Topic 1. Cell Composition and Water

SL: 15 hours
HL: 28 hours

Contents

Objectives from the Biology Guide 2025, published by the IB

2.2 Cell Structure

Standard level and higher level: 4 hours

Additional higher level: 1 hour

A2.2.1—Cells as the basic structural unit of all living organisms
NOS: Students should be aware that deductive reason can be used to generate predictions from theories. Based on cell theory, a newly discovered organism can be predicted to consist of one or more cells.

A2.2.2—Microscopy skills
Application of skills: Students should have experience of making temporary mounts of cells and tissues, staining, measuring sizes using an eyepiece graticule, focusing with coarse and fine adjustments, calculating actual size and magnification, producing a scale bar and taking photographs.
NOS: Students should appreciate that measurement using instruments is a form of quantitative observation.

A2.2.3—Developments in microscopy
Include the advantages of electron microscopy, freeze fracture, cryogenic electron microscopy, and the use of fluorescent stains and immunofluorescence in light microscopy.

A2.2.4—Structures common to cells in all living organisms
Typical cells have DNA as genetic material and a cytoplasm composed mainly of water, which is enclosed by a plasma membrane composed of lipids. Students should understand the reasons for these structures.

A2.2.5—Prokaryote cell structure
Include these cell components: cell wall, plasma membrane, cytoplasm, naked DNA in a loop and 70S ribosomes. The type of prokaryotic cell structure required is that of Gram-positive eubacteria such as *Bacillus* and *Staphylococcus*. Students should appreciate that prokaryote cell structure varies. However, students are not required to know details of the variations such as the lack of cell walls in phytoplasmas and mycoplasmas.

A2.2.6—Eukaryote cell structure
Students should be familiar with features common to eukaryote cells: a plasma membrane enclosing a compartmentalized cytoplasm with 80S ribosomes; a nucleus with chromosomes made of DNA bound to histones, contained in a double membrane with pores; membrane-bound cytoplasmic organelles including mitochondria, endoplasmic reticulum, Golgi apparatus and a variety of vesicles or vacuoles including lysosomes; and a cytoskeleton of microtubules and microfilaments.

A2.2.7—Processes of life in unicellular organisms
Include these functions: homeostasis, metabolism, nutrition, movement, excretion, growth, response to stimuli and reproduction.

A2.2.8—Differences in eukaryotic cell structure between animals, fungi and plants
Include presence and composition of cell walls, differences in size and function of vacuoles, presence of chloroplasts and other plastids, and presence of centrioles, cilia and flagella.

A2.2.9—Atypical cell structure in eukaryotes
Use numbers of nuclei to illustrate one type of atypical cell structure in aseptate fungal hyphae, skeletal muscle, red blood cells and phloem sieve tube elements.

A2.2.10—Cell types and cell structures viewed in light and electron micrographs
Application of skills: Students should be able to identify cells in light and electron micrographs as prokaryote, plant or animal. In electron micrographs, students should be able to identify these structures: nucleoid region, prokaryotic cell wall, nucleus, mitochondrion, chloroplast, sap vacuole, Golgi apparatus, rough and smooth endoplasmic reticulum, chromosomes, ribosomes, cell wall, plasma membrane and microvilli.

A2.2.11—Drawing and annotation based on electron micrographs
Application of skills: Students should be able to draw and annotate diagrams of organelles (nucleus, mitochondria, chloroplasts, sap vacuole, Golgi apparatus, rough and smooth endoplasmic reticulum and chromosomes) as well as other cell structures (cell wall, plasma membrane, secretory vesicles and microvilli) shown in electron micrographs. Students are required to include the functions in their annotations.

Additional higher level

A2.2.12—Origin of eukaryotic cells by endosymbiosis
Evidence suggests that all eukaryotes evolved from a common unicellular ancestor that had a nucleus and reproduced sexually. Mitochondria then evolved by endosymbiosis. In some eukaryotes, chloroplasts subsequently also had an endosymbiotic origin. Evidence should include the presence in mitochondria and chloroplasts of 70S ribosomes, naked circular DNA and the ability to replicate. **NOS:** Students should recognize that the strength of a theory comes from the observations the theory explains and the predictions it supports. A wide range of observations are accounted for by the theory of endosymbiosis.

A2.2.13—Cell differentiation as the process for developing specialized tissues in multicellular organisms
Students should be aware that the basis for differentiation is different patterns of gene expression often triggered by changes in the environment.

A2.2.14—Evolution of multicellularity
Students should be aware that multicellularity has evolved repeatedly. Many fungi and eukaryotic algae and all plants and animals are multicellular. Multicellularity has the advantages of allowing larger body size and cell specialization.

A 2.3 Viruses

Additional higher level: 2 hours

Guiding questions

- How can viruses exist with so few genes?
- In what ways do viruses vary?

