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Edexcel International Advanced Level (IAL) Biology Revision Series

1A: Chemistry for Biologists

Topic 1: Molecules, Transport and Health

COMPREHENSIVE HIGH-YIELD LECTURE NOTES & SPEC COMPANION

Introduction: Underpinning all biological systems, from microscopic cells to complex multi-organ transport chains, are the absolute laws of biochemistry [cite: uploaded:1A Chemistry for Biologists.pdf]. The exact properties and spatial orientation of chemical bonds govern metabolic pathways, cellular structure, and overall organism function [cite: uploaded:1A Chemistry for Biologists.pdf].

BIOLOGICAL ADAPTATION SPOTLIGHT: THE DESERT JERBOA

The jerboa (family *Dipodidae*) is a small desert rodent native to hot and cold arid zones from the Sahara to the Gobi [cite: uploaded:1A Chemistry for Biologists.pdf]. It exhibits remarkable physical and biochemical adaptations to live without ever drinking free liquid water [cite: uploaded:1A Chemistry for Biologists.pdf]. It synthesizes metabolic water strictly from moisture locked inside dietary seeds, roots, and vegetation [cite: uploaded:1A Chemistry for Biologists.pdf]. To prevent dehydrating systemic loss, its specialized kidneys eliminate metabolic waste by yielding tiny volumes of exceptionally concentrated urine [cite: uploaded:1A Chemistry for Biologists.pdf].

1. Foundations of Chemical Bonding

Living matter depends on combinations of subatomic particles reacting to attain stable, low-energy configurations. When outermost valence electron shells lack a full stable octet, atoms interact via two primary structural mechanisms [cite: uploaded:1A Chemistry for Biologists.pdf]:

Ionic Bonding

Formed through the absolute transfer of valence electrons between reacting species, producing discrete fully-charged entities [cite: uploaded:1A Chemistry for Biologists.pdf]:

- **Anions:** Electronegative non-metals that gain electrons, acquiring a net negative charge [cite: uploaded:1A Chemistry for Biologists.pdf].
- **Cations:** Electropositive metals that lose electrons, acquiring a net positive charge [cite: uploaded:1A Chemistry for Biologists.pdf].

The subsequent strong, multi-directional electrostatic attraction holding oppositely charged ions together builds rigid ionic crystal structures [cite: uploaded:1A Chemistry for Biologists.pdf].

Covalent Bonding

Formed when reacting atoms share pairs of outer valence electrons to fulfill filled orbital configurations [cite: uploaded:1A Chemistry for Biologists.pdf]. These bonds are structurally strong and directional, creating stable intramolecular frameworks. Most covalent compounds remain electrically neutral across the entire molecular structure [cite: uploaded:1A Chemistry for Biologists.pdf].

Dipoles and Molecular Polarity

In many covalent bonds, electrons are shared unequally due to differences in electronegativity between the bonded nuclei [cite: uploaded:1A Chemistry for Biologists.pdf]. For instance, an atom with a high electronegativity (such as oxygen) pulls the shared electron density closer to its own nucleus and away from a less electronegative partner (such as hydrogen) [cite: uploaded:1A Chemistry for Biologists.pdf]. This uneven spatial distribution of charge sets up a permanent internal electrical **dipole** [cite: uploaded:1A Chemistry for Biologists.pdf]. This continuous charge separation is represented by the symbols δ^- (partial negative) and δ^+ (partial positive), making the compound a **polar molecule** [cite: uploaded:1A Chemistry for Biologists.pdf].

EXAM HINT: PRECISE BIOLOGICAL NOMENCLATURE

In exams, distinguish carefully between **fully-charged ionic species** (free discrete particles with complete whole-integer charges) [cite: uploaded:1A Chemistry for Biologists.pdf] and **polar covalent molecules** (electrically neutral molecules that contain internal fractional, partial dipoles due to unequal electron sharing) [cite: uploaded:1A Chemistry for Biologists.pdf].

