covalent bond. Students should also understand that a carbon atom can form up to four single bonds or a combination of single and double bonds with other carbon atoms or atoms of other non-metallic elements. Include among the diversity of carbon compounds examples of molecules with branched or unbranched chains and single or multiple rings. **NOS:** Students should understand that scientific conventions are based on international agreement (SI metric unit prefixes “kilo”, “centi”, “milli”, “micro” and “nano”).

B1.1.2—Production of macromolecules by condensation reactions that link monomers to form a polymer
Students should be familiar with examples of polysaccharides, polypeptides and nucleic acids.

B1.1.3—Digestion of polymers into monomers by hydrolysis reactions
Water molecules are split to provide the -H and -OH groups that are incorporated to produce monomers, hence the name of this type of reaction.

B1.1.4—Form and function of monosaccharides
Students should be able to recognize pentoses and hexoses as monosaccharides from molecular diagrams showing them in the ring forms. Use glucose as an example of the link between the properties of a monosaccharide and how it is used, emphasizing solubility, transportability, chemical stability and the yield of energy from oxidation as properties.

B1.1.5—Polysaccharides as energy storage compounds
Include the compact nature of starch in plants and glycogen in animals due to coiling and branching during polymerization, the relative insolubility of these compounds due to large molecular size and the relative ease of adding or removing alpha-glucose monomers by condensation and hydrolysis to build or mobilize energy stores.

B1.1.6—Structure of cellulose related to its function as a structural polysaccharide in plants
Include the alternating orientation of beta-glucose monomers, giving straight chains that can be grouped in bundles and cross-linked with hydrogen bonds.

B1.1.7—Role of glycoproteins in cell–cell recognition
Include ABO antigens as an example.

B1.1.8—Hydrophobic properties of lipids

Lipids are substances in living organisms that dissolve in non-polar solvents but are only sparingly soluble in aqueous solvents. Lipids include fats, oils, waxes and steroids.

B1.1.9—Formation of triglycerides and phospholipids by condensation reactions
One glycerol molecule can link three fatty acid molecules or two fatty acid molecules and one phosphate group.

B1.1.10—Difference between saturated, monounsaturated and polyunsaturated fatty acids
Include the number of double carbon (C=C) bonds and how this affects melting point. Relate this to the prevalence of different types of fatty acids in oils and fats used for energy storage in plants and endotherms respectively.

B1.1.11—Triglycerides in adipose tissues for energy storage and thermal insulation
Students should understand that the properties of triglycerides make them suited to long-term energy storage functions. Students should be able to relate the use of triglycerides as thermal insulators to body temperature and habitat.

B1.1.12—Formation of phospholipid bilayers as a consequence of the hydrophobic and hydrophilic regions
Students should use and understand the term “amphipathic”.

B1.1.13—Ability of non-polar steroids to pass through the phospholipid bilayer
Include oestradiol and testosterone as examples. Students should be able to identify compounds as steroids from molecular diagrams.

B 1.2 Proteins

Standard level and higher level: 2 hours

Additional higher level: 2 hours

B1.2.1—Generalized structure of an amino acid
Students should be able to draw a diagram of a generalized amino acid showing the alpha carbon atom with amine group, carboxyl group, R-group and hydrogen attached.

B1.2.2—Condensation reactions forming dipeptides and longer chains of amino acids
Students should be able to write the word equation for this reaction and draw a generalized dipeptide after modelling the reaction with molecular models.

B1.2.3—Dietary requirements for amino acids
Essential amino acids cannot be synthesized and must be obtained from food. Non-essential amino acids can be made from other amino acids. Students are not required to give examples of essential and non-essential amino acids. Vegan diets require attention to ensure essential amino acids are consumed.

B1.2.4—Infinite variety of possible peptide chains
Include the ideas that 20 amino acids are coded for in the genetic code, that peptide chains can have any number of amino acids, from a few to thousands, and that amino acids can be in any order. Students should be familiar with examples of polypeptides.

B1.2.5—Effect of pH and temperature on protein structure
Include the term “denaturation”.

Additional higher level

B1.2.6—Chemical diversity in the R-groups of amino acids as a basis for the immense diversity in protein form and function
Students are not required to give specific examples of R-groups. However, students should understand that R-groups determine the properties of assembled polypeptides. Students should appreciate that R-groups are hydrophobic or hydrophilic and that hydrophilic R-groups are polar or charged, acidic or basic.