Additional higher level

Note: There is no SL content in A2.3.

A2.3.1—Structural features common to viruses
Relatively few features are shared by all viruses: small, fixed size; nucleic acid (DNA or RNA) as genetic material; a capsid made of protein; no cytoplasm; and few or no enzymes.

A2.3.2—Diversity of structure in viruses
Students should understand that viruses are highly diverse in their shape and structure. Genetic material may be RNA or DNA, which can be either single- or double-stranded. Some viruses are enveloped in host cell membrane and others are not enveloped. Virus examples include bacteriophage lambda, coronaviruses and HIV.

A2.3.3—Lytic cycle of a virus
Students should appreciate that viruses rely on a host cell for energy supply, nutrition, protein synthesis and other life functions. Use bacteriophage lambda as an example of the phases in a lytic cycle.

A.2.3.4—Lysogenic cycle of a virus
Use bacteriophage lambda as an example.

A2.3.5—Evidence for several origins of viruses from other organisms
The diversity of viruses suggests several possible origins. Viruses share an extreme form of obligate parasitism as a mode of existence, so the structural features that they have in common could be regarded as convergent evolution. The genetic code is shared between viruses and living organisms.

A2.3.6—Rapid evolution in viruses
Include reasons for very rapid rates of evolution in some viruses. Use two examples of rapid evolution: evolution of influenza viruses and of HIV. Consider the consequences for treating diseases caused by rapidly evolving viruses.

A 2.1 Origins of Cells

Additional higher level: 2 hours

A2.1.1—Conditions on early Earth and the pre-biotic formation of carbon compounds
Include the lack of free oxygen and therefore ozone, higher concentrations of carbon dioxide and methane, resulting in higher temperatures and ultraviolet light penetration. The conditions may have caused a variety of carbon compounds to form spontaneously by chemical processes that do not now occur.

A2.1.2—Cells as the smallest units of self-sustaining life
Discuss the differences between something that is living and something that is non-living. Include reasons that viruses are considered to be non-living.

A2.1.3—Challenge of explaining the spontaneous origin of cells
Cells are highly complex structures that can currently only be produced by division of pre-existing cells. Students should be aware that catalysis, self-replication of molecules, self-assembly and the emergence of compartmentalization were necessary requirements for the evolution of the first cells. **NOS:** Students should appreciate that claims in science, including hypotheses and theories, must be testable. In some cases, scientists have to struggle with hypotheses that are difficult to test. In this case the exact conditions on pre-biotic Earth cannot be replicated and the first protocells did not fossilize.

A2.1.4—Evidence for the origin of carbon compounds
Evaluate the Miller–Urey experiment.

A2.1.5—Spontaneous formation of vesicles by coalescence of fatty acids into spherical bilayers
Formation of a membrane-bound compartment is needed to allow internal chemistry to become different from that outside the compartment.

A2.1.6—RNA as a presumed first genetic material
RNA can be replicated and has some catalytic activity so it may have acted initially as both the genetic material and the enzymes of the earliest cells. Ribozymes in the ribosome are still used to catalyse peptide bond formation during protein synthesis.

A2.1.7—Evidence for a last universal common ancestor
Include the universal genetic code and shared genes across all organisms. Include the likelihood of other forms of life having evolved but becoming extinct due to competition from the last universal common ancestor (LUCA) and descendants of LUCA.

A2.1.8—Approaches used to estimate dates of the first living cells and the last universal common ancestor
Students should develop an appreciation of the immense length of time over which life has been evolving on Earth.

A2.1.9—Evidence for the evolution of the last universal common ancestor in the vicinity of hydrothermal vents
Include fossilized evidence of life from ancient seafloor hydrothermal vent precipitates and evidence of conserved sequences from genomic analysis.

B 2.2 Organelles and Compartmentalization

Standard level and higher level: 1 hour

Additional higher level: 2 hours

B2.2.1—Organelles as discrete subunits of cells that are adapted to perform specific functions
Students should understand that the cell wall, cytoskeleton and cytoplasm are not considered organelles, and that nuclei, vesicles, ribosomes and the plasma membrane are. **NOS:** Students should recognize that progress in science often follows development of new techniques. For example, study of the function of individual organelles became possible when ultracentrifuges had been invented and methods of using them for cell fractionation had been developed.

B2.2.3—Advantages of compartmentalization in the cytoplasm of cells
Include concentration of metabolites and enzymes and the separation of incompatible biochemical processes. Include lysosomes and phagocytic vacuoles as examples.

Additional higher level

B2.2.4—Adaptations of the mitochondrion for production of ATP by aerobic cell respiration

Include these adaptations: a double membrane with a small volume of intermembrane space, large surface area of cristae and compartmentalization of enzymes and substrates of the Krebs cycle in the matrix.

