IBDP Biology Year 1 Review

# Topic 1: Cell Biology

## 1.1 Introduction to Cells

**U1 ​According to the cell theory, living organisms are composed of cells.**

* State the three parts of the cell theory.
* Outline evidence that supports the cell theory.
* Compare the use of the word theory in daily language and scientific language.

**U2 Unicellular organisms carry out all functions of life.**

* Outline the functional characteristics of life.

**U3 ​Cell Surface to volume is an important limitation to cell size.**

* ​Outline the activities occurring in the volume and at the surface of the cell.
* Calculate the surface area, volume and SA:V ratio of a cube.
* Explain the benefits and limitations of using cubes to model the surface area and volume of a cell.
* Describe the relationship between cell size and the SA:V ratio of the cell.
* Explain why cells are often limited in size by the SA:V ratio.
* List three adaptations of cells that maximize the SA: volume ratio.

**U4 ​Multicellular organisms have properties that emerge due to the interaction of their cellular components.**

* Define and provide an example of a multicellular organism.
* Define and provide an example of a unicellular organism.
* Define “emergent property.”​
* Provide an example of emergent properties at different hierarchical levels of life.

**U5 ​Specialized tissues can develop by cell differentiation in multicellular organisms.**

* Define tissue.​
* Outline the benefits of cell specialization in a multicellular organism.
* Define differentiation.​

**U6 ​Differentiation involves the expressions of some genes and not others in a cell’s genome.**

* Describe the relationship between cell differentiation and gene expression.

**U7 ​The capacity of stem cells to divide and differentiate along different pathways is necessary in embryonic development and also makes stem cells suitable for therapeutic uses.**

* Define zygote and embryo.
* List 2 key properties of stem cells that have made them on the active areas of research in biology and medicine today.
* Explain why stem cells are most prevalent in the early embryonic development of a multicellular organism.
* Contrast the characteristics of embryonic, umbilical cord and adult somatic stem cells.
* Define totipotent, multipotent and pluripotent.

**A1 ​Questioning the cell theory using atypical examples, including striated muscle, giant algae and aseptate fungal hyphae.**

* Describe features of striated muscle fibers that make them a discrepancy from a typical cell.
* Describe features of red blood cells that make them a discrepancy from a typical cell.
* Describe features of aseptate fungal hyphae that make them a discrepancy from a typical cell.
* Describe features of giant algae that make them a discrepancy from a typical cell.​

**A2 ​Investigation of functions of life in Paramecium and one named photosynthetic unicellular organism.**

* Describe characteristics of *Paramecium* that enable it to perform the functions of life.
* Describe characteristics of *Chlamydomonas* that enable it to perform the functions of life.

**A3 ​Use of stem cells to treat Stargardt’s disease and one other named condition.**

* Outline why stem cells are used in medical research and treatment.
* Outline the cause and symptoms of Stargardt’s disease.
* Explain how stem cells are used in the treatment of Stargardt’s disease.
* Outline the cause of leukemia.
* Explain how stem cells are used in the treatment of leukemia.​

**A4 ​Ethics of the therapeutic use of stem cells from specially created embryos, from the umbilical cord blood of a newborn baby and from an adult’s own tissues.**

* Discuss the benefits and drawbacks in using adult stem cells.
* Discuss the benefits and drawbacks in using embryonic stem cells.
* Discuss the benefits and drawbacks in using cord blood stem cells.

**S1 ​Use of a light microscope to investigate the structure of cells and tissues.**

* Label the names of parts of the microscope.
* Define magnification.
* Given the magnification of the ocular and objective lenses, calculate the total microscope magnification.
* Define "field of view."
* Outline how to determine the diameter of a field of view using low power magnification.
* Calculate the field of view diameter of a microscope under medium or high power.
* Outline how to estimate the size of a sample in the microscope field of view.
* Demonstrate how to focus the microscope on a sample.

**S2 ​Drawing of cell structures as seen with the light microscope.**

* Demonstrate how to draw cell structures seen with a microscope using sharp, carefully joined lines and straight edge lines for labels.​

**S3 ​Calculation of the magnification of drawings and the actual size of structures and ultrastructures shown in drawings or micrographs.**

* Define micrograph.
* State why the magnification of a drawing or micrograph is not the same as the magnification of the microscope.
* Use a formula to calculate the magnification of a micrograph or drawing.
* If given the magnification of a micrograph or drawing, use a formula to calculate the actual size of a specimen.​

## 1.2 Ultrastructure of Cells

**U1 Prokaryotes have a simple cell structure without compartmentalization.**

* Outline the major differences between prokaryotic and eukaryotic cells.
* List the functions of the following structures of a prokaryotic cell: cell membrane, nucleoid, plasmid, cytoplasm, ribosome, cell wall, pili, capsule, and flagella.
* ​Contrast the size of eukaryotic and prokaryotic ribosomes.

**U2 Eukaryotes have a compartmentalized cell structure.**

* State the meaning and advantages of eukaryotic cells being “compartmentalized.”
* State structural differences between plant and animal cells.

**U3 Prokaryotes divide by binary fission.**

* Define asexual reproduction.
* Outline the steps of binary fission.

**U4 Electron microscopes have a much higher resolution than light microscopes.**

* Define resolution.
* Compare the functionality of light and electron microscopes.

**A1 Structure and function of organelles within exocrine gland cells of the pancreas.**

* State the function of an exocrine gland cell.
* Describe the function of the following structures in an exocrine gland cell: plasma membrane, nucleus, mitochondria, Golgi apparatus, lysosomes, vesicles and endoplasmic reticulum.

**A2 Structure and function of organelles within palisade mesophyll cells of the leaf.**

* State the function of a palisade mesophyll cell.
* Draw a labeled diagram of a palisade cell from the leaf mesophyll.
* ​Describe the function of the following structures in a palisade mesophyll cell: cell wall, plasma membrane, chloroplasts, vacuole, nucleus, and mitochondria.

**S1 Drawings of the ultrastructure of prokaryotic cells based on electron micrographs.**

* Explain why the ultrastructure of prokaryotic cells must be based on electron micrographs.
* Draw the ultrastructure of E.coli as seen in an electron micrograph.

**S2 Drawings of the ultrastructure of eukaryotic cells based on electron micrographs.**

* ​Draw and label a diagram of the ultrastructure of a generic animal cell.
* Draw and label a diagram of the ultrastructure of a generic plant cell.

**S3 Interpretations of electron micrographs to identify organelles and deduce the function of specialized cells.**

* Explain why cells with different functions will have different structures.
* Identify ultrastructures visible in a micrograph of a eukaryotic cell.
* Given a micrograph of a cell, deduce the function of the cell based on the structures present.​​

## 1.3 Membrane Structure

**U1 Phospholipids form bilayers in water due to the amphipathic properties of phospholipid molecules.**

* Draw a simplified diagram of the structure of the phospholipid, including a phosphate-glycerol head and two fatty acid tails.
* Define hydrophilic and hydrophobic.
* Define amphipathic and outline the amphipathic properties of phospholipids.
* Explain why phospholipids form bilayers in water, with reference to hydrophilic phosphate heads and two hydrophobic hydrocarbon tails.

**U2 Membrane proteins are diverse in terms of structure, position in the membranes and function.**

* State the primary function of the cell membrane.
* Contrast the structure of integral and peripheral proteins.
* List at least four functions (with example) of membrane proteins.
* Contrast the two types of transport proteins: pumps and channels.​

**U3 Cholesterol is a component of animal cell membranes.**

* Identify the structure of cholesterol in molecular diagrams.
* Describe the structural placement of cholesterol within the cell membrane.

**A1 Cholesterol in mammalian membranes reduces membrane fluidity and permeability to some solutes.**

* Outline how temperature affects cell membrane fluidity.
* Describe the function of cholesterol molecules in the cell membrane.​

**S1 Drawing of the fluid mosaic model.**

* Draw and label the structure of membranes. Include:
  + Phospholipid bilayer
  + Integral proteins shown spanning the membrane
  + Peripheral proteins on membrane surface
  + Protein channels with a pore
  + Glycoproteins with a carbohydrate side chain
  + Cholesterol between phospholipids in the hydrophobic region

**S2 Analysis of evidence from electron microscopy that led to the proposal of the Davson-Danielli model.**

* Describe the observations and conclusions drawn by Davson and Danielli in discovering the structure of cell membranes.

**S3 Analysis of the falsification of the Davson-Danielli model that led to the Singer-Nicolson model.**

* Describe conclusions about cell membrane structure drawn from freeze-etched electron micrograph images of the cell membrane.
* Describe conclusions about cell membrane structure drawn from cell fusion experiments.
* Describe conclusions about cell membrane structure drawn from improvements in techniques for determining the structure of membrane proteins.
* Compare the Davson-Danielli model of membrane structure with the Singer-Nicolson model.

## 1.4 Membrane Transport

**U1 Particles move across membranes by simple diffusion, facilitated diffusion, osmosis and active transport.**

* Describe simple diffusion.
* Explain two examples of simple diffusion of molecules into and out of cells.
* Outline factors that regulate the rate of diffusion.
* Describe facilitated diffusion.
* Describe one example of facilitated diffusion through a protein channel.
* Define osmosis.
* Predict the direction of water movement based upon differences in solute concentration.
* Compare active transport and passive transport.
* Explain one example of active transport of molecules into and out of cells through protein pumps.​

**U2 The fluidity of membranes allows materials to be taken into cells by endocytosis or released by exocytosis. Vesicles move materials within cells.**

* Describe the fluid properties of the cell membrane and vesicles.
* Explain vesicle formation via endocytosis.
* Outline two examples of materials brought into the cell via endocytosis.
* Explain release of materials from cells via exocytosis.
* Outline two examples of materials released from a cell via exocytosis.

**U3 Vesicles move materials within cells.**

* List two reasons for vesicle movement.
* Describe how organelles of the endomembrane system function together to produce and secrete proteins (rough ER, smooth ER, Golgi and vesicles).
* Outline how phospholipids and membrane bound proteins are synthesized and transported to the cell membrane.

**A1 Structure and function of the sodium-potassium pumps for active transport and potassium channels for facilitated diffusion in axons.**

* Describe the structure of the sodium-potassium pump.
* Describe the role of the sodium-potassium pump in maintaining neuronal resting potential.
* Outline the six steps of sodium-potassium pump action.
* Describe the structure of the potassium channel.
* Describe the mechanism of potassium movement through the potassium channel.
* Explain the specificity of the potassium channel.
* Describe the action of the “voltage gate” of the potassium channel.

**A2 Tissues or organs to be used in medical procedures must be bathed in a solution with the same osmolarity as the cytoplasm to prevent osmosis.**

* Explain what happens to cells when placed in solutions of the same osmolarity, higher osmolarity and lower osmolarity.
* Outline the use of normal saline in medical procedures.

**S1 Estimation of osmolarity in tissues by bathing samples in hypotonic and hypertonic solutions.**

* Define osmolarity, isotonic, hypotonic and hypertonic.
* Calculate the percentage change between measurement values.
* Calculate the mean value of a data set.
* Calculate the standard deviation value of a data set.
* State that the term standard deviation is used to summarize the spread of values around the mean, and that 68% of the values fall within one standard deviation of the mean.
* Explain how the standard deviation is useful for comparing the means and the spread of data between two or more samples.
* Determine the correct type of graph to represent experimental results.
* State that error bars are a graphical representation of the variability of data.
* Accurately graph mean and standard deviation of data sets.
* Determine osmolarity of a sample given changes in mass when placed in solutions of various tonicities.

**NOS Experimental design- accurate quantitative measurements in osmosis experiments are essential.**

* Define quantitative and qualitative.
* Determine measurement uncertainty of a measurement tool.
* Explain the need for repeated measurements (multiple trials) in experimental design.
* Explain the need to control variables in experimental design.

## 1.5 The Origin of Cells

**U1 Cells can only be formed by division of preexisting cells.**

* Discuss implications of all cells being formed from preexisting cells.​​

**U2 The first cells must have arisen from non-living material.**

* Outline the four processes needed for the spontaneous origin of cells on Earth.
* Outline the experiments of Miller and Urey into the origin of organic compounds.
* Define polymerization, monomer and polymer.
* Outline two properties of RNA that would have allowed it to play a role in the origin of life.
* ​Outline why fatty acids were likely the primary component of the membrane of early cells.