2. Inorganic Ions and Their Physiological Functions

When ionic structures dissolve in aqueous cellular environments, they split apart in a process called **dissociation** [cite: uploaded:1A Chemistry for Biologists.pdf]. Because cytoplasm is predominantly water, these dissolved inorganic ions are critical for driving metabolic reactions and maintaining cellular homeostasis [cite: uploaded:1A Chemistry for Biologists.pdf]:

Inorganic Ion	Chemical Formula	Core Biological Function & Importance
Nitrate Ions	NO_3^-	Absorbed by plants from the soil to provide the essential nitrogen needed to synthesize DNA, RNA, amino acids, and structural proteins [cite: uploaded:1A Chemistry for Biologists.pdf].
Phosphate Ions	PO_4^{3-}	Required across all living organisms to construct ATP, ADP, as well as the sugar-phosphate backbone of nucleic acids (DNA/RNA) [cite: uploaded:1A Chemistry for Biologists.pdf].
Chloride Ions	Cl^-	Essential for generating electrochemical nerve impulses, producing sweat, and maintaining correct osmotic balance in secretory systems [cite: uploaded:1A Chemistry for Biologists.pdf].
Hydrogencarbonate	HCO_3^-	Acts as a vital physiological buffer to maintain blood pH within strict limits, preventing clinical acidosis [cite: uploaded:1A Chemistry for Biologists.pdf].
Sodium Ions	Na^+	The primary extracellular cation required for secondary active co-transport mechanisms, nerve impulse propagation, and osmotic regulation [cite: uploaded:1A Chemistry for Biologists.pdf].
Calcium Ions	Ca^{2+}	Combines to form calcium pectate in the middle lamella to glue plant cell walls together [cite: uploaded:1A Chemistry for Biologists.pdf]; critical for bone density and muscle contraction cascades in animals.
Hydrogen Ions	H^+	Directly determines pH levels; drives chemiosmotic proton pumps during cellular respiration (mitochondria) and photosynthesis (thylakoids) [cite: uploaded:1A Chemistry for Biologists.pdf].
Magnesium Ions	Mg^{2+}	The central coordinating atom in the porphyrin ring of chlorophyll molecules, absolutely required for light absorption in plants [cite: uploaded:1A Chemistry for Biologists.pdf].

3. The Polar Chemistry and Properties of Water

Water possesses the molecular formula H_2O, with a single oxygen atom covalently bonded to two hydrogen atoms [cite: uploaded:1A Chemistry for Biologists.pdf]. Because oxygen has a high electronegativity, it strongly attracts the shared electron pairs, creating an asymmetric, bent molecular structure with an internal bond angle of $104.5°$ [cite: uploaded:1A Chemistry for Biologists.pdf].

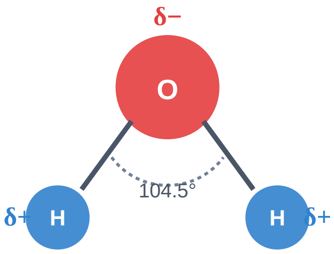


Figure 1: Polar asymmetric layout of a water molecule with partial electrical charges.

This permanent asymmetry allows water molecules to form electrostatic connections called **hydrogen bonds** [cite: uploaded:1A Chemistry for Biologists.pdf]. The partial negative (δ^-) oxygen of one water molecule exerts an electrostatic pull on a partial positive (δ^+) hydrogen of an adjacent molecule [cite: uploaded:1A Chemistry for Biologists.pdf]. While individual hydrogen bonds are weak and dynamic, a bulk volume of water contains billions of these interactions, giving water unique thermal and physical properties [cite: uploaded:1A Chemistry for Biologists.pdf]:

- **High Specific Heat Capacity:** Substantial thermal energy must be absorbed to disrupt the vast matrix of hydrogen bonds before the kinetic energy of the molecules can increase [cite: uploaded:1A Chemistry for Biologists.pdf]. This stabilizes aquatic environments and cellular systems against sudden temperature fluctuations [cite: uploaded:1A Chemistry for Biologists.pdf].
- **High Latent Heat of Vaporisation:** Requires significant energy input to convert liquid water into water vapor [cite: uploaded:1A Chemistry for Biologists.pdf]. This provides an effective cooling mechanism for organisms via evaporation, such as sweating or panting.
- **Excellent Polar Solvent:** Water molecules surround and isolate solute ions by aligning their opposite dipoles with the solute's charges [cite: uploaded:1A Chemistry for Biologists.pdf]. For example, partial positive hydrogens group around negative anions (Cl^-), while partial negative oxygens surround positive cations (Na^+), bringing ionic substances into solution [cite: uploaded:1A Chemistry for Biologists.pdf]. This makes water an ideal medium for metabolic reactions and bulk transport [cite: uploaded:1A Chemistry for Biologists.pdf].
- **Anomalous Density Profile:** As water cools toward $4°C$, it contracts and becomes denser [cite: uploaded:1A Chemistry for Biologists.pdf]. However, cooling below $4°C$ causes the water molecules to lock into a rigid, open crystalline lattice where they are spaced further apart [cite: uploaded:1A Chemistry for Biologists.pdf]. Consequently, ice is less dense than liquid water and floats on top, forming an insulating surface layer that protects liquid habitats below [cite: uploaded:1A Chemistry for Biologists.pdf].

- **Cohesion and Adhesion:** Cohesion describes the tendency of water molecules to stick to each other via hydrogen bonds, facilitating bulk transport up plant xylem vessels under tension [cite: uploaded:1A Chemistry for Biologists.pdf]. Adhesion describes water's attraction to other polar surfaces, such as cellulose cell walls [cite: uploaded:1A Chemistry for Biologists.pdf].
- **High Surface Tension:** At an air-water boundary, inward cohesive forces between water molecules are much stronger than their attraction to the air molecules above [cite: uploaded:1A Chemistry for Biologists.pdf]. This creates a resilient surface "skin" that can support specialized surface-dwelling organisms [cite: uploaded:1A Chemistry for Biologists.pdf].

4. Carbohydrates: Monosaccharides and Disaccharides

Carbohydrates are organic molecules composed strictly of Carbon, Hydrogen, and Oxygen [cite: uploaded:1A Chemistry for Biologists.pdf]. They function as immediate respiratory substrates, energy stores, and key structural materials [cite: uploaded:1A Chemistry for Biologists.pdf]. They are classified into three groups based on molecular complexity: **Monosaccharides**, **Disaccharides**, and **Polysaccharides** [cite: uploaded:1A Chemistry for Biologists.pdf].

Monosaccharides: Single Sugar Monomers

Monosaccharides are simple single sugars that conform to the general stoichiometric empirical formula $(CH_2O)_n$ [cite: uploaded:1A Chemistry for Biologists.pdf]. They are classified by the number of carbon atoms they contain:

- **Triose Sugars ($n=3, C_3H_6O_3$):** Crucial intermediate compounds generated during the metabolic breakdown of glucose in cellular respiration [cite: uploaded:1A Chemistry for Biologists.pdf].
- **Pentose Sugars ($n=5, C_5H_{10}O_5$):** Structural components of nucleic acids, such as Ribose in RNA and Deoxyribose in DNA [cite: uploaded:1A Chemistry for Biologists.pdf].
- **Hexose Sugars ($n=6, C_6H_{12}O_6$):** High-energy ring compounds including Glucose, Galactose, and Fructose [cite: uploaded:1A Chemistry for Biologists.pdf].

Isomerism in Glucose: α-Glucose vs. β-Glucose

Molecules that share identical chemical formulas but possess distinct structural layouts are defined as **isomers** [cite: uploaded:1A Chemistry for Biologists.pdf]. Glucose displays two structurally critical isomers: **α-glucose** and **β-glucose** [cite: uploaded:1A Chemistry for Biologists.pdf]. They differ solely in the relative spatial orientation of the hydroxyl group (–OH) attached to Carbon 1 (C1) [cite: uploaded:1A Chemistry for Biologists.pdf]:

α-Glucose (OH Down on C1)

β-Glucose (OH Up on C1)

Figure 2: Spatial orientation of the hydroxyl (-OH) group on C1 in alpha vs beta glucose.