B2.2.5—Adaptations of the chloroplast for photosynthesis
Include these adaptations: the large surface area of thylakoid membranes with photosystems, small volumes of fluid inside thylakoids, and compartmentalization of enzymes and substrates of the Calvin cycle in the stroma.

B2.2.6—Functional benefits of the double membrane of the nucleus
Include the need for pores in the nuclear membrane and for the nucleus membrane to break into vesicles during mitosis and meiosis.

B2.2.7—Structure and function of free ribosomes and of the rough endoplasmic reticulum
Contrast the synthesis by free ribosomes of proteins for retention in the cell with synthesis by membrane-bound ribosomes on the rough endoplasmic reticulum of proteins for transport within the cell and secretion.

B2.2.8—Structure and function of the Golgi apparatus
Limit to the roles of the Golgi apparatus in processing and secretion of protein.

B2.2.9—Structure and function of vesicles in cells
Include the role of clathrin in the formation of vesicles.

B 2.1 Membranes and Membrane Transport

Standard level and higher level: 4 hours

Additional higher level: 2 hours

B2.1.1—Lipid bilayers as the basis of cell membranes
Phospholipids and other amphipathic lipids naturally form continuous sheet-like bilayers in water.

B2.1.2—Lipid bilayers as barriers
Students should understand that the hydrophobic hydrocarbon chains that form the core of a membrane have low permeability to large molecules and hydrophilic particles, including ions and polar molecules, so membranes function as effective barriers between aqueous solutions.

B2.1.3—Simple diffusion across membranes
Use movement of oxygen and carbon dioxide molecules between phospholipids as an example of simple diffusion across membranes.

B2.1.4—Integral and peripheral proteins in membranes
Emphasize that membrane proteins have diverse structures, locations and functions. Integral proteins are embedded in one or both of the lipid layers of a membrane. Peripheral proteins are attached to one or other surface of the bilayer.

B2.1.5—Movement of water molecules across membranes by osmosis and the role of aquaporins
Include an explanation in terms of random movement of particles, impermeability of membranes to solutes and differences in solute concentration.

B2.1.6—Channel proteins for facilitated diffusion
Students should understand how the structure of channel proteins makes membranes selectively permeable by allowing specific ions to diffuse through when channels are open but not when they are closed.

B2.1.7—Pump proteins for active transport
Students should appreciate that pumps use energy from adenosine triphosphate (ATP) to transfer specific particles across membranes and therefore that they can move particles against a concentration gradient.

B2.1.8—Selectivity in membrane permeability
Facilitated diffusion and active transport allow selective permeability in membranes. Permeability by simple diffusion is not selective and depends only on the size and hydrophilic or hydrophobic properties of particles.

B.2.1.9—Structure and function of glycoproteins and glycolipids
Limit to carbohydrate structures linked to proteins or lipids in membranes, location of carbohydrates on the extracellular side of membranes, and roles in cell adhesion and cell recognition.

B2.1.10—Fluid mosaic model of membrane structure
Students should be able to draw a two-dimensional representation of the model and include peripheral and integral proteins, glycoproteins, phospholipids and cholesterol. They should also be able to indicate hydrophobic and hydrophilic regions.

Additional higher level

B2.1.11—Relationships between fatty acid composition of lipid bilayers and their fluidity
Unsaturated fatty acids in lipid bilayers have lower melting points, so membranes are fluid and therefore flexible at temperatures experienced by a cell. Saturated fatty acids have higher melting points and make membranes stronger at higher temperatures. Students should be familiar with an example of adaptations in membrane composition in relation to habitat.

B2.1.12—Cholesterol and membrane fluidity in animal cells
Students should understand the position of cholesterol molecules in membranes and also that cholesterol acts as a modulator (adjustor) of membrane fluidity, stabilizing membranes at higher temperatures and preventing stiffening at lower temperatures.

B2.1.13—Membrane fluidity and the fusion and formation of vesicles
Include the terms “endocytosis” and “exocytosis”, and examples of each process.

B2.1.14—Gated ion channels in neurons
Include nicotinic acetylcholine receptors as an example of a neurotransmitter-gated ion channel and sodium and potassium channels as examples of voltage-gated channels.

B2.1.15—Sodium–potassium pumps as an example of exchange transporters
Include the importance of these pumps in generating membrane potentials.

B2.1.16—Sodium-dependent glucose cotransporters as an example of indirect active transport
Include the importance of these cotransporters in glucose absorption by cells in the small intestine and glucose reabsorption by cells in the nephron.

B2.1.17—Adhesion of cells to form tissues
Include the term “cell-adhesion molecules” (CAMs) and the understanding that different forms of CAM are used for different types of cell–cell junction. Students are not required to have detailed knowledge of the different CAMs or junctions.