**U3 The origin of eukaryotic cells can be explained by the endosymbiotic theory.**

* State the endosymbiosis theory.
* Outline the major events in the origin of eukaryotic cells.
* Describe the evidence for the endosymbiotic theory.​

**A1 Evidence from Pastuer’s experiments that spontaneous generation of cells and organisms does not now occur on Earth.**

* Define spontaneous generation.
* Describe Pasteur’s experiments about spontaneous generation.
* ​Explain why Pasteur’s experiments did not support the idea of spontaneous generation. ​

**NOS Testing the general principles that underline the natural world- the principles that cells only come from pre-existing cells needs to be verified.**

* ​Outline historical thinking about spontaneous generation.
* Summarize the Redi experiment.
* Summarize the Spallanzani experiment.
* List reasons why biologists now universally accept that cells only come from preexisting cells.

## 1.6 Cell Division

**U1 Mitosis is the division of the nucleus into two genetically identical daughter nuclei.**

* State the function of mitosis.
* List four processes which involve mitosis.
* State the names of the four phases of mitosis.
* Draw typical eukaryotic cells as they would appear during the interphase and the four phases of mitosis.
* Outline four events that occur during prophase.
* Outline the process of metaphase, inclusive of the role of microtubules and the kinetochore.
* Outline the process of anaphase.
* Outline four events that occur during telophase.

**U2 Chromosomes condense by supercoiling during mitosis.**

* Describe the structure of a replicated chromosome, include the centromere and sister chromatids.
* Explain why chromosomes must condense during mitosis.

**U3 Cytokinesis occurs after mitosis and is different in plants and animal cells.**

* Define cytokinesis.
* State the difference between mitosis and cytokinesis.
* Contrast cytokinesis in plant and animal cells.
* Describe the formation of the cleavage furrow in animal cell cytokinesis.
* Describe the formation of the middle lamella and cell wall in plant cell cytokinesis.

**U4 Interphase is a very active phase of the cell cycle with many processes occurring in the nucleus and cytoplasm.**

* List example metabolic reactions occurring during cell interphase.
* Outline events of G1, S, G2 and G0 phases of interphase.

**U5 Cyclins are involved in the control of the cell cycle.**

* Explain the role of cyclin and cyclin-CDK complexes in controlling the cell cycle.
* State the role of cyclins D, B, A and E in the cell cycle.

**U6 Mutagens, oncogenes and metastasis are involved in the development of primary and secondary tumors.**

* Define tumor, benign, malignant, metastasis, cancer, mutagen and carcinogen.
* Describe why mutagens are not necessarily carcinogens.
* Describe how cancer arises, referring to accumulation of mutations over time.
* Explain the relationship between oncogenes, tumor suppressor genes and cancer.

**A1 The correlation between smoking and incidence of cancers.**

* Explain the use of correlations to determine the relationship between two variables (inclusive of positive and negative correlations).
* Explain why the existence of a correlation does not necessitate a causal relationship between two variables.
* Calculate a correlation coefficient using Pearson's R.
* Determine if a correlation coefficient value is significant.
* Define significant as related to the relationship between two variables.
* Use epidemiological case study information to outline the relationships between smoking and cancer.

**S1 Identification of phases of mitosis in cells viewed with a microscope or in a micrograph.**

* Determine the phase of mitosis of a cell viewed in a micrograph or with a microscope.

# Topic 2: Molecular Biology

## 2.1 Molecules to Metabolism

**U1 Molecular biology explains living processes in terms of the chemical substances involved.**

* Define “molecular biology.”
* Compare the benefits of a reductionist vs. systems approach to studying biology.
* Recognize common functional groups.
* Draw skeletal molecular structures from full structure diagrams.

**U2 Carbon atoms can form four covalent bonds allowing a diversity of stable compounds to exist.**

* Outline the number and type of bond carbon can form with other atoms.

**U3 Life is based on carbon compounds including carbohydrates, lipids proteins and nucleic acids.**

* List the four major classes of carbon compounds used by living organisms.

**U4 Metabolism is the web of all the enzyme-catalyzed reactions in a cell or organism.**

* Define metabolism and catalysis.
* State the role of enzymes in metabolism.

**U5 Anabolism is the synthesis of complex molecules from simpler molecules including the formation of macromolecules from monomers by condensation reactions.**

* Define anabolism, monomer and polymer.
* Describe condensation (dehydration synthesis) reactions.
* Using simple shapes to represent monomers, diagram a condensation reaction.

**U6 Catabolism is the breakdown of complex molecules into simpler molecules including the hydrolysis of macromolecules into monomers.**

* Define catabolism.
* Contrast anabolism and catabolism.
* Describe hydrolysis reactions.
* Using simple shapes to represent monomers, diagram a hydrolysis reaction.

**A1 Urea as an example of a compound that is produced by living organisms but can also be artificially synthesized.**

* Draw the molecular structure of urea.
* Describe how urea can be synthesized by living and artificial mechanisms.

**S1 Drawing molecular diagrams of glucose, ribose, a saturated fatty acid and a generalized amino acid.**

* Draw the molecular diagram of ribose.
* Draw the molecular diagram of alpha-glucose.
* Draw the molecular diagram of a saturated fatty acid.
* Identify the carboxyl and methyl groups on a fatty acid.
* Draw the generalized structure of an amino acid.
* Label the amine group, carboxyl group, alpha carbon and R group on an amino acid.

**S2 Identification of biochemical such as sugars, lipids, or amino acids from molecular drawings.**

* Identify the four major classes of carbon compounds used by living organisms from given diagrams (examples will include D-ribose, alpha glucose, beta glucose, trigylcerides, phospholipids and steroids).
* State the generalized chemical formula of the carbohydrates.
* Identify the following carbohydrates from molecular drawings: D-ribose, alpha glucose, beta glucose, cellulose, glycogen, amylose starch and amylopectin starch.
* Compare the relative amount of oxygen atoms in lipids to the amount in carbohydrates.
* Identify the following lipids from molecular drawings: triglycerides, phospholipids and steroids.

## 2.2 Water

**U1 Water molecules are polar and hydrogen bonds form between them.**

* Describe the structure of an atom (in terms of protons, neutrons and electrons).
* Contrast ion with atom.
* Define anion and cation.
* Contrast covalent, ionic and hydrogen bonds.
* Write the molecular formula for water and draw the atomic structure of the molecule.
* Describe the cause and effect of the polar nature of water.
* Describe where and how water is able to form hydrogen bonds.

**U2 Hydrogen bonding and dipolarity explain the cohesive, adhesive, thermal and solvent properties of water.**

* Contrast adhesion with cohesion.
* Outline an example of the cohesive property of water being of benefit to life.
* Outline an example of the adhesive property of water being of benefit to life.
* Explain three thermal properties of water that are useful to living organisms.
* Outline a benefit to life of water's high specific heat capacity.
* Outline a benefit to life of water's high latent heat of vaporization.
* Outline a benefit to life of water's high boiling point.
* Explain why is water such a good solvent.
* List the types of molecules that water will dissolve.

**U3 Substances can be hydrophilic or hydrophobic.**

* State that polar and ionic molecules are hydrophilic.
* State that non-polar, non-ionic molecules are hydrophobic.
* Given a diagram of a molecular structure, determine if the molecule is hydrophilic or hydrophobic.

**A1 Comparison of the thermal properties of water with those of methane.**

* Compare the physical properties of methane and water.
* Explain why water and methane have different thermal properties based on their molecular structures.

**A2 Use of water as a coolant in sweat.**

* Explain sweating as a mechanism to cool the body.

**A3 Modes of transport of glucose, amino acids, cholesterol, fats. oxygen, and sodium in blood in relations to their solubility in water.**

* State if the following molecules are hydrophobic or hydrophilic: glucose, amino acids, cholesterol, fats, oxygen, and sodium chloride.
* Outline the mechanism of transport in the blood of the following molecules: glucose, amino acids, cholesterol, fats, oxygen, and sodium chloride.

## 2.3 Carbohydrates and Lipids

**U1 Monosaccharide monomers are linked together by condensation reactions to form disaccharides and polysaccharide polymers.**

* Define monosaccharide, disaccharide and polysaccharide.
* List three examples of monosaccharides.
* List three examples of disaccharides.
* List three examples of polysaccharides.
* Use molecular diagrams to draw the formation of maltose from two glucose monomers.
* Explain a condensation reaction connecting two monosaccharides in the formation of a disaccharide.

**U2 Fatty acids can be saturated, monounsaturated and polyunsaturated.**

* Describe the differences between saturated and unsaturated (mono- or poly-) fatty acids.

**U3 Unsaturated fatty acids can be cis or trans isomers.**

* Describe the differences between cis- and trans- fatty acids.

**U4 Triglycerides are formed by condensation from three fatty acids and one glycerol.**

* Outline the difference between fats and oils.
* Explain a condensation reaction connecting fatty acids and glycerol to form a triglyceride..
* State two functions of triglycerides.

**A1 Structure and function of cellulose and starch in plants and glycogen in humans.**

* State the structural difference between alpha and beta glucose.
* Contrast the structure and functions of cellulose, amylose, amylopectin and glycogen.

**A2 Scientific evidence for health risks of trans fat and saturated fatty acids.**

* Discuss the relationship between saturated fatty acid and trans-unsaturated fat intake and rates of coronary heart disease.

**A3 Lipids are more suitable for long term energy storage in humans than carbohydrates.**

* Explain the energy storage of lipids compared to that of carbohydrates.

**A4 Evaluation of evidence and the methods used to obtain the evidence for health claims made about lipids.**

* Define evaluation in respect to evidence from and methods of research.
* Outline the manner in which the implications of research can be assessed.
* Outline the manner in which the limitations of research can be assessed.
* Evaluate a given health claim made about lipids.

**S1 Use of molecular visualization software to compare cellulose, starch and glycogen.**

* Demonstrate use of JMol to view molecular structures, including changing image size, rotating the image and changing the style of the molecular model.
* Identify carbon, hydrogen and oxygen atoms by color.

**S2 Determination of body mass index by calculation or use of a nomogram.**

* Calculate BMI using the formula.
* Determine BMI using a nomogram.
* Outline effects of a BMI that is too high or too low.

**NOS Evaluating claims- health claims made about lipids in diets need to be assessed.**

* Describe how the effect of lipids on health can be assessed scientifically.

## 2.4 Proteins

**U1 Amino Acids are linked together by condensation to form polypeptides.**

* Describe polypeptide chain formation in terms of the formation of peptide bonds and condensation reactions.
* Determine the number of peptide bonds given the number of amino acids in a polypeptide.
* Define dipeptide, oligopeptides and polypeptide.

**U2 There are 20 different amino acids in polypeptides synthesized on ribosomes.**

* State the number of amino acids used by living organisms to make polypeptides.
* Given an image of an amino acid, classify the amino acid chemical properties based on R group properties.
* Outline the role vitamin C plays in the conversion of proline to hydroxyproline.

**U3 Amino Acids can be linked together in any sequence giving a huge range of possible polypeptides.**

* Calculate the possible number of amino acid sequences given n number of amino acids.

**U4 The amino acid sequence of polypeptides is coded for by genes.**

* Outline the relationship between genes and polypeptides.

**U5 A protein may consist of a single polypeptide or more than one polypeptide linked together.**

* Outline the structure and function of three example proteins composed of two or more polypeptides linked together.

**U6 The amino acid sequence determines the three-dimensional conformation of a protein.**

* Contrast the structure of globular proteins with the structure of fibrous proteins.
* Describe the structure of membrane bound globular proteins.

**U7 Living organisms synthesize many different proteins with a wide range of functions.**

* Contrast the generalized function of globular proteins with generalized function of fibrous proteins.
* List ten functions of proteins in a cell or organism.
* Describe the function of enzyme proteins.
* Describe the function of hormone proteins.
* Describe the function of immunoglobulin proteins.
* Describe the function of pigment proteins.
* Describe the function of structural proteins

**U8 Every individual has a unique proteome.**

* Define proteome.
* Contrast proteome with genome.

**A1 Rubisco, insulin immunoglobulins, rhodopsin, collagen and spider silk as examples of the range of protein functions.**

* State the function of each of the following proteins: rubisco, insulin, immunoglobulin, rhodopsin. collagen, spider silk, actin, myosin, casein, hemoglobin, acetylcholine receptor, oxytocin, prolactin, ferritin, billirubin, fibrinogen, transferrin and albumin.

**A2 Denaturation of proteins by heat or by deviation of pH from the optimum.**

* Define denaturation.
* Outline the effect of heat and pH on protein structure.

**S1 Drawing molecular diagrams to show the formation of a peptide bond.**

* Draw peptide bond formation in a condensation reactions.

## 2.5 Enzymes

**U1 Enzymes have an active site to which specific substrates bind.**

* State the relationship between enzyme substrate and enzyme active site.
* Explain the relationship between enzyme structure and enzyme specificity, including the role of the active site.