B1.2.7—Impact of primary structure on the conformation of proteins
Students should understand that the sequence of amino acids and the precise position of each amino acid within a structure determines the three-dimensional shape of proteins. Proteins therefore have precise, predictable and repeatable structures, despite their complexity.

B1.2.8—Pleating and coiling of secondary structure of proteins
Include hydrogen bonding in regular positions to stabilize alpha helices and beta-pleated sheets.

B1.2.9—Dependence of tertiary structure on hydrogen bonds, ionic bonds, disulfide covalent bonds and hydrophobic interactions
Students are not required to name examples of amino acids that participate in these types of bonding, apart from pairs of cysteines forming disulfide bonds. Students should understand that amine and carboxyl groups in R-groups can become positively or negatively charged by binding or dissociation of hydrogen ions and that they can then participate in ionic bonding.

B1.2.10—Effect of polar and non-polar amino acids on tertiary structure of proteins
In proteins that are soluble in water, hydrophobic amino acids are clustered in the core of globular proteins. Integral proteins have regions with hydrophobic amino acids, helping them to embed in membranes.

B1.2.11—Quaternary structure of non-conjugated and conjugated proteins

Include insulin and collagen as examples of non-conjugated proteins and haemoglobin as an example of a conjugated protein. **NOS:** Technology allows imaging of structures that would be impossible to observe with the unaided senses. For example, cryogenic electron microscopy has allowed imaging of single-protein molecules and their interactions with other molecules.

B1.2.12—Relationship of form and function in globular and fibrous proteins
Students should know the difference in shape between globular and fibrous proteins and understand that their shapes make them suitable for specific functions. Use insulin and collagen to exemplify how form and function are related.

C 1.1 Enzymes and Metabolism

Standard level and higher level: 3 hours

Additional higher level: 2 hours

C1.1.1—Enzymes as catalysts
Students should understand the benefit of increasing rates of reaction in cells.

C1.1.2—Role of enzymes in metabolism
Students should understand that metabolism is the complex network of interdependent and interacting chemical reactions occurring in living organisms. Because of enzyme specificity, many different enzymes are required by living organisms, and control over metabolism can be exerted through these enzymes.

C1.1.3—Anabolic and catabolic reactions
Examples of anabolism should include the formation of macromolecules from monomers by condensation reactions including protein synthesis, glycogen formation and photosynthesis. Examples of catabolism should include hydrolysis of macromolecules into monomers in digestion and oxidation of substrates in respiration.

C1.1.4—Enzymes as globular proteins with an active site for catalysis
Include that the active site is composed of a few amino acids only, but interactions between amino acids within the overall three-dimensional structure of the enzyme ensure that the active site has the necessary properties for catalysis.

C1.1.5—Interactions between substrate and active site to allow induced-fit binding
Students should recognize that both substrate and enzymes change shape when binding occurs.

C1.1.6—Role of molecular motion and substrate-active site collisions in enzyme catalysis
Movement is needed for a substrate molecule and an active site to come together. Sometimes large substrate molecules are immobilized while sometimes enzymes can be immobilized by being embedded in membranes.

C1.1.7—Relationships between the structure of the active site, enzyme–substrate specificity and denaturation
Students should be able to explain these relationships.

C1.1.8—Effects of temperature, pH and substrate concentration on the rate of enzyme activity
The effects should be explained with reference to collision theory and denaturation. **Application of skills:** Students should be able to interpret graphs showing the effects. **NOS:** Students should be able to describe the relationship between variables as shown in graphs. They should recognize that generalized sketches of relationships are examples of models in biology. Models in the form of sketch graphs can be evaluated using results from enzyme experiments.

C1.1.9—Measurements in enzyme-catalysed reactions
Application of skills: Students should determine reaction rates through experimentation and using secondary data.

C1.1.10—Effect of enzymes on activation energy

Application of skills: Students should appreciate that energy is required to break bonds within the substrate and that there is an energy yield when bonds are made to form the products of an enzyme-catalysed reaction. Students should be able to interpret graphs showing this effect.

Additional higher level

C1.1.11—Intracellular and extracellular enzyme-catalysed reactions
Include glycolysis and the Krebs cycle as intracellular examples and chemical digestion in the gut as an extracellular example.