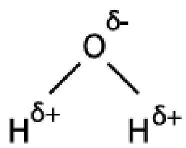
A 1.1 Water

Standard level and higher level: 2 hours

Additional higher level: 1 hour

SL and HL

A1.1.1—Water as the medium for life
Students should appreciate that the first cells originated in water and that water remains the medium in which most processes of life occur.

A1.1.2—Hydrogen bonds as a consequence of the polar covalent bonds within water molecules
Students should understand that polarity of covalent bonding within water molecules is due to unequal sharing of electrons and that hydrogen bonding due to this polarity occurs between water molecules. Students should be able to represent two or more water molecules and hydrogen bonds between them with the notation shown below to indicate polarity. 

A1.1.3—Cohesion of water molecules due to hydrogen bonding and consequences for organisms
Include transport of water under tension in xylem and the use of water surfaces as habitats due to the effect known as surface tension.

A1.1.4—Adhesion of water to materials that are polar or charged and impacts for organisms
Include capillary action in soil and in plant cell walls.

A1.1.5—Solvent properties of water linked to its role as a medium for metabolism and for transport in plants and animals
Emphasize that a wide variety of hydrophilic molecules dissolve in water and that most enzymes catalyse reactions in aqueous solution. Students should also understand that the functions of some molecules in cells depend on them being hydrophobic and insoluble.

A1.1.6—Physical properties of water and the consequences for animals in aquatic habitats
Include buoyancy, viscosity, thermal conductivity and specific heat capacity. Contrast the physical properties of water with those of air and illustrate the consequences using examples of animals that live in water and in air or on land, such as the black-throated loon (*Gavia arctica*) and the ringed seal (*Pusa hispida*). *Note: When students are referring to an organism in an examination, either the common name or the scientific name is acceptable.*

Additional higher level

A1.1.7—Extraplanetary origin of water on Earth and reasons for its retention
The abundance of water over billions of years of Earth's history has allowed life to evolve. Limit hypotheses for the origin of water on Earth to asteroids and reasons for retention to gravity and temperatures low enough to condense water.

A1.1.8—Relationship between the search for extraterrestrial life and the presence of water
Include the idea of the "Goldilocks zone".

D 2.3 Water Potential

Standard level and higher level: 2 hours

Additional higher level: 2 hours

D2.3.1—Solvation with water as the solvent
Include hydrogen bond formation between solute and water molecules, and attractions between both positively and negatively charged ions and polar water molecules.

D2.3.2—Water movement from less concentrated to more concentrated solutions
Students should express the direction of movement in terms of solute concentration, not water concentration. Students should use the terms “hypertonic”, “hypotonic” and “isotonic” to compare concentration of solutions.

D2.3.3—Water movement by osmosis into or out of cells
Students should be able to predict the direction of net movement of water if the environment of a cell is hypotonic or hypertonic. They should understand that in an isotonic environment there is dynamic equilibrium rather than no movement of water.

D2.3.4—Changes due to water movement in plant tissue bathed in hypotonic and those bathed in hypertonic solutions
Application of skills: Students should be able to measure changes in tissue length and mass, and analyse data to deduce isotonic solute concentration. Students should also be able to use standard deviation and standard error to help in the analysis of data. Students are not required to memorize formulae for calculating these statistics. Standard deviation and standard error could be determined for the results of this experiment if there are repeats for each concentration. This would allow the reliability of length and mass measurements to be compared. Standard error could be shown graphically as error bars.

D2.3.5—Effects of water movement on cells that lack a cell wall
Include swelling and bursting in a hypotonic medium, and shrinkage and crenation in a hypertonic medium. Also include the need for removal of water by contractile vacuoles in freshwater unicellular organisms and the need to maintain isotonic tissue fluid in multicellular organisms to prevent harmful changes.

D2.3.6—Effects of water movement on cells with a cell wall
Include the development of turgor pressure in a hypotonic medium and plasmolysis in a hypertonic medium.

D2.3.7—Medical applications of isotonic solutions

Include intravenous fluids given as part of medical treatment and bathing of organs ready for transplantation as examples.

Additional higher level

D2.3.8—Water potential as the potential energy of water per unit volume
Students should understand that it is impossible to measure the absolute quantity of the potential energy of water, so values relative to pure water at atmospheric pressure and 20°C are used. The units are usually kilopascals (kPa).

D2.3.9—Movement of water from higher to lower water potential
Students should appreciate the reasons for this movement in terms of potential energy.

D2.3.10—Contributions of solute potential and pressure potential to the water potential of cells with walls
Use the equation $\psi_w = \psi_s + \psi_p$. Students should appreciate that solute potentials can range from zero downwards and that pressure potentials are generally positive inside cells, although negative pressure potentials occur in xylem vessels where sap is being transported under tension.

D2.3.11—Water potential and water movements in plant tissue
Students should be able to explain in terms of solute and pressure potentials the changes that occur when plant tissue is bathed in either a hypotonic or hypertonic solution.