**U2 Enzyme catalysis involves molecular motion and the collision of substrates with the active site.**

* Outline the three stages of enzyme activity.
* Explain the role of random collisions in the binding of the substrate with the enzyme active site.
* Describe the induced fit model of enzyme action.

**U3 Temperature, pH and substrate concentration affect the rate of activity of enzymes.**

* Explain how temperature affects the rate of enzyme activity.
* Draw a graph of depicting the effect of temperature on the rate of enzyme activity.
* Explain how pH affects the rate of enzyme activity.
* Draw a graph of depicting the effect of pH on the rate of enzyme activity.
* Identify the optimum temperature or pH for enzyme activity on a graph.
* Explain how substrate concentration affects the rate of enzyme activity.
* Draw a graph of depicting the effect of substrate concentration on the rate of enzyme activity.

**U4 Enzymes are denatured.**

* State the effect of denaturation on enzyme structure and function.

**U5 Immobilized enzymes are widely used in industry.**

* List industries that use commercially useful enzymes.
* Explain how and why industrial enzymes are often immobilized.

**A1 Methods of production of lactose-free milk and its advantages.**

* State the source of the lactase enzyme used in food processing.
* State the reaction catalyzed by lactase.
* Outline four reasons for using lactase in food processing.

**S1 Design of experiments to test the effect of temperature, pH, and substrate concentration on the activity of enzymes.**

* Identify and manipulated, responding and controlled variables in descriptions of experiments testing the activity of enzymes.

**S2 Experimental investigation of a factor affecting enzyme activity.**

* Describe three techniques for measuring the activity of an example enzyme.

**NOS Experimental design-accurate, quantitative measurements in enzyme experiments require replicates to ensure reliability.**

* Define quantitative and qualitative.
* Determine measurement uncertainty of a measurement tool.
* Explain the need for repeated measurements (multiple trials) in experimental design.
* Explain the need to controlled variables in experimental design.

## 2.6 Structure of DNA and RNA

**U1 The nucleic acids DNA and RNA are polymers of nucleotides.**

* State the two types of nucleic acid.
* Outline the parts of a nucleotide.
* Identify and label carbons by number (for example, C1, C2, C3) on a nucleotide drawing.
* Explain how nucleotides can connect to form a nucleic acid polymer.
* State the names of the nitrogenous bases found in DNA and RNA.
* Identify nitrogenous bases as either a pyrimidine or purine.
* State the complementary base pairing rules.

**U2 DNA differs from RNA in the number of strands present, the base composition and the type of pentose.**

* Compare the structure of DNA and RNA.

**U3 DNA is double helix made of two antiparallel strands of nucleotides linked by hydrogen bonding between complimentary base pairs.**

* Define antiparallel in relation to DNA structure.
* Outline the formation of a DNA double helix by hydrogen bonding between nitrogenous bases.
* Identify the four bases of DNA based on the numbers of rings (purines or pyrimidines) and the number of hydrogen bonds it can form.
* State the number of nitrogenous bases per complete turn of the DNA double helix.

**A1 Crick and Watson’s elucidation of the structure of DNA using model making.**

* Outline the role of Chargaff, Watson, Crick, Franklin and Wilkins in the discovery of DNA structure.
* Explain how Watson and Crick used model building to determine the structure of DNA.

**S1 Drawing simple diagrams of the structure of single nucleotides of DNA and RNA, using circles, pentagons, and rectangles to represent phosphates, pentoses and bases.**

* Draw the basic structure of a single nucleotide (using circle, pentagon and rectangle).
* Draw a simple diagram of the structure of RNA.
* Draw a simple diagram of the structure of DNA,
* Identify and label the 5’ and 3’ ends on a DNA or RNA diagram

## 2.7 DNA Replication, Transcription, and Translation

**U1 The replication of DNA is semi-conservative and depends on complimentary base pairing.**

* Describe the meaning of “semi-conservative” in relation to DNA replication.
* Explain the role of complementary base pairing in DNA replication.

**U2 Helicase unwinds the double helix and separates the two strands by breaking hydrogen bonds.**

* State why DNA strands must be separated prior to replication.
* Outline two functions of helicase.
* State the role of the origin of replication in DNA replication.
* Contrast the number of origins in prokaryotic cells to the number in eukaryotic cells.

**U3 DNA polymerase links nucleotides together to form a new strand, using a pre-existing strand as a template.**

* Describe the movement of DNA polymerase along the DNA template strand.
* Describe the action of DNA polymerase III in pairing nucleotides during DNA replication.

**U4 Transcription is the synthesis of mRNA copied from the DNA base sequences by RNA polymerase.**

* Define transcription.
* Outline the process of transcription, including the role of RNA polymerase and complementary base pairing.
* Identify the sense and antisense strands of DNA given a diagram of transcription.

**U5 Translation is the synthesis of polypeptides on ribosomes.**

* Define translation.
* State the location of translation in the cell.

**U6 The amino acid sequence of polypeptides is determined by mRNA according to the genetic code.**

* Outline the role of messenger RNA in translation.

**U7 Codons of three bases on mRNA correspond to one amino acid in a polypeptide.**

* Define codon, redundant and degenerate as related to the genetic code.
* Explain how using a 4 letters nucleic acid “language” can code for a “language” of 20 amino acid letters in proteins.

**U8 Translation depends on complimentary base-pairing between codons on mRNA and anti codons on tRNA.**

* Outline the role of complementary base pairing between mRNA and tRNA in translation.

**A1 Use of Taq DNA polymerase to produce multiple copies of DNA rapidly by the polymerase chain reaction (PCR).**

* Outline the process of the PCR.
* Explain the use of Taq DNA polymerase in the PCR.

**A2 Production of human insulin in bacteria as an example of the universality of the genetic code allowing gene transfer between species.**

* Outline the source and use of pharmaceutical insulin prior to the use of gene transfer technology.
* Outline the benefits of using gene transfer technology in the production of pharmaceutical insulin.

**S1 Use a table of the genetic code to deduce which codons corresponds to which amino acids.**

* Use a genetic code table to deduce the mRNA codon(s) given the name of an amino acid.

**S2 Analysis of Meselson and Stahl’s results to obtain support for the theory of semi-conservative replication of DNA.**

* Compare dispersive, conservative and semi-conservative replication.
* Predict experimental results in the Meselson and Stahl experiment if DNA replication was dispersive, conservative or semi-conservative.

**S3 Use a table of mRNA codons and their corresponding amino acids to deduce the sequence of amino acids coded by a short mRNA strand of known base sequence.**

* Use a genetic code table to determine the amino acid sequence coded for by a given antisense DNA sequence or an mRNA sequence.

**S4 Deducing the DNA base sequence for the mRNA strand.**

* Deduce the antisense DNA base sequence that was transcribed to produce a given mRNA sequence.

**NOS Obtaining of evidence for scientific theories- Meselson and Stahl obtained evidence for the semi-conservative replication of DNA.**

* Describe the procedure of the Meselson and Stahl experiment.
* Explain how the Meselson and Stahl experiment demonstrated semi-conservative DNA replication.

### Topic 7: Nucleic Acids (AHL)

#### 7.1 DNA Structure and Replication

**U1 DNA structure suggested a mechanism for DNA replication.**

* Outline the features of DNA structure that suggested a mechanism for DNA replication.

**U2 Nucleosomes help to supercoil the DNA.**

* Draw and label the structure of a nucleosome, including the H1 protein, the octamer core proteins, linker DNA and two wraps of DNA.
* Explain the levels of supercoiling (DNA→ nucleosome → beads on a string → 30nm fiber → unreplicated interphase chromosome → replicated metaphase chromosome).

**U3 DNA replication is continuous on the leading strand and discontinuous on the lagging strand.**

* Compare replication on the the leading strand and the lagging strand of DNA.
* Explain why replication is different on the leading and lagging strands of DNA.
* Outline the formation of Okazaki fragments on the lagging strand.

**U4 DNA replication is carried out by a complex system of enzymes.**

* Outline the role of the following proteins in DNA replications: helicase, topoisomerase (AKA gyrase), single stranded binding proteins, primase, DNA polymerase III, DNA polymerase I, and DNA ligase.

**U5 DNA polymerases can only add nucleotides to the 3’ end of a primer.**

* Explain the need for RNA primers in DNA replication.
* Explain what is meant by DNA replication occurring in a 5' to 3' direction.

**U6 Some regions of DNA do not code for proteins but have other important functions.**

* Define “coding sequences” and “repetitive sequences” of DNA.
* Outline five functions of non-coding DNA sequences found in genomes, one of which must be the telomere.

**A1 Rosalind Franklin and Maurice Wilkins’ investigation of DNA structures by X-ray diffraction.**

* Outline the process of X-ray diffraction.
* Outline the deductions about DNA structure made from the X-ray diffraction pattern.

**A2 Tandem repeats are used in DNA profiling.**

* Define VNTR.
* Explain why VNTR are used in DNA profiling

**A3 Use of nucleotides containing dideoxyrubonucleic acid to stop DNA replication in preparation of samples for base sequencing.**

* Outline the process of DNA sequencing, including the role of chain terminator nucleotides, fluorescence, and electrophoresis.

**S1 Analysis of results of the Hershey and Chase experiment providing evidence that DNA is the genetic material.**

* State the experimental question being tested in the Hershey and Chase experiment.
* Explain the procedure of the Hershey and Chase experiment.
* Explain how the results of the Hershey and Chase experiment supported the notion of nucleic acids as the genetic material.

**S2 Utilization of molecular visualization software to analyze the association between protein and DNA within a nucleosome.**

* Identify nucleosome structures using molecular visualization software.
* Outline the mechanism of histone-DNA association.

**NOS Making careful observations-Rosalind Franklin’s X-ray diffraction provided crucial evidence that DNA is a double helix.**

* Describe Rosalind Franklin’s role in the elucidation of the structure of DNA.

#### 7.2 Transcription and Gene Expression

**U1 Gene expression is regulated by proteins that bind to specific base sequences in DNA.**

* Define gene expression.
* State two reasons why gene expression must be regulated.
* Outline the environmental regulation of the breakdown of lactose in E. coli.
* Outline the role of enhancers, silencers and promoter-proximal elements in regulation of gene expression.

**U2 The environment of a cell and of an organism has an impact on gene expression.**

* Describe the use of twin studies to measure the impact of environment on gene expression.
* Outline two examples of environmental influence on gene expression.

**U3 Nucleosomes help to regulate transcription in eukaryotes.**

* Outline the effect of methylation of nucleosome tails on rates of gene expression.
* Outline the effect of acetylation of nucleosome tails on rates of gene expression.

**U4 Transcription occurs in a 5’ to 3’ direction.**

* Describe the initiation of transcription, including the role of the promoter, transcription factors, the TATA box and RNA polymerase.
* Describe elongation of transcription, including the role of nucleotide triphosphates and the direction of transcription.
* Describe termination of transcription, including the role of the terminator.

**U5 Eukaryotic cells modify mRNA after transcription.**

* List two major differences in gene expression between prokaryotic cells and eukaryotic cells.
* Describe the three post-transcriptional modifications of pre-mRNA in eukaryotes.

**U6 Splicing of mRNA increases the number of different proteins an organism can produce.**

* Describe the process of alternative RNA splicing.
* Outline an example of alternative splicing the results in different protein products.

**A1 The promoter as an example of non-coding DNA with a function.**

* Outline the role of promoter DNA.

**S1 Analysis of changes in the DNA methylation patterns.**

* State the effect of DNA methylation on gene expression.
* Compare methylation patterns in twins using superimposed images of dyed chromosomes.

**NOS Looking for patterns, trends and discrepancies- there is mounting evidence that the environment can trigger heritable changes in epigenetic factors.**

* Define epigenetic and epigenome.
* List types of epigenetic tags.
* Discuss the role of reprogramming and imprinting on epigenetic factors.

#### 7.3 Translation

**U1 Initiation of translation involves assembly of the components that carry out the process.**

* Outline the process of translation initiation.

**U2 Synthesis of the polypeptide involves a repeated cycle of events.**

* Outline the process of translation elongation, including codon recognition, bond formation and translocation.
* State the direction of movement of the ribosome along the mRNA molecule.

**U3 Disassembly of the components follows termination of translation.**

* Outline the process of translation termination, including the role of the stop codon.

**U4 Free ribosomes synthesize proteins primarily for use primarily within the cell.**

* State the difference between free and bound ribosomes.
* List destinations of proteins synthesized on free ribosomes.

**U5 Bound ribosomes synthesize proteins for secretion or use in lysosomes.**

* List destinations of proteins synthesized on bound ribosomes.
* Outline how a ribosome becomes bound to the endoplasmic reticulum.