Disaccharide Synthesis via Condensation Reactions

Disaccharides are constructed when two independent monosaccharide monomers are linked together through a **condensation reaction** [cite: uploaded:1A Chemistry for Biologists.pdf]. This reaction involves the removal of a water molecule (H_2O), creating a covalent bond called a **glycosidic bond** [cite: uploaded:1A Chemistry for Biologists.pdf]. The carbons participating in this link are explicitly numbered based on their position [cite: uploaded:1A Chemistry for Biologists.pdf]:

- **Maltose:** Formed by the condensation of two α-glucose monomers, creating a 1,4-glycosidic bond [cite: uploaded:1A Chemistry for Biologists.pdf].
- **Sucrose:** Formed by the condensation of an α-glucose monomer and a fructose monomer [cite: uploaded: 1A Chemistry for Biologists.pdf].
- **Lactose:** Formed by the condensation of an α-glucose monomer and a galactose monomer [cite: uploaded:1A Chemistry for Biologists.pdf].

CORE PRACTICAL 1: TESTING FOR BIOCHEMICAL CARBOHYDRATES

Reducing Sugars: All monosaccharides and select disaccharides (e.g., maltose, lactose) act as reducing agents [cite: uploaded:1A Chemistry for Biologists.pdf]. When heated with bright blue Benedict's reagent, they reduce blue Cu^{2+} ions to form an insoluble copper(I) oxide (Cu_2O) precipitate [cite: uploaded:1A Chemistry for Biologists.pdf]. The color shifts along a concentration gradient from blue → green → yellow → brown → brick-red [cite: uploaded:1A Chemistry for Biologists.pdf].

Non-Reducing Sugars: Sucrose does not react directly with Benedict's reagent because its reducing groups are locked within its glycosidic bond [cite: uploaded:1A Chemistry for Biologists.pdf]. To test for sucrose, heat the sample with dilute hydrochloric acid (HCl) to split the glycosidic link via **hydrolysis** [cite: uploaded:1A Chemistry for Biologists.pdf]. Cool, neutralize with sodium hydrogencarbonate ($NaHCO_3$), and re-test with Benedict's reagent to obtain a positive brick-red result from the freed monomers [cite: uploaded:1A Chemistry for Biologists.pdf].

5. Polysaccharides: Complex Carbohydrates

Polysaccharides are large macromolecules constructed from many monosaccharide units linked by glycosidic bonds [cite: uploaded:1A Chemistry for Biologists.pdf]. True polysaccharides are insoluble in water and lack a sweet taste [cite: uploaded:1A Chemistry for Biologists.pdf]. This insolubility makes them ideal storage compounds because they have no osmotic effect on the water potential (ψ) of the cell [cite: uploaded:1A Chemistry for Biologists.pdf]. When energy is required, these storage polymers are broken down via **hydrolysis reactions**, adding water molecules to split the glycosidic bonds and release hexose sugars for respiration [cite: uploaded:1A Chemistry for Biologists.pdf].

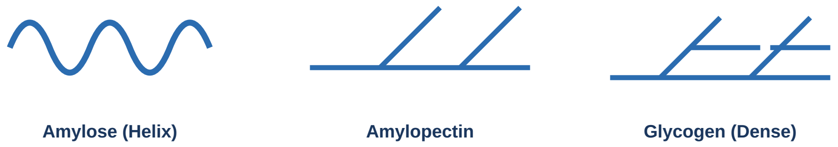
Starch: The Plant Storage Reserve

Starch serves as the main energy reserve in plant tissues and is composed entirely of α-glucose monomers [cite: uploaded:1A Chemistry for Biologists.pdf]. It is a mixture of two distinct structural macromolecules [cite: uploaded:1A Chemistry for Biologists.pdf]:

- **Amylose:** An unbranched polymer featuring exclusively **1,4-glycosidic bonds** [cite: uploaded:1A Chemistry for Biologists.pdf]. The chain twists into a tight, compact helix that optimizes space-saving storage within plant cells [cite: uploaded:1A Chemistry for Biologists.pdf].
- **Amylopectin:** A branched polymer [cite: uploaded:1A Chemistry for Biologists.pdf]. It combines a primary 1,4-glycosidic backbone with frequent **1,6-glycosidic bonds** that create branching points [cite: uploaded:1A Chemistry for Biologists.pdf]. These terminal branches provide many ends where enzymes can attach to quickly hydrolyze and release glucose when energy is needed [cite: uploaded:1A Chemistry for Biologists.pdf].