C1.1.12—Generation of heat energy by the reactions of metabolism
Include the idea that heat generation is inevitable because metabolic reactions are not 100% efficient in energy transfer. Mammals, birds and some other animals depend on this heat production for maintenance of constant body temperature.

C1.1.13—Cyclical and linear pathways in metabolism
Use glycolysis, the Krebs cycle and the Calvin cycle as examples.

C1.1.14—Allosteric sites and non-competitive inhibition
Students should appreciate that only specific substances can bind to an allosteric site. Binding causes interactions within an enzyme that lead to conformational changes, which alter the active site enough to prevent catalysis. Binding is reversible.

C1.1.15—Competitive inhibition as a consequence of an inhibitor binding reversibly to an active site
Use statins as an example of competitive inhibitors. Include the difference between competitive and non-competitive inhibition in the interactions between substrate and inhibitor and therefore in the effect of substrate concentration.

C1.1.16—Regulation of metabolic pathways by feedback inhibition
Use the pathway that produces isoleucine as an example of an end product acting as an inhibitor.

C1.1.17—Mechanism-based inhibition as a consequence of chemical changes to the active site caused by the irreversible binding of an inhibitor
Use penicillin as an example. Include the change to transpeptidases that confers resistance to penicillin.

C 1.2 Cell Respiration

Standard level and higher level: 2 hours

Additional higher level: 3 hours

C1.2.1—ATP as the molecule that distributes energy within cells
Include the full name of ATP (adenosine triphosphate) and that it is a nucleotide. Students should appreciate the properties of ATP that make it suitable for use as the energy currency within cells.

C1.2.2—Life processes within cells that ATP supplies with energy
Include active transport across membranes, synthesis of macromolecules (anabolism), movement of the whole cell or cell components such as chromosomes.

C1.2.3—Energy transfers during interconversions between ATP and ADP
Students should know that energy is released by hydrolysis of ATP (adenosine triphosphate) to ADP (adenosine diphosphate) and phosphate, but energy is required to synthesize ATP from ADP and phosphate. Students are not required to know the quantity of energy in kilojoules, but students should appreciate that it is sufficient for many tasks in the cell.

C1.2.4—Cell respiration as a system for producing ATP within the cell using energy released from carbon compounds
Students should appreciate that glucose and fatty acids are the principal substrates for cell respiration but that a wide range of carbon/organic compounds can be used. Students should be able to distinguish between the processes of cell respiration and gas exchange.

C1.2.5—Differences between anaerobic and aerobic cell respiration in humans
Include which respiratory substrates can be used, whether oxygen is required, relative yields of ATP, types of waste product and where the reactions occur in a cell. Students should be able to write simple word equations for both types of respiration, with glucose as the substrate. Students should appreciate that mitochondria are required for aerobic, but not anaerobic, respiration.

C1.2.6—Variables affecting the rate of cell respiration
Application of skills: Students should make measurements allowing for the determination of the rate of cell respiration. Students should also be able to calculate the rate of cellular respiration from raw data that they have generated experimentally or from secondary data.

Additional higher level

C1.2.7—Role of NAD as a carrier of hydrogen and oxidation by removal of hydrogen during cell respiration
Students should understand that oxidation is a process of electron loss, so when hydrogen with an electron is removed from a substrate (dehydrogenation) the substrate has been oxidized. They should appreciate that redox reactions involve both oxidation and reduction, and that NAD is reduced when it accepts hydrogen.

C1.2.8—Conversion of glucose to pyruvate by stepwise reactions in glycolysis with a net yield of ATP and reduced NAD

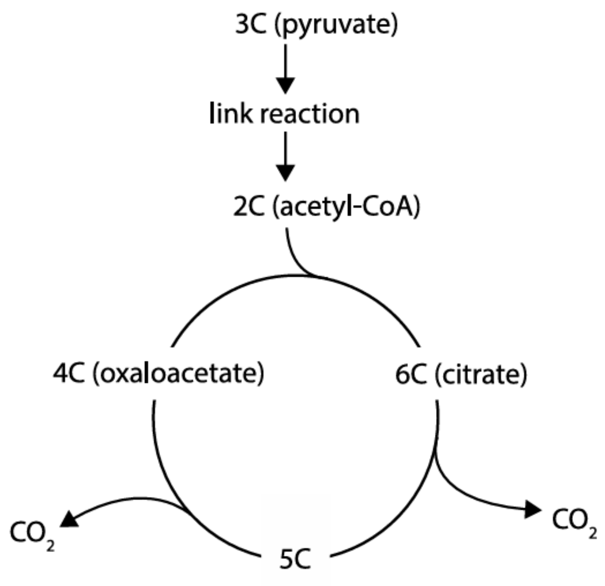
Include phosphorylation, lysis, oxidation and ATP formation. Students are not required to know the names of the intermediates, but students should know that each step in the pathway is catalysed by a different enzyme.