**U6 Translation can occur immediately after transcription in prokaryotes due to the absence of a nuclear membrane.**

* Compare the timing and location of transcription and translation between prokaryotes and eukaryotes.

**U7 The sequence and number of amino acids in the polypeptide is the primary structure.**

* Describe the primary structure of a protein, including the type of bonding involved.

**U8 The secondary structure is the formation of alpha helices and beta pleated sheets stabilized by hydrogen bonding.**

* Describe the secondary structure of a protein, including the type of bonding involved.
* Identify the alpha-helix and beta-pleated sheet in images of protein structure.

**U9 The tertiary structure is the further folding of the polypeptide stabilized by interactions between R groups.**

* Describe the tertiary structure of a protein, including the types of R group interactions involved.
* Explain how the chemical characteristics of R groups in the polypeptide chain affect protein folding.

**U10 The quaternary structure exists in proteins with more than one polypeptide chain.**

* Outline the quaternary structure of protein folding.
* Describe the structure of a conjugated protein, including the prosthetic group.

**A1 tRNA-activating enzymes illustrate enzyme-substrate specificity and the role of phosphorylation.**

* State the role of the tRNA activating enzymes.
* Outline the process of attaching an amino acid to tRNA by the tRNA activating enzyme.

**S1 The use of molecular visualization software to analyze the structure of eukaryotic ribosomes and tRNA molecules.**

* Describe the structure of the ribosomes, including the small and large subunits and the names and roles of the tRNA binding sites.
* Use molecular visualization software to view and identify the small and large subunit and tRNA binding sites of the ribosome.
* Outline the structure of tRNA molecules.
* Use molecular visualization software to view and identify the anticodon and amino acid binding site of a tRNA.

**S2 Identification of polysomes in electron micrographs of prokaryotes and eukaryotes.**

* Outline the structure of a polysome.
* Identify the beginning of an mRNA strand in a micrograph of polysomes.

**NOS Developments in scientific research follow improvements in computing- the use of commuters has enabled scientists to make advances in bioinformatics applications such as locating genes within genomes and identifying conserved sequences.**

* Define bioinformatics.
* Outline why computers are necessary for genome analysis.
* List seven species for which the entire genome has been sequenced.

## 2.8 Cell Respiration

**U1 Cell respiration is the controlled release of energy from organic compounds to produce ATP.**

* ​Define “cell respiration.”
* State the reaction for cellular respiration.
* State the types of organic compounds used in cellular respiration by animals and plants.

**U2 ATP from cell respiration is immediately available as a source of energy in the cell.**

* State three example uses of cellular energy.
* Outline energy transfer in the formation and use of ATP.
* State three reasons why cellular respiration must be continuously performed by all cells.

**U3 Anaerobic cell respiration gives a small yield of ATP from glucose.**

* ​Define “anaerobic respiration”
* List three situations in which anaerobic respiration is useful.
* Compare anaerobic respiration in yeasts and humans.

**U4 Aerobic cell respiration requires oxygen and gives a large yield of ATP from glucose.**

* Compare the total amount of ATP made from anaerobic and aerobic respiration.
* ​State the location of aerobic respiration.

**A1 Use of anaerobic cell respiration in yeasts to produce ethanol and carbon dioxide in baking.​**

* Outline how anaerobic respiration in yeast is used in baking.
* Outline how anaerobic respiration in yeast is used in ethanol production.

**A2 Lactate production in humans when anaerobic respiration is used to maximize the power of muscle contractions.**

* State the condition in which humans would perform anaerobic respiration.
* ​Outline production of lactate in humans during anaerobic respiration.

**S1 Analysis of results from experiments involving measurement of respiration rates in germinating seeds or invertebrates using a respirometer.**

* Outline the use of a respirometer to measure cellular respiration rate.

## 2.9 Photosynthesis

**U1 Photosynthesis is the production of carbon compounds in cells using light energy.**

* Define photosynthesis.
* State the chemical equation for photosynthesis.

**U2 Visible light has a range of wavelengths with violet the shortest wavelength and red the longest.**

* Define visible light.
* State the relationship between wavelength and energy.
* State the range of wavelengths that fall within the visible spectrum.

**U3 Chlorophyll absorbs red and blue light most effectively and reflects green light more than other colours.**

* Define pigment.
* State the primary and accessory pigments found in chloroplasts.
* Explain why plants are green.

**U4 Oxygen is produced in photosynthesis from the photolysis of water.**

* Define photolysis.
* State the equation for photolysis.
* State that the oxygen produced in photolysis is a waste product of photosynthesis.

**U5 Energy is needed to produce carbohydrates and other carbon compounds from carbon dioxide.**

* State the energy conversion that occurs during photosynthesis.

**U6 Temperature, light intensity and carbon dioxide concentration are possible limiting factors on the rate photosynthesis.**

* Define “limiting factor.”
* Explain how the following factors limit the rate of photosynthesis:
  + Temperature
  + Light intensity
  + CO2 concentration

**A1 Changes to the Earth’s atmosphere, oceans and rock deposition due to photosynthesis.**

* State that (some) prokaryotes, algae and plants carry out photosynthesis.
* Define and state evidence for the “Great Oxidation Event.”

**S1 Drawing an absorption spectrum for chlorophyll and an action spectrum for photosynthesis.**

* Distinguish between an action spectrum and an absorption spectrum.
* Describe the shape of the curve for an absorption spectrum.
* Describe the shape of the curve for an action spectrum.

**S2 Design an experiment to investigate limiting factors on photosynthesis.**

* ​List mechanism for measuring the rate of photosynthesis.

**S3 Separation of photosynthetic pigments by chromatograph.**

* Outline the process of separating pigments using chromatography
* Calculate the Rf value for pigments using pigment chromatography.

### Topic 8: Metabolism, cell respiration and photosynthesis (AHL) [We did not address this in class, but if you plan on taking the HL exam you need to know this]

#### 8.1 Metabolism

**U1 Metabolic pathways consist of chains and cycles of enzyme-catalyzed reactions.**

* Contrast metabolic chain reaction pathways with cyclical reaction pathways.

**U2 Enzymes lower the activation energy of the chemical reactions that they catalyze.**

* Define activation energy.
* Explain the role of enzymes in lowering the activation energy of a reaction.

**U3 Enzyme inhibitors can be competitive or non-competitive.**

* Define enzyme inhibitor.
* Contrast competitive and noncompetitive enzyme inhibition.
* Outline one example of a competitive enzyme inhibitor and one example of a noncompetitive enzyme inhibitor.

**U4 Metabolic pathways can be controlled by end-product inhibition.**

* Describe allosteric regulation of enzyme activity.
* Outline the mechanism and benefit of end-product inhibition.

**A1 End-product inhibition of the pathway that converts threonine is isoleucine.**

* Illustrate end-product inhibition of the threonine to isoleucine metabolic pathway.
* State the consequence of an increase in isoleucine concentration.

**A2 Use of databases to identify potential new anti-malarial drugs.**

* Outline the reasons for development of new anti-malarial drugs.
* Explain the use of databases in identification of potential new anti-malarial drugs.

**S1 Distinguish different types of inhibition from graphs at specified substrate concentration.**

* Explain why the rate of reaction with increasing substrate concentration is lower with a non-competitive inhibitor compared to a competitive inhibitor.

**S2 Calculating and plotting rates of reaction from raw experimental results.**

* State two methods for determining the rate of enzyme controlled reactions.
* State the unit for enzyme reaction rate.
* Given data, calculate and graph the rate of an enzyme catalyzed reaction.

**NOS Developments in scientific research follow improvements in computing- developments in bioinformatics, such as the interrogation of databases have facilitated research into metabolic pathways.**

* Outline the use and benefits of the bioinformatics technique of chemogenomics in development of new pharmaceutical drugs.

#### 8.2 Cell Respiration

**U1 Cell respiration involves the oxidation and reduction of electron carriers.**

* Outline oxidation and reduction reactions in terms of movement of electrons, hydrogen or oxygen atoms.
* Define “electron carrier.”
* State the name of the electron carrier molecule used in cellular respiration.

**U2 Phosphorylation of molecules makes them less stable.**

* Define phosphorylation.
* State the consequence of a molecule being phosphorylated.

**U3 In glycolysis, glucose is converted to pyruvate in the cytoplasm.**

* Outline the glycolysis reaction, including phosphorylation, lysis and energy harvest.

**U4 Glycolysis gives a small net gain of ATP without the use of oxygen.**

* State the formula for the glycolysis reaction.
* State that glycolysis occurs in both anaerobic and aerobic respiration.
* State that glycolysis is an example of a metabolic pathway.

**U5 In aerobic cell respiration pyruvate is decarboxylated and oxidized, and converted into acetyl compound and attached to coenzyme A to form acetyl coenzyme A in the link reaction.**

* Define decarboxylation and oxidation.
* ​Summarize the reactant and products of the link reaction.

**U6 In the Krebs cycle, the oxidation of acetyl groups is coupled to the reduction of hydrogen carriers, liberating carbon dioxide.**

* State that NADH and FADH2 are electron carriers formed during the Krebs cycle.
* Outline the events of the Krebs cycle, referencing the formation of NADH and FADH2, formation of ATP and decarboxylation of acetyl groups.

**U7 Energy released by oxidation reactions is carried to the cristae of the mitochondria by reduced NAD and FAD.**

* State that NAD+ is reduced to become NADH in the link reaction and Krebs cycle.
* State that FAD is reduced to become FADH2 in the Krebs cycle.
* State that NADH and FADH2 carry electrons to the electron transport chain on the mitochondrial inner membrane.

**U8 Transfer of the electrons between carriers in the electron transport chain in the membrane of the cristae is coupled to proton pumping.**

* State that at the electron transport chain, FADH2 and NADH given electrons to electron carrier proteins.
* State that the movement of electrons through electron carrier proteins in the electron transport chain is used to pump protons (H+) across the inner mitochondrial membrane into the intermembrane space.

**U9 In chemiosmosis protons diffuse through ATP synthase to generate ATP.**

* Define oxidative phosphorylation and chemiosmosis.

**U10 Oxygen is needed to bind with the free protons to maintain the hydrogen gradient, resulting in the formation of water.**

* ​State that oxygen is the final electron acceptor in aerobic cellular respiration.
* State that that formation of water in the matrix at the end of the electron transport chain helps to maintain the hydrogen gradient between the intermembrane space and the matrix.

**U11 The structure of the mitochondrion is adapted to the function it performs.**

* Outline how mitochondria structure could evolve through natural selection.
* State evidence that suggests mitochondria were once free living prokaryotes.

**A1 Electron tomography used to produce images of active mitochondria.**

* State that electron tomography enables scientists to view the dynamic nature of mitochondrial membranes.

**S1 Analysis of diagrams of the pathways of aerobic respiration to decide where decarboxylation and oxidation reactions occur.**

* State that decarboxylation of glucose occurs in the linking reaction and Krebs cycle of aerobic respiration.

**S2 Annotations of a diagram of mitochondrion to indicate the adaptations to its function.**

* Draw and label a diagram of the mitochondria.
* State the function of the following mitochondrial structures: outer membrane, inner membrane, cristae, intermembrane space, matrix, ribosome and mtDNA.

**NOS Paradigm shift-chemiosmotic theory led to a paradigm shift in the field of bioenergetics.**

* State that Peter Mitchell’s proposal of the chemiosmotic hypothesis in 1961 lead to a major shift in our understanding of cellular processes.

#### 8.3 Photosynthesis

**U1 Light-dependent reactions take place in the intermembrane space of the thylakoids.**

* State the location of the light dependent reactions of photosynthesis.
* State that the light dependent reactions of photosynthesis include:
  + Photoactivation
  + Photolysis
  + Electron transport
  + Chemiosmosis
  + ATP synthesis
  + ​Reduction of NADP to NADPH + H+

**U2 Light –independent reactions take place in the stroma.**

* State that the light dependent reactions convert light energy into chemical energy in the form of ATP and NADH.

**U3 Reduced NADP and ATP are produced in the light-dependent reactions.**

* State the location of the light independent reactions of photosynthesis.
* State that the light independent reactions of photosynthesis include:
  + Carbon fixation
  + Carboxylation of RuBP
  + Production of triosphosphate
  + ATP and NADPH as energy sources
  + ATP used to regenerate RuBP
  + ATP used to produce carbohydrates​

**U4 Absorption of light by photosystems generates excited electrons.**

* Define photosystem and reaction center.
* State that the light dependent reactions of photosynthesis begin at Photosystem II.
* Outline process of photoactivation of the reaction center chlorophyll.
* State that in photoactivation at Photosystem II, the reaction center chlorophyll is oxidized and the plastoquinone (Pq) is reduced.

**U5 Photolysis of water generates electrons for use in the light-independent reactions.**

* State that to replace the electrons lost during photoactivation, the reaction center chlorophyll takes electrons by splitting water.

**U6 Transfer of excited electrons occurs between carriers in thylakoid membranes.**

* Draw a cross section of the thylakoid membrane to show the path of transfer of excited electrons, inclusive of Photosystem II, ATP synthase, an electron transport chain (with Pq first) and Photosystem II.

**U7 Excited electrons from Photosytem II are used to contribute to generate a proton gradient.**

* State that electrons pass from plastoquinone (Pq) through a chain of electron carrier molecules.
* State that the energy released by the movement of electrons is used to pump protons across the thylakoid membrane, from the stroma into the thylakoid lumen.
* State that the result of the electron transport chain is a proton gradient, with a high concentration of protons in the thylakoid lumen.

**U8 ATP synthase in thylakoids generates ATP using the proton gradient.**

* State that in chemiosmosis, ATP is generated as protons move down their concentration gradient through ATP synthase.

**U9 Excited electrons from Photosytem I are used to reduce NADP.**

* State that photoactivation of the reaction center chlorophyll in photosystem I excites electrons which pass through a different electron transport chain.
* State that the electrons of Photosystem I are used to reduce NADP+ to form NADPH.
* State that NADPH is an electron carrier molecule.
* State that the electrons from the Photosystem II electron transport chain are used to replace the electrons lost during photoactivation of Photosystem I.

**U10 In the light-independent reaction a carboxylase catalyzes the carboxylation of ribulose-bisphosphate.**

* Define carbon fixation and carboxylation.
* State that carbon fixation occurs in the chloroplast stroma.
* State that the 5-carbon molecule ribulose bisphosphate (RuBP) is carboxylated by CO2, forming 2 3-carbon molecules called glycerate-3-phosphate (G3P).
* State that the enzyme that catalyzes the carboxylation of RuBP is called ribulose bisphosphate carboxylase (rubisco).

**U11 Glycerate 3-phosphate is reduced to triose phosphate using a reduced NADP and ATP.**

* State that ATP (from the light dependent reaction) provides the energy for NADPH (from the light dependent reaction) to reduce G3P, forming a three carbon carbohydrate, triose phosphate.

**U12 Triose phosphate is used to regenerate RuBP and produce carbohydrates.**

* State that in the Calvin Cycle, triose phosphate is used to regenerate RuBP and create glucose.
* State that six turns of the Calvin Cycle are needs to produce one molecule of glucose.

**U13 Ribulose bisphosphate is reformed using ATP.**

* State that ATP is used to regenerate RuBP from triose phosphate.

**U14 The structure of the chloroplast is adapted to its function in photosynthesis.**

* Outline how chloroplast structure could evolve through natural selection.
* State evidence that suggests chloroplast were once free living prokaryotes.

**A1 Calvin’s experiment to elucidate the carboxylation of RuBP.**

* Outline Calvin’s “lollipop” experiment, including the role of:
  + Radioactive carbon-14
  + Green algae
  + Air with CO2
  + Light
  + Varying the time of light exposure
  + Heated alcohol
  + Chromatography
  + Autoradiography

**S1 Annotation of a diagram to indicate the adaptations of a chloroplast to its function.**

* Draw and label a diagram of the chloroplast.
* State the function of the following chloroplast structures: double membrane, thylakoids, pigment molecules, thylakoid lumen, and stroma.

**NOS Developments in scientific research follow improvements in apparatus- sources of 14C and autoradiography enabled Calvin to elucidate the pathways of carbon fixation.**

* State that the discovery of the radioactive 14C isotope allowed Calvin to determine the pathway of the light independent reactions of photosynthesis.

# Topic 3: Genetics

## 3.1 Genes

**U1 A gene is a heritable factor that consists of a length of DNA and influences a specific characteristic.**

* Define gene.

**U2 A gene occupies a specific position on a chromosome.**

* Define gene locus.

**U3 The various specific forms of a gene are alleles.**

* Define allele.
* List two examples of genes with multiple alleles.
* State a similarity between alleles of the same gene.

**U4 Alleles differ from each other by one or only a few bases.**

* State the difference between alleles of the same gene.

**U5 New alleles are formed by mutation.**

* State the source of new alleles of a gene.
* Describe a base substitution mutation.

**U6 The genome is the whole of the genetic information of an organism.**

* Define genome.
* State the size in base pairs of the human genome.

**U7 The entire base sequence of human genes was sequenced in the Human Genome Project.**

* Define “sequence” in relation to genes and/or genomes.
* State the aim of the Human Genome Project.
* Outline two outcomes of the Human Genome Project.

**A1 The causes of sickle cell anemia, including a base substitution mutation, a change to the base sequence of mRNA transcribed from it and a change to the sequence of a polypeptide in hemoglobin.**

* State the cause of sickle cell anemia, including the name of differences in the Hb alleles.
* State the difference in amino acid sequences in transcription of normal and mutated Hb mRNA.Outline the consequences of the Hb mutation on the impacted individual.

**A2 Comparison of the number of genes in humans with other species.**

* State the number of genes in the human genome.
* Describe the relationship between the number of genes in a species and the species complexity in structure, physiology and behavior.

**S1 Use of a database to determine differences in the base sequence of a gene in two species.**

* Explain why cytochrome oxidase 1 is often used to assess the differences in the base sequences of a gene between two species.
* Use NCBI to search for COX1 sequences for different species.
* Use a computer software tool to create an alignment of the gene sequences between different species.
* Outline information that can be determined given gene sequence alignment data.

**NOS Developments in scientific research follow improvements in technology-gene sequencers are used for the sequencing of genes.**

* Outline the technological improvements that have sped the DNA sequencing process.
* Determine a DNA sequence from an electropherogram.

## 3.2 Chromosomes

**U1 Prokaryotes have one chromosome consisting of a circular DNA molecule.**

* Describe the structure and function of nucleoid DNA.​
* Define the term “naked” in relation to prokaryotic DNA.​
* Compare the genetic material of prokaryotes and eukaryotes.

**U2 Some prokaryotes also have plasmids but eukaryotes do not.**

* Describe the structure and function of plasmid DNA.

**U3 Eukaryote chromosomes are linear DNA molecules associated with histone proteins.**

* Describe the structure of eukaryotic DNA and associated histone proteins during interphase (chromatin).
* Explain why chromatin DNA in interphase is said to look like “beads on a string.”

**U4 In a eukaryote species there are different chromosomes that carry different genes.**

* List three ways in which the types of chromosomes within a single cell are different.
* State the number of nuclear chromosome types in a human cell.​

**U5 Homologous chromosomes carry the same sequence of genes but not necessarily the same alleles of those genes.**

* Define homologous chromosome.
* State a similarity and a difference found between pairs of homologous chromosomes.

**U6 Diploid nuclei have pairs of homologous chromosomes.**

* Define diploid.
* State the human cell diploid number.
* Outline the formation of a diploid cell from two haploid gametes.
* State an advantage of being diploid.

**U7 Haploid nuclei have one chromosomes of each pair.**

* Define haploid.
* State the human cell haploid number.
* List example haploid cells.

**U8 The number of chromosomes is a characteristic feature of member of a species.**

* State that chromosome number and type is a distinguishing characteristic of a species.
* List mechanisms by which a species chromosome number can change.

**U9 A karyogram shows the chromosomes of an organism in homologous pairs of decreasing length.**

* Describe the process of creating a karyogram.
* List the characteristics by which chromosomes are arranged on the karyogram.

**U10 Sex is determined by sex chromosomes and autosomes are chromosomes that do not determine sex.**

* Outline the structure and function of the two human sex chromosomes.
* Outline sex determination by sex chromosomes.

**A1 Cairns’ technique for measuring the length of DNA by autoradiography.**

* Describe Cairn’s technique for producing images of DNA molecules from E. coli.
* Outline conclusions drawn from the images produced using Cairn’s autoradiography technique. ​​

**A2 Comparison of genome size in T2 phage, *Escherichia coli, Drosophila melanogaster, Homo sapiens, Paris japonica.***

* Describe the relationship between the genome size of a species and the species complexity in structure, physiology and behavior.

**A3 Comparison of diploid chromosome numbers of *Homo sapiens, Pan troglodytes, Canis familiaris, Oryza sativa, Parascarsis equorum.***

* State the minimum chromosome number in eukaryotes.
* Explain why the typical number of chromosomes in a species is always an even number.
* Explain why the chromosome number of a species does not indicate the number of genes in the species.
* Explain the relationship between the number of human and chimpanzee chromosomes.

**A4 Use karyograms to deduce sex and diagnose Down Syndrome in humans.**

* Distinguish between a karyogram and a karyotype.
* Deduce the sex of an individual given a karyogram.
* Describe the use of a karyogram to diagnose Down syndrome.

**S1 Use of databases to identify the focus of a human gene and its polypeptide product.**

* Search NCBI or OMIM for a given gene.
* Determine the gene locus, abbreviated gene name, and description of the gene.

## 3.3 Meiosis

**U1 One of diploid nucleus divides by meiosis to produce four haploid nuclei.**

* Compare divisions of meiosis I and meiosis II.

**U2 The halving of the chromosomes number allows a sexual life cycle with fusion of gametes.**

* Compare sexual and asexual life cycles.
* Explain why meiosis must occur as part of a sexual life cycle.

**U3 DNA is replicated before meiosis so that all chromosomes consist of two sister chromatids.**

* State that DNA is replicated in interphase before meiosis.
* Given a diploid number (for example 2n=4), outline the movement and structure of DNA through the stages of meiosis.

**U4 The early stages of meiosis involves pairing of homologous chromosomes and crossing over followed by condensation.**

* ​List three events that occur in prophase 1 of meiosis.
* Define bivalent and synapsis.
* Outline the process and result of crossing over.

**U5 Orientation of pairs of homologous chromosomes prior to separation is random.**

* Describe the attachment of spindle microtubules to chromosomes during meiosis I.
* Describe random orientation of chromosomes during meiosis I.

**U6 Separation of pairs of homologous chromosomes in the first division of meiosis halves the chromosome number.**

* Explain why meiosis I is a reductive division.
* State that cells are haploid at the end of meiosis I.

**U7 Crossing over and random orientation promotes genetic variation.**

* Explain how meiosis leads to genetic variation in gametes.
* State the the number of chromosome combinations possible due to random orientation is 2^n.

**U8 Fusion of gametes from different parents promotes genetic variation.**

* Outline the role of fertilization as a source of genetic variation.

**A1 Non-disjunction can cause Down syndrome and other chromosome abnormalities. Studies showing age of parents influences chances of non-disjunction.**

* Define non-disjunction.
* State the result of nondisjunction.
* Describe the cause and symptoms of Down syndrome.
* Explain the relationship between parental age and chances of non-disjunction.

**A2 Description of methods used to obtain cells for karyotype analysis e.g. chorionic villus sampling and amniocentesis and the associated risks.**

* Describe the two procedures for obtaining fetal cells for production of a karyotype.

**S1 Drawing diagrams to show the stages of meiosis resulting in the formation of four haploid cells.**

* Outline the events of prophase, metaphase, anaphase and telophase in meiosis I and meiosis II.
* Draw diagrams of cells in prophase, metaphase, anaphase and telophase in meiosis I and meiosis II.

## 3.4 Inheritance

**U1 Mendel discovered the principles of inheritance with experiments in which large numbers of pea plants were crossed.**

* Describe Mendel’s pea plant experiments.

**U2 Gametes are haploid so contain only one allele of each gene.**

* Define gamete and zygote.
* State two similarities and two differences between male and female gametes

**U3 The alleles of each gene separate into different haploid daughter nuclei during meiosis.**

* State the outcome of allele segregation during meiosis.

**U4 Fusion of gametes results in diploid zygotes with two alleles of each gene that may be the same allele or different alleles.**

* Outline the possible combination of alleles in a diploid zygote for a gene with two alleles.
* Outline the possible combination of alleles in a diploid zygote for a gene with three alleles.

**U5 Dominant alleles mask the effect of recessive alleles but co-dominant alleles have joint effects.**

* Define dominant allele and recessive allele.
* State an example of a dominant and recessive allele found in pea plants.
* State the usual cause of one allele being dominant over another.
* Define codominant alleles.
* Using the correct notation, outline an example of codominant alleles.