C1.2.9—Conversion of pyruvate to lactate as a means of regenerating NAD in anaerobic cell respiration
Regeneration of NAD allows glycolysis to continue, with a net yield of two ATP molecules per molecule of glucose.

C1.2.10—Anaerobic cell respiration in yeast and its use in brewing and baking
Students should understand that the pathways of anaerobic respiration are the same in humans and yeasts apart from the regeneration of NAD using pyruvate and therefore the final products.

C1.2.11—Oxidation and decarboxylation of pyruvate as a link reaction in aerobic cell respiration
Students should understand that lipids and carbohydrates are metabolized to form acetyl groups (2C), which are transferred by coenzyme A to the Krebs cycle.

C1.2.12—Oxidation and decarboxylation of acetyl groups in the Krebs cycle with a yield of ATP and reduced NAD
Students are required to name only the intermediates citrate (6C) and oxaloacetate (4C). Students should appreciate that citrate is produced by transfer of an acetyl group to oxaloacetate and that oxaloacetate is regenerated by the reactions of the Krebs cycle, including four oxidations and two decarboxylations. They should also appreciate that the oxidations are dehydrogenation reactions.



C1.2.13—Transfer of energy by reduced NAD to the electron transport chain in the mitochondrion
Energy is transferred when a pair of electrons is passed to the first carrier in the chain, converting reduced NAD back to NAD. Students should understand that reduced NAD comes from glycolysis, the link reaction and the Krebs cycle.

C1.2.14—Generation of a proton gradient by flow of electrons along the electron transport chain

C1.2.15—Chemiosmosis and the synthesis of ATP in the mitochondrion
Students should understand how ATP synthase couples release of energy from the proton gradient with phosphorylation of ADP.

C1.2.16—Role of oxygen as terminal electron acceptor in aerobic cell respiration
Oxygen accepts electrons from the electron transport chain and protons from the matrix of the mitochondrion, producing metabolic water and allowing continued flow of electrons along the chain.

C.1.2.17—Differences between lipids and carbohydrates as respiratory substrates
Include the higher yield of energy per gram of lipids, due to less oxygen and more oxidizable hydrogen and carbon. Also include glycolysis and anaerobic respiration occurring only if carbohydrate is the substrate, with 2C acetyl groups from the breakdown of fatty acids entering the pathway via acetyl-CoA (acetyl coenzyme A).

C 1.3 Photosynthesis

Standard level and higher level: 3 hours

Additional higher level: 3 hours

C1.3.1—Transformation of light energy to chemical energy when carbon compounds are produced in photosynthesis
This energy transformation supplies most of the chemical energy needed for life processes in ecosystems.

C1.3.2—Conversion of carbon dioxide to glucose in photosynthesis using hydrogen obtained by splitting water
Students should be able to write a simple word equation for photosynthesis, with glucose as the product. $$\text{carbon dioxide} + \text{water} \xrightarrow{\text{light}} \text{glucose} + \text{oxygen}$$

C1.3.3—Oxygen as a by-product of photosynthesis in plants, algae and cyanobacteria

Students should know the simple word equation for photosynthesis. They should know that the oxygen produced by photosynthesis comes from the splitting of water.

C1.3.4—Separation and identification of photosynthetic pigments by chromatography
Application of skills: Students should be able to calculate R_f values from the results of chromatographic separation of photosynthetic pigments and identify them by colour and by values. Thin-layer chromatography or paper chromatography can be used.

C1.3.5—Absorption of specific wavelengths of light by photosynthetic pigments
Include excitation of electrons within a pigment molecule, transformation of light energy to chemical energy and the reason that only some wavelengths are absorbed. Students should be familiar with absorption spectra. Include both wavelengths and colours of light in the horizontal axis of absorption spectra.