**U6 Many genetic diseases in human are due to recessive alleles of autosomal genes.**

* Define “carrier” as related to genetic diseases.
* Explain why genetic diseases usually appear unexpectedly in a population.

**U7 Some genetic diseases are sex-linked and some are due to dominant or co-dominant alleles.**

* Describe why it is not possible to be a carrier of a disease caused by a dominant allele.
* Outline inheritance patterns of genetic diseases caused by dominant alleles.
* Explain sickle cell anemia as an example of a genetic disease caused by codominant alleles.
* Define sex linkage.

**U8 The pattern of inheritance is different with sex-linked genes due to to their location on sex chromosomes.**

* Outline Thomas Morgan’s elucidation of sex linked genes with Drosophila.
* Use correct notation for sex linked genes.
* Describe the pattern of inheritance for sex linked genes.
* Construct Punnett grids for sex linked crosses to predict the offspring genotype and phenotype ratios.

**U9 Many genetic diseases have been identified in humans but most are very rare.**

* List five example genetic diseases.
* Explain why most genetic diseases are rare in a population.

**U10 Radiation and mutagenic chemicals increase the mutation rate and can cause genetic diseases and cancer.**

* State two factors that can increase the mutation rate.
* Outline the effects of gene mutations in body cells and gamete cells.

**A1 Inheritance of ABO blood groups.**

* Describe ABO blood groups as an example of complete dominance and codominance.
* Outline the differences in glycoproteins present in people with different blood types.

**A2 Red-green color blindness and hemophilia as examples of sex-linked inheritance.**

* Describe the cause and effect of red-green color blindness.
* Explain inheritance patterns of red-green color blindness.
* Describe the cause and effect of hemophilia.
* Explain inheritance patterns of hemophilia.

**A3 Inheritance of cystic fibrosis and Huntington’s disease.**

* Describe the relationship between the genetic cause of cystic fibrosis and the symptoms of the disease.
* Outline the inheritance pattern of cystic fibrosis.
* Outline the inheritance pattern of Huntington’s disease.
* List effects of Huntington’s disease on an affected individual.

**A4 Consequences of radiation after nuclear bombing of Hiroshima and accident at Chernobyl.**

* Outline the effects of radiation exposure after nuclear exposure at Hiroshima and Chernobyl.

**S1 Construction of Punnett grids for predicting the outcomes of monohybrid genetic crosses.**

* Define monohybrid, true breeding, hybrid, F1 and F2.
* Determine possible alleles present in gametes given parent genotypes.
* Construct Punnett grids for single gene crosses to predict the offspring genotype and phenotype ratios.

**S2 Comparison of predicted and actual outcomes of genetic crosses using real data.**

* Explain the reason why the outcomes of genetic crosses do not usually correspond exactly with the predicted outcomes.
* Describe the role of statistical tests in deciding whether an actual result is a close fit to a predicted result.

**S3 Analysis of pedigree charts to deduce the pattern of inheritance of genetic diseases.**

* Outline the conventions for constructing pedigree charts.
* Deduce inheritance patterns given a pedigree chart.

## 3.5 Genetic Modification and Biotechnology

**U1 Gel electrophoresis is used to separate proteins or fragments of DNA according to size.**

* Match restriction enzyme names to the bacteria in which they are naturally found.
* Describe the role of restriction enzymes in nature and in biotechnology applications.
* Contrast sticky vs. blunt ends.
* Identify a restriction site as either leaving sticky or blunt ends.
* Demonstrate accurate use of a micro-pipette.
* Determine the number and size of DNA fragments after being exposed to restriction enzymes (both linear and plasmid DNA).
* Explain the function and purpose of DNA electrophoresis.
* Describe how and why DNA fragments separate during electrophoresis.
* Outline the functions of the buffer, marker and loading dye in DNA electrophoresis.

**U2 PCR can be used to amplify small amounts of DNA.**

* State the function of the PCR.
* Describe the selectivity of the PCR.

**U3 DNA profiling involves comparison of DNA.**

* Outline the process of DNA profiling.

**U4 Genetic modification is carried out by gene transfer between species.**

* Outline how the universality of the genetic code allows for gene transfer between species.

**U5 Clones are groups of genetically identical organisms, derived from a single original parent cell.**

* Contrast sexual and asexual reproduction.
* Define clone and cloning.
* Describe different ways in which natural clones can arise.

**U6 Many plants species and some animal species have natural methods of cloning.**

* Define clone.
* Outline two examples of natural cloning in plants.

**U7 Animals can be cloned at the embryo stage by breaking up the embryo into more than one group of cells.**

* Describe the process of reproductive cloning via embryo splitting.
* Outline example of cloning animal embryos via natural and artificial embryo splitting.

**U8 Methods have been developed for cloning adult animals using differentiated cells.**

* Describe the process of reproductive cloning via somatic cell nuclear transfer.
* ​Outline the production of Dolly the sheep using somatic cell nuclear transfer.​​

**A1 Use of DNA profiling in paternity and forensic investigations.**

* List example sources of DNA that can be used in DNA profiling.

**A2 Gene transfer in bacteria using plasmids makes use of restriction endonucleases and DNA ligases.**

* Describe a technique for genetic modification including plasmids, restriction enzymes, reverse transcriptase and ligase.
* Outline why plasmids with genes coding for antibiotic resistance are chosen as vectors in gene transfer between species.

**A3 Assessment of potential risks and benefits associated with genetic modification of crops.**

* Outline potential environmental, health and agricultural benefits and risks associated with genetic modification of crops.
* Assess the risks and benefits of an example of a genetically modified crop (i.e. golden rice).

**A4 Production of clones embryos produced by somatic-cell nuclear transfer.**

* Compare therapeutic cloning to reproductive cloning.
* Outline the production of embryos via somatic cell nuclear transfer.

**S1 Design of an experiment to assess one factor affecting the rooting of stem-cuttings.**

* Outline preparation of a plant for rooting of a stem cutting.
* List manipulated, responding and controlled variables in an experiment of rooting stem-cuttings.

**S2 Analysis of examples of DNA profiles.**

* Analyze a DNA profile to determine relatedness or forensic guilt.

**S3 Analysis of data on risks to monarch butterflies of Bt crops.**

* Outline the formation and use of Bt crops in agriculture.
* Assess the impact of Bt corn on monarch butterflies.

**NOS Assessing risks associated with scientific research- scientists attempt to assess the risks associated with genetically modified crops or livestock.**

* State two ways in which the risk of scientific research can be assessed.

### Topic 10: Genetics and Evolution (AHL)

#### 10.1 Meiosis

**U1 Chromosomes replicate in interphase before meiosis.**

* Identify tetrad, bivalent, sister chromatids and non-sister chromatids in diagrams of replicated chromosomes.

**U2 Crossing over is the exchange of DNA material between non-sister homologous chromatids.**

* State that crossing over occurs during prophase I.
* Define chiasmata.

**U3 Crossing over produces new combinations of alleles on the chromosomes of the haploid cells.**

* State two consequences of chiasmata formation between non-sister chromatids.

**U4 Chiasmata formation between non-sister chromatids can results in an exchange of alleles.**

* Draw a diagram to illustrate the formation of new allele combinations as a results of crossing over.
* Explain how crossing over between linked genes can lead to genetic recombinants.

**U5 Homologous chromosomes separate in meiosis I.**

* Contrast meiosis I with meiosis II.

**U6 Independent assortment of genes in due to random orientation of homologous chromosomes pairs in meiosis I.**

* Describe random orientation and independent assortment.
* Given a parent cell genotype, determine the allele combinations that are possible in the gametes due to independent assortment and random orientation.

**U7 Sister chromatids separate in meiosis II.**

* Compare meiosis II with mitosis.

**S1 Drawing diagrams to show chiasmata formed by crossing over.**

* Draw a diagram to illustrate the process and result of crossing over.

**NOS Making careful observations- careful observations and record keeping turned up anomalous data that Mendel’s law of independent assortment could not account for. Thomas Hunt Morgan developed the notion of linked genes to account for the anomalies.**

* Describe the experiment of Bateson and Punnett that lead to results that did not support Mendel’s law of independent assortment.
* Describe the trends and discrepancies that led Morgan to propose the idea of linked genes.

#### 10.2 Inheritance

**U1 Unlinked genes segregate independently as a result of meiosis.**

* State the difference between independent assortment of genes and segregation of alleles.
* Describe segregation of alleles and independent assortment of unlinked genes in meiosis.

**U2 Gene loci are said to be linked if on the same chromosome.**

* Define autosome and sex chromosome.
* Describe what makes genes “linked.”

**U3 Variations can be discrete or continuous.​**

* Contrast discrete with continuous variation.
* State an example of a discrete variation,
* State an example of a continuous variation.

**U4 The phenotypes of polygenic characteristics tend to show continuous variation.**

* Explain polygenetic inheritance using an example of a two gene cross with codominant alleles.
* Outline the use of Pascal’s triangle to determine phenotype frequencies that results from polygenic crosses.
* State that a normal distribution of variation is often the result of polygenic inheritance.
* State example human characteristics that are associated with polygenic inheritance.

**U5 Chi-squared tests are used to determine whether the difference between an observed and expected frequency distribution is statistically significant.**

* State the two possible hypotheses of a statistical test.
* Calculate the chi square value to determine the significance of differences between the observed and expected results of a genetic cross.
* Determine the degrees of freedom and critical value for the chi-square test.
* Draw a conclusion of significance by comparing the calculated and critical chi-square values.

**A1 Completion and analysis of Punnett squares for dihybrid traits.**

* Determine possible allele combinations in gametes for crosses involving two genes.
* Use correct notation to depict a dihybrid cross between two unlinked genes.
* Construct a Punnett square to show the possible genotype and phenotype outcomes in a dihybrid cross.

**A2 Morgans’s discovery of non-Mendellian ratios in Drosophilia.**

* Describe how Morgan discovered relationship between eye color and sex in Drosophila.

**A3 Polygenic traits such as human height may be influenced by environmental factors.**

* Outline two example environmental factors that can influence phenotypes.
* Compare continuous to discrete variation.

**S1 Calculation of the predicted genotypic and phenotypic ratio of offspring of dihybrid crosses involving unlinked autosomal genes.**

* Determine the predicted genotype and phenotype ratios of F1 and F2 offspring of dihybrid crosses.

**S2 Identification of recombinants in crosses involving two linked genes.**

* Use correct notation to show alleles of linked genes.
* Construct a Punnett square to show the possible genotype and phenotype outcomes in a dihybrid cross involving linked genes.
* Explain how crossing over between linked genes can lead to genetic recombinants.

**S3 Use of chi-squared test on data from dihybrid crosses.**

* Calculate a chi-square value to compare observed and expected results of a dihybrid genetic cross.
* Using the df and critical chi-square value, determine if there is a significant difference between observed and expected results of a dihybrid cross.

**NOS Looking for patterns, trends and discrepancies- Mendel used observations of the natural world to find and explain patterns and tends, Since then, scientists have looked for discrepancies and asked questions based on further observations to show exceptions to the rules. For example, Morgan discovered non-Mendellian ratios in his experiments with Drosophilia.**

* Describe the trends and discrepancies that led Morgan to propose the idea of linked genes.

#### 10.3 Gene Pools and Speciation

**U1 A gene pool consists of all the genes, and their different alleles, present in an interbreeding population.​**

* Define gene pool.
* Given data, calculate allele frequencies of genes in a gene pool.
* Given data, calculate genotype frequencies for genes in a gene pool.

**U2 Evolution required that allele frequencies change with time in populations.**

* Define evolution.
* Outline five factors that can cause evolutionary change.

**U3 Reproductive isolation of populations can be temporal, behavioral or geographic.**

* Compare allopatric and sympatric speciation.
* Define reproductive isolation.
* Explain temporal, behavioral and geographic isolation as mechanisms of speciation.
* Describe an example of temporal, behavioral and geographic reproductive isolation.
* Define speciation.

**U4 Speciation due to divergence of isolated populations can be gradual.**

* Outline a limitation of the idea of evolution through gradualism.
* Identify gradualism from graphs of morphology changes over time.
* Define gradualism.

**U5 Speciation can occur abruptly.**

* Define punctuated equilibrium.
* Outline a possible cause of rapid speciation events.
* Identify punctuated equilibrium from graphs of morphology changes over time.

**A1 Identifying examples of directional, stabilizing and disruptive selection.**

* Define stabilizing, disruptive and directional selection.
* Use graphs to illustrate or identify stabilizing, disruptive and directional selection.

**A2 Speciation in the genus Allium by polyploidy.**

* Outline how polyploidy has led to many species of Allium.
* List example species in the genus Allium (by common name)

**S1 Comparison of allele frequencies of geographically isolated populations.​**

* Compare allele frequencies of two populations.
* Describe how variations in the allele frequencies of a gene may be evidence of speciation.

**NOS Looking for patterns, trends and discrepancies- patterns of chromosome number in some genera can be explained by speciation due to polyploidy.​**

* Define polyploidy.
* Outline causes of polyploidy.
* Explain how polyploidy can lead to speciation.

# Topic 4: Ecology

## 4.1 Species, Communities, Ecosystems

**U1 Species are groups of organisms that can potentially interbreed to produce fertile offspring.**

* Describe limitations of the biological species concept.
* Define species according to the biological species concept.

**U2 Members of a species may be reproductively isolated in separate populations.**

* Define population.
* Outline how reproductive isolation can lead to speciation.

**U3 Species have either an autotrophic or heterotrophic method of nutrition (a few species have both methods).**

* Define autotroph and heterotroph.

**U4 Consumers are heterotrophs that feed on living organisms by ingestion.**

* Describe the feeding behaviors of consumers.
* List three example consumer organisms.​

**U5 Detrivores are heterotrophs that obtain organic nutrients from detritus by internal digestion.**

* Describe the feeding behaviors of detritivores.
* List two example detritivore organisms.

**U6 Saprotrophs are heterotrophs that obtain organic nutrients from dead organisms by external digestion.​**

* Describe the feeding behaviors of saprotrophs.
* List two example saprotroph organisms.

**U7 A community is formed by populations of different species living together and interacting with each other.​**

* Define species, population and community.
* Give an example of a community of organisms.

**U8 A community forms an ecosystem by its interactions with the abiotic environment.**

* Define abiotic and ecosystem.

**U9 Autotrophs obtain inorganic nutrients from the abiotic environment.**

* Define nutrient.
* List the common nutrients needed by organisms.
* Outline how nutrients enter living systems.

**U10 The supply of inorganic nutrients is maintained by nutrient recycling.**

* State that chemical elements can be recycled but energy can not.
* Outline the generalized flow of nutrients between the abiotic and biotic components of an ecosystem.

**U11 Ecosystems have the potential to be sustainable over long periods of time.**

* Define sustainability.​
* Give an example of an unsustainable practice.
* Outline three requirements of a sustainable ecosystem.

**S1 Classifying species as autotrophs, consumers, detrivores or saprotrophs from a knowledge of their mode of nutrition.**

* Use a dichotomous key to identify the mode of nutrition of an organism.​

**S2 Testing for association between two species using the chi-squared test with data obtained from quadrat sampling.​**

* Outline why sampling must be random.
* Explain methods of random sampling, including the use of a quadrat.
* State the null and alternative hypothesis of the chi-square test of association.
* Use a contingency table to complete a chi-square test of association.

**S3 Recognizing and interpreting statistical significance.**

* Calculate a chi-square statistic based on observed and expected values.
* State the null and alternative hypothesis of statistical tests.
* Determine if the null hypothesis is supported or rejected given a critical value and a calculated statistic.
* State the minimum acceptable significance level (p value) in published research.
* Explain the meaning of a “statistically significant” result, including the probability of chance having a role in the result.

**S4 Setting up sealed mecocosms to try to establish sustainability.**

* Define mesocosm.
* List three example mesocosms.
* Outline requirements of setting up a mesocosm.

## 4.2 Energy Flow

**U1 Most ecosystems rely on a supply of energy from sunlight.**

* State how energy in carbon compounds enters most biological communities.
* List three groups of autotrophs.

**U2 Light energy is converted to chemical energy in carbon compounds by photosynthesis.**

* Outline how light energy is converted to chemical energy.​

**U3 Chemical energy in carbon compounds flows through food chains by means of feeding.**

* Define food chain and food web.
* State the meaning of the arrow in a food web or chain.
* Draw a food chain, labeling the producer, primary consumer, secondary consumer and tertiary consumer.

**U4 Energy released from carbon compounds by respiration is used in living organisms and converted to heat.**

* List three reasons why living organisms need energy for cell activities.
* State the function of ATP.
* Outline how ATP is formed, referencing exothermic and endothermic reactions.
* Outline the reason why respiration releases heat.

**U5 Living organisms cannot convert heat to other forms of energy.**

* Draw a flow chart to illustrate the energy conversions performed by living organisms.

**U6 Heat is lost from ecosystems.**

* State the reason why heat created by living organisms is eventually lost from the ecosystem.

**U7 Energy losses between trophic levels restrict the length of food chains and the biomass of higher trophic levels.**

* Define biomass.
* Define trophic level.
* State the unit used for communicating the energy in each trophic level of a food chain.
* Outline three reasons why the amount of energy decreases at higher trophic levels.
* State the average amount of energy passed through each trophic level of a food chain.

**S1 Quantitative representations of energy flow using pyramids of energy.**

* Describe the shape and units of a pyramid of energy.
* Draw a pyramid of energy given data for an ecosystem.​

**NOS Use theories to explain natural phenomena- the concepts of energy flow explains the limited length of food chains.**

* Explain why there is a limited number of organisms in a food chain.​

## 4.3 Carbon Cycling

**U1 Autotrophs convert carbon dioxide into carbohydrates and other carbon compounds.**

* State the role of photosynthesis in the carbon cycle.

**U2 In aquatic ecosystems carbon is present as dissolved carbon dioxide and hydrogen carbonate ions.**

* Outline the process that converts CO2 to hydrogen carbonate ion in water, leading to a reduction of the pH in the water.

**U3 Carbon dioxide diffuses from the atmosphere or water into autotrophs.**

* State that in diffusion, molecules move from an area of higher concentration to an area of lower concentration.

**U4 Carbon dioxide is produced by respiration and diffuses out of organisms into water or the atmosphere.**

* ​State that carbon dioxide is a waste product of aerobic cellular respiration.​
* State that carbon dioxide diffuses out of cells into the atmosphere or water.

**U5 Methane is produced from organic matter in anaerobic conditions by methanogenic archaeans and some diffuses into the atmosphere or accumulates in the ground.**

* Outline the role of methanogenic archaea in the transformation of organic material into methane.

**U6 Methane is oxidized to carbon dioxide and water in the atmosphere.**

* ​State that methane is oxidized to carbon dioxide in the atmosphere.

**U7 Peat forms when organic matter is not fully decomposed because of acidic and/or anaerobic conditions in waterlogged soils.**

* Define peat.
* Outline formation of peat.

**U8 Partially decomposed organic matter from past geological eras was converted either into coal or into oil and gas that accumulate in porous rocks.​**

* Outline formation of coal.
* Outline formation of oil and natural gas.

**U9 Carbon dioxide is produced by combustion of biomass and fossilized organic matter.**

* Define combustion.
* State the products of a combustion reaction.
* State sources of fuel for a combustion reaction. ​​

**U10 Animals such as reef-building corals and Mollusca have hard parts that are composed of calcium carbonate and can become fossilized in limestone.**

* State that hard shells, such as in mollusk and coral, are made of calcium carbonate.

**A1 Estimation of carbon fluxes due to processes in the carbon cycle.**

* List seven flux processes in the carbon cycle.
* State the unit of measure for carbon flux values. ​

**A2 Analysis of data from air monitoring stations to explain annual fluctuations.​**

* Sketch a graph of the annual fluctuation in atmospheric carbon dioxide concentration.
* Explain the annual fluctuation in atmospheric carbon dioxide concentration in the northern hemisphere.

**S1 Construct a diagram of the carbon cycle.**

* Draw a diagram of the terrestrial carbon cycle.
* Draw a diagram of the aquatic carbon cycle.
* Define pool and flux.

**NOS Making accurate, quantitative measurements-it is important to obtain reliable data on the concentrations of carbon dioxide and methane in the atmosphere.​**

* Explain why accurate measurements of CO2 and methane in the atmosphere are important.
* Outline how data on concentration of atmospheric CO2 and methane are collected.

## 4.4 Climate Change

**U1 Carbon dioxide and water vapor are the most significant greenhouse gases.​**

* State the sources of CO2 and water vapor in the atmosphere.
* Outline the mechanism by which greenhouse gases trap heat in the atmosphere.

**U2 Other gases including methane and nitrogen oxides have less impact.**

* State the sources of methane and NO gases in the atmosphere.

**U3 The impact of a gas depends on its ability to absorb long wave radiation as well as on its concentration in the atmosphere.**

* State two factors that determine the warming impact of a greenhouse gas.
* State two variables that determine the concentration of a gas in the atmosphere.
* Compare the impact of atmospheric methane to CO2.
* State how long water, methane and CO2 remain in the atmosphere, on average.

**U4 The warmed Earth emits longer wavelength radiation (heat).**

* State that the Earth absorbs short-wave energy from the sun and re-emits longer wavelengths.
* ​Compare wavelengths of UV, visible and infrared radiation.

**U5 Longer wave radiation is absorbed by greenhouse gases that retain the heat in the atmosphere.​**

* Explain the greenhouse effect, with reference to short wave radiation from the sun, long wave radiation from the Earth and the effects of ozone and greenhouse gases.
* Explain why water vapor, CO2, methane and NO are greenhouse gases.

**U6 Global temperatures and climate patterns are influenced by concentrations of greenhouse gases.​**

* Explain why atmospheric CO2 concentration would logically impact global temperatures.
* Outline the effect of global temperature on climate, specifically location and frequency of of rain and frequency of severe storms.

**U7 There is a correlation between rising atmospheric concentrations of carbon dioxide since the start of the industrial revolution 200 years ago and average global temperatures.**

* State the atmospheric CO2 concentration prior to the industrial revolution.
* Outline the impact of the industrial revolution on atmospheric CO2 concentration.
* ​Describe the correlation between atmospheric CO2 concentrations since the industrial revolution and global temperatures.

**U8 Recent increases in atmospheric carbon dioxide are largely due to increases in the combustion of fossilized organic matter.**

* Explain why industrial revolution would increase atmospheric CO2 concentrations.

**A1 Correlations between global temperatures and carbon dioxide concentrations on Earth.​**

* Explain how historical temperature data has been collected.
* Using ice core data, outline the correlation between atmospheric CO2 concentration and global temperatures.

**A2 Evaluating claims that human activities are not causing climate change.**

* Outline three reasons why there is vigorous debate around the claim that human activities are causing climate change.

**A3 Threats to coral reefs from increasing concentrations of dissolved carbon dioxide.**

* Outline the effect of atmospheric CO2 concentration on ocean pH.
* Describe the impact of lower ocean pH on animals that make skeletons from calcium carbonate.​

**NOS Assessing claims- Evaluating claims that human activities are not causing climate change**

* Outline ways by which claims can be evaluated for truth.

# Topic 5: Evolution and Biodiversity

## 5.1 Evidence for Evolution

**U1 Evolution occurs when heritable characteristics of species change.**

* Define evolution.

**U2 The fossil record provides evidence for evolution.**

* Define strata and paleontology.
* Explain three pieces of evidence that fossils provide that evolution has occurred.​ ​

**U3 Selective breeding of domesticated animals shows that artificial selection can cause evolution.**

* Use an example to explain how selective breeding has lead to evolution in a species.
* Explain the process of artificial selection using selective breeding.

**U4 Evolution of homologous structures by adaptive radiation explains similarities in structure when there are differences in function.​**

* Contrast analogous structures and homologous structures.
* Contrast convergent evolution and adaptive radiation.
* State an example of analogous structures.
* State an example of homologous structures.
* Define vestigial structure.
* State an example of a vestigial structure.

**U5 Populations of a species can gradually diverge into separate species by evolution.​**

* Describe the process of gradual speciation.

**U6 Continuous variation across the geographical range of related populations matches the concept of gradual divergence.**

* Explain how continuous variation across geographical ranges is evidence of evolutionary change.
* State an example of recognizably different populations of the same species across a geographical range.

**A1 Comparison of the pentadactyl limb of mammals, birds, amphibians, and reptiles with different methods of locomotion.**

* Define pentadactyl limb.
* List the bone structures present in the pentadactyl limb.
* Identify pentadactyl limb structures in diagrams of amphibians, reptiles, birds and mammals.
* Relate differences in pentadactyl limb structures to differences in limb function.

**A2 Development of melanistic insects in polluted areas.**

* ​Explain how natural selection leads to changes in the melanistic variety of insects in polluted areas.

**NOS Looking for patterns, trends and discrepancies- there are common features in the bone structure of vertebrate limbs despite their varied use.**

* Propose a mechanism that explains the pattern found in vertebrate limb structure yet allows for the specialization of different limb functions.