C1.3.6—Similarities and differences of absorption and action spectra
Application of skills: Students should be able to determine rates of photosynthesis from data for oxygen production and carbon dioxide consumption for varying wavelengths. They should also be able to plot this data to make an action spectrum.

C1.3.7—Techniques for varying concentrations of carbon dioxide, light intensity or temperature experimentally to investigate the effects of limiting factors on the rate of photosynthesis
Application of skills: Students should be able to suggest hypotheses for the effects of these limiting factors and to test these through experimentation. **NOS:** Hypotheses are provisional explanations that require repeated testing. During scientific research, hypotheses can either be based on theories and then tested in an experiment or be based on evidence from an experiment already carried out. Students can decide in this case whether to suggest hypotheses for the effects of limiting factors on photosynthesis before or after performing their experiments. Students should be able to identify the dependent and independent variable in an experiment.

C1.3.8—Carbon dioxide enrichment experiments as a means of predicting future rates of photosynthesis and plant growth
Include enclosed greenhouse experiments and free-air carbon dioxide enrichment experiments (FACE). **NOS:** Finding methods for careful control of variables is part of experimental design. This may be easier in the laboratory but some experiments can only be done in the field. Field experiments include those performed in natural ecosystems. Students should be able to identify a controlled variable in an experiment.

Additional higher level

C1.3.9—Photosystems as arrays of pigment molecules that can generate and emit excited electrons
Students should know that photosystems are always located in membranes and that they occur in cyanobacteria and in the chloroplasts of photosynthetic eukaryotes. Photosystems should be described as molecular arrays of chlorophyll and accessory pigments with a special chlorophyll as the reaction centre from which an excited electron is emitted.

C1.3.10—Advantages of the structured array of different types of pigment molecules in a photosystem

Students should appreciate that a single molecule of chlorophyll or any other pigment would not be able to perform any part of photosynthesis.

C1.3.11—Generation of oxygen by the photolysis of water in photosystem II
Emphasize that the protons and electrons generated by photolysis are used in photosynthesis but oxygen is a waste product. The advent of oxygen generation by photolysis had immense consequences for living organisms and geological processes on Earth.

C1.3.12—ATP production by chemiosmosis in thylakoids
Include the proton gradient, ATP synthase, and proton pumping by the chain of electron carriers. Students should know that electrons are sourced, either from photosystem I in cyclic photophosphorylation or from photosystem II in non-cyclic photophosphorylation, and then used in ATP production.

C1.3.13—Reduction of NADP by photosystem I
Students should appreciate that NADP is reduced by accepting two electrons that have come from photosystem I. It also accepts a hydrogen ion that has come from the stroma. The paired terms "NADP and reduced NADP" or "$NADP^+$ and NADPH" should be paired consistently.

C1.3.14—Thylakoids as systems for performing the light-dependent reactions of photosynthesis
Students should appreciate where photolysis of water, synthesis of ATP by chemiosmosis and reduction of NADP occur in a thylakoid.

C1.3.15—Carbon fixation by Rubisco
Students should know the names of the substrates RuBP and CO_2 and the product glycerate 3-phosphate. They should also know that Rubisco is the most abundant enzyme on Earth and that high concentrations of it are needed in the stroma of chloroplasts because it works relatively slowly and is not effective in low carbon dioxide concentrations.

C1.3.16—Synthesis of triose phosphate using reduced NADP and ATP
Students should know that glycerate-3-phosphate (GP) is converted into triose phosphate (TP) using NADPH and ATP.

C1.3.17—Regeneration of RuBP in the Calvin cycle using ATP
Students are not required to know details of the individual reactions, but students should understand that five molecules of triose phosphate are converted to three molecules of RuBP, allowing the Calvin cycle to continue. If glucose is the product of photosynthesis, five-sixths of all the triose phosphate produced must be converted back to RuBP.

C1.3.18—Synthesis of carbohydrates, amino acids and other carbon compounds using the products of the Calvin cycle and mineral nutrients
Students are not required to know details of metabolic pathways, but students should understand that all of the carbon in compounds in photosynthesizing organisms is fixed in the Calvin cycle and that carbon compounds other than glucose are made by metabolic pathways that can be traced back to an intermediate in the cycle.

C1.3.19—Interdependence of the light-dependent and light-independent reactions

Students should understand how a lack of light stops light-dependent reactions and how a lack of CO_2 prevents photosystem II from functioning.