## 5.2 Natural Selection

**U1 Natural selection can only occur if there is variation among members of the same species.**

* Define variation.
* Explain why natural selection can only function if there is variation in a species.

**U2 Mutation, meiosis and sexual reproduction cause variation between individuals in a species.**

* List sources of genetic variation.

**U3 Adaptations are characteristics that make an individual suited to its environment and way of life.**

* Define adaptation.
* List examples of adaptations.

**U4 Species tend to produce more offspring than the environment can support.**

* Use an example to illustrate the potential for overproduction of offspring in a population.​
* State that species have the ability to produce more offspring than the environment can support.

**U5 Individuals that are better adapted tend to survive and produce more offspring while the less well adapted tend to die or produce fewer offspring.​**

* Outline how a “selective pressure” acts on the variation in a population.
* List examples of “selective pressures.”
* Explain the effect of the selective pressure on the more and less adapted individuals in a population.

**U6 Individuals that reproduce pass on characteristics to their offspring.​**

* Contrast acquired characteristics with inheritable characteristics.
* State that only inherited characteristics can be acted upon by natural selection.

**U7 Natural selection increases the frequency of characteristics that make individuals better adapted and decreases the frequency of other characteristics leading to changes within the species.**

* Compare the reproductive success of better and less well adapted individuals in a population.
* Explain the cause of the change in frequency of traits in a population through natural selection.​.

**A1 Changes in beaks of finches on Daphne Major.**

* Outline the role of Charles Darwin and Peter and Rosemary Grant in the study of Galapagos finches.
* Explain how natural selection leads to changes in the beaks of Galapagos finches with changes in weather conditions.

**A2 Evolution of antibiotic resistance in bacteria.**

* Explain how natural selection leads to changes in antibiotic resistance.
* List reasons why evolution of antibiotic resistance has been rapid.
* Outline the effect of not completing a full dose of antibiotics on the development of antibiotic resistance.​

**NOS Use theories to explain natural phenomena- the theory of evolution by natural selection can explain the development of antibiotic resistance in bacteria.​**

* List three trends that have been observed in the development of antibiotic resistance.
* Use a graph to illustrate antibiotic resistance over time.

## 5.3 Classification of Biodiversity

**U1 The binomial system of names for species is universal among biologists and has been agreed and developed at a series of congresses.**

* ​Outline the role of botanical and zoological congresses in the naming of plants and animals.

**U2 When species are discovered they are given scientific names using the binomial system.**

* Define binomial nomenclature.
* State three rules of binomial nomenclature formatting.

**U3 Taxonomists classify species using a hierarchy of taxa.​**

* Define taxon and taxonomist.
* List the hierarchy of taxa, from largest to smallest.

**U4 All organisms are classified into three domains.**

* State the two groups of prokaryotes.
* List the three domains of life.
* Outline differences between the three domains of life.
* Draw a tree diagram to illustrate the evolutionary relationship between organisms of the three domains.

**U5 The principal taxa for classifying eukaryotes are kingdom, phylum, class, order, family and genus and species.**

* List the four kingdoms of eukaryotes.
* List the hierarchy of taxa, from largest to smallest​.

**U6 In a natural classification, the genus and accompanying higher taxa consist of all the species that have evolved from one common ancestral species.**

* ​Define natural classification.
* List two difficulties in determining the natural classification of species.

**U7 Taxonomists sometimes reclassify groups of species when new evidence shows that a previous taxon contains species that have evolved from different ancestral species.**

* List two situations in which the reclassification of a species may be necessary.
* Outline an example of a species (or group of species) which were reclassified when new evidence was discovered.

**U8 Natural classification helps in identification of species and allows the prediction of characteristics shared by species within a group.**

* Explain two specific advantages of natural classification.

**A1 Classification of one plant and one animal species from domain to species level**

* ​State the classification of a plant, from domain to species.
* State the classification of an animal, from domain to species.

**A2 Recognition features of bryophyte, filicinophyta, coniferophyta, and angiospermophyta.**

* State the four major plant phyla.
* Outline the differences between the four major plant phyla in regard to external recognition features.
* Identify the phyla of plant given external recognition features.

**A3 Recognition features of porifera, cnidaria, pletyhelmintha, annelida, Mollusca, arthropda and chordata.**

* State seven major animal phyla.
* Outline the characteristics of seven major animal phyla.
* Identify the phyla of animal given external recognition features.

**A4 Recognition of features of birds, mammals, amphibians, reptiles and fish.​**

* Contrast chordate and vertebrate.
* State five major classes of chordata.
* Outline the characteristics of five major vertebrate classes.
* Identify the vertebrate class of animal given external recognition features.

**S1 Construction of dichotomous keys for use in identifying specimens.**

* Explain the use of a dichotomous key in the identification of a specimen.
* Create a dichotomous key given a sample of known specimens. ​

**NOS Cooperation and collaboration between groups of scientists- scientists use the binomial system to identify a species rather than the many different local names.**

* ​​Outline why the binomial naming system is used in science rather than local names.
* State the role of Carl Linnaeus in naming species.

## 5.4 Cladistics

**U1 A clade is a group of organisms that have evolved from a common ancestor.**

* Define clade and cladistics.

**U2 Evidence for which species are part of a clade can be obtained from the base sequences of a gene or the corresponding amino acid sequence of a protein.**

* Outline the relationship between time, evolutionary relationships and biological sequences (nitrogenous base or amino acid).

**U3 Sequence differences accumulate gradually so there is a positive correlation between the number of differences between two species and the time since they diverged from a common ancestor.**

* Outline the use of a “molecular clock” to determine time since divergence between two species.
* State the source of differences between biological sequences (nitrogenous base or amino acid).

**U4 Traits can be analogous or homologous.​**

* Contrast analogous and homologous traits.
* State an example of analogous and homologous traits.

**U5 Cladograms are tree diagrams that show the most probable sequence of divergence in clades.​**

* Define cladogram and node.
* Outline how computer programs analyze biological sequence data to create cladograms.
* Identify members of clades given a cladogram.

**U6 Evidence from cladistics has shown that classifications of some groups based on structure did not correspond with the evolutionary origins of a group or species.​**

* Outline the role of technological advancements in the development of cladistics.
* Explain why the development of cladistics lead to the reclassification of some species.

**A1 Cladograms including human and other primates.**

* Interpret a cladogram depicting primate species.

**A2 Reclassification of the figwort family using evidence from cladistics.**

* Outline the reason and evidence for the reclassification of the figwort family.

**S1 Analysis of cladograms to deduce evolutionary relationships.​**

* Analyze a cladogram to explain the evolutionary relationship between species.
* Discuss the use of cladograms as hypotheses of evolutionary relationships.

**NOS Falsification of theories with one theory being superseded by another- plant families have been reclassified as a result of evidence from cladistics.**

* Outline the reason why biological theories may change with time.

# Option C: Ecology and Conservation (paper 3)

## C.1 Species and Communities

**U1 The distribution of species is affected by limiting factors**

**U2 Community structure can be strongly affected by keystone species**

**U3 Each species plays a unique role within a community because of the unique combination of its spatial habitat and interactions with other species**

**U4 Interactions between species in a community can be classified according to their effect**

**U5 Two species cannot survive indefinitely in the same habitat if their niches are identical**

**A1 Distribution of one animal and one plant species to illustrate limits of tolerance and zones of stress**

**A2 Local examples to illustrate the range of ways in which species can interact within a community**

**A3 The symbiotic relationship between zooxanthellae and reef-building coral reef species**

**S1 ANalysis of a data set that illustrates the distinction between fundamental and realized niche**

**S2 Use of a transect to correlate the distribution of plant or animal species with an abiotic value**

**NOS Use models as representations of the real world: zones of stress and limits of tolerance graphs are models of the real world that have predictive power and explain community structure**

## C.2 Communities and Ecosystems

**U1 Most species occupy different trophic levels in multiple food chains**

**U2 A food web shows all the possible food chains in a community**

**U3 The percentage of ingested energy converted to biomass is dependent on the respiration rate**

**U4 The type of stable ecosystem that will emerge in an area is predictable based on climate**

**U5 In closed ecosystems energy but not matter is exchanged with the surroundings**

**U6 Disturbance influences the structure and rate of change within ecosystems**

**A1 Conversion ratio in sustainable food production practices**

**A2 Consideration of one example of how humans interfere with nutrient cycling**

**S1 Comparison of pyramids of energy from different ecosystems**

**S2 Analysis of a climograph showing the relationship between temperature, rainfall, and ecosystem type**

**S3 Construction of Gersmehl diagrams to show the inter-relationships between nutrient stores and flows between taiga, desert, and tropical rainforest**

**S4 Analysis of data showing primary succession**

**S5 Investigation into the effect of an environmental disturbance on an ecosystem**

**NOS models are representations of the real world: pyramids of energy model the energy flow through ecosystems**

## C.3 Impacts of Humans on Ecosystems

**U1 Introduced alien species can escape into local ecosystems and become invasive**

**U2 Competitive exclusion and the absence of predators can lead to a reduction in the numbers of endemic species when alien species become invasive**

**U3 Pollutants become concentrated in the tissues of organisms at higher trophic levels by biomagnification**

**U4 Macroplastic and microplastic debris has accumulated in marine environments**

**A1 Study of the introduction of cane toads in Australia and one other local example of the introduction of an alien species**

**A2 Discussion of the trade-off between control of the malarial parasite and DDT pollution**

**A3 Case study of the impact of marine plastic debris on Laysan albatrosses and one other named species**

**S1 Analysis of data illustrating the causes and consequences of biomagnification**

**S2 Evaluation of eradication programmes and biological control as measures to reduce the impact of alien species**

**NOS Assessing risks and benefits associated with scientific research: the use of biological control has associated risk and requires verification by tightly controlled experiments before it is approved**

## C.4 Conservation of Biodiversity

**U1 An indicator species is an organism used to assess a specific environmental condition**

**U2 Relative numbers of indicator species can be used to calculate the value of a biotic index**

**U3 *In situ* conservation may require active management of nature reserves or national parks**

**U4 *Ex situ* conservation is the preservation of species outside their natural habitats**

**U5 Biogeographic factors affect species diversity**

**U6 Richness and evenness are components of biodiversity**

**A1 Case study of the captive breeding and reintroduction of an endangered animal species**

**A2 Analysis of the impact of biogeographic factors on diversity limited to island size and edge effects**

**S1 Analysis of the biodiversity of two local communities using Simpson’s reciprocal index of diversity**

**NOS Scientists collaborate with other agencies: the preservation of species involves international cooperation through intergovernmental and non-governmental organizations**

## C.5 Population Ecology (AHL)

**U1 Sampling techniques are used to estimate population size**

**U2 The exponential growth pattern occurs in an ideal, unlimited environment**

**U3 Population growth slows as population reaches the carrying capacity of the environment**

**U4 The phases shown in the sigmoid curve can be explained by relative rates of natality, mortality, immigration, and emigration**

**U5 Limiting factors can be top-down or bottom-up**

**A1 Evaluating the methods used to estimate the size of commercial stock of marine resources**

**A2 Use of the capture-mark-release-recapture method to estimate the population size of an animal species**

**A3 Discussion of the effect of natality, mortality, immigration, and emigration on population size**

**A4 Analysis of the effect of population size, age, and reproductive status on sustainable fishing practices**

**A5 Bottom-up control of algal blooms by shortage of nutrients and top-down control by herbivory**

**S1 Modeling the growth curve using a simple organism such as yeast or a species of *Lemna***

**NOS Avoiding bias: A random number generator helps ensure population sampling is free from bias**

## C.6 Nitrogen and Phosphorus Cycles (AHL)

**U1 Nitrogen-fixing bacteria convert atmospheric nitrogen to ammonia**

**U2 *Rhizobium* associates with roots in a mutualistic relationship**

**U3 In the absence of oxygen, denitrifying bacteria reduce nitrate in the soil**

**U4 Phosphorus can be added to the phosphorus cycle by application of fertilizer, or removed by the harvesting of agricultural crops**

**U5 The rate of turnover in the phosphorus cycle is much lower than the nitrogen cycle**

**U6 Availability of phosphate may become limiting to agriculture in the future**

**U7 Leaching of mineral nutrients from agricultural land into rivers causes eutrophication and leads to increased biochemical oxygen demand**

**A1 The impact of waterlogging on the nitrogen cycle**

**A2 Insectivorous plants as an adaptation for low nitrogen availability in waterlogged soils**

**S1 Drawing and labeling a diagram of the nitrogen cycle**

**S2 Assess the nutrient content of a soil sample**

**NOS Assessing risks and benefits of scientific research: agricultural practices can disrupt the phosphorus cycle**