Glycogen: Animal Storage

Glycogen is the primary carbohydrate storage compound in animals and fungi, stored heavily inside liver and skeletal muscle cells [cite: uploaded:1A Chemistry for Biologists.pdf]. Structurally, glycogen is similar to amylopectin but features significantly more 1,6-glycosidic branching points [cite: uploaded:1A Chemistry for Biologists.pdf]. This highly branched layout allows rapid, parallel enzymatic breakdown, releasing glucose to support muscle contraction and metabolic demands during high activity [cite: uploaded:1A Chemistry for Biologists.pdf].



Amylose (Helix) **Amylopectin** **Glycogen (Dense)**

Figure 3: Structural topology comparison of alpha-glucose storage polymers.

6. Lipids: Macromolecular Energy Repositories

Lipids are non-polar organic molecules comprising Carbon, Hydrogen, and Oxygen [cite: uploaded:1A Chemistry for Biologists.pdf]. Because they contain a lower proportion of oxygen than carbohydrates, they are highly hydrophobic and insoluble in water, though they dissolve easily in organic solvents like ethanol [cite: uploaded:1A Chemistry for Biologists.pdf]. Lipids yield roughly double the energy content per unit mass compared to carbohydrates, making them ideal long-term energy stores [cite: uploaded:1A Chemistry for Biologists.pdf].

Triglyceride Structure and Esterification

A standard triglyceride is constructed from one central **glycerol molecule** bound to three independent **fatty acid chains** [cite: uploaded:1A Chemistry for Biologists.pdf]. The connection requires a condensation reaction between the carboxyl group (–COOH) of each fatty acid and a hydroxyl group (–OH) of the glycerol molecule [cite: uploaded:1A Chemistry for Biologists.pdf]. This process, known as **esterification**, releases three water molecules and forms three covalent **ester bonds** [cite: uploaded:1A Chemistry for Biologists.pdf].

Saturated vs. Unsaturated Fatty Acids

- **Saturated Fatty Acids:** Every carbon atom in the hydrocarbon chain is joined to its neighbor via single covalent bonds [cite: uploaded:1A Chemistry for Biologists.pdf]. This creates straight carbon chains that pack tightly together, meaning saturated lipids typically exist as solid fats at room temperature (common in animals) [cite: uploaded:1A Chemistry for Biologists.pdf].
- **Unsaturated Fatty Acids:** Contain one or more carbon-carbon double bonds ($C{=}C$) within the chain [cite: uploaded:1A Chemistry for Biologists.pdf]. These double bonds introduce physical kinks into the hydrocarbon tail, preventing tight molecular packing and causing these lipids to exist as fluid oils at room temperature (common in plants) [cite: uploaded:1A Chemistry for Biologists.pdf].

7. Proteins: Molecular Machinery and Folding Hierarchies

Proteins serve crucial structural roles (e.g., keratin, collagen) and functional roles (e.g., catalytic enzymes, hormones, hemoglobin) [cite: uploaded:1A Chemistry for Biologists.pdf, uploaded:1B Mamalian Transportation System.pdf]. They are polymers formed from 20 naturally occurring **amino acid** monomers linked together via condensation reactions [cite: uploaded:1A Chemistry for Biologists.pdf].

Amino Acid Structure and the Peptide Bond

Every amino acid shares a centralized structural design built around a central Carbon atom bound to four groups: an alkaline **amino group** (–NH_2), an acidic **carboxyl group** (–COOH), a Hydrogen atom, and a variable **residual R group** [cite: uploaded:1A Chemistry for Biologists.pdf]. Two amino acids couple via a condensation reaction where the amino group of one monomer reacts with the carboxyl group of another, eliminating a water molecule to create a strong covalent **peptide bond** [cite: uploaded:1A Chemistry for Biologists.pdf].

The Four Levels of Protein Structure

1. **Primary Structure:** The specific linear sequence of amino acids within a polypeptide chain, dictated entirely by the cell's genetic code [cite: uploaded:1A Chemistry for Biologists.pdf]. This linear order determines all subsequent folding stages [cite: uploaded:1A Chemistry for Biologists.pdf].
2. **Secondary Structure:** Localized folding within the polypeptide backbone driven by **hydrogen bonds** between the negative oxygen of a carboxyl group and the positive hydrogen of an amino group [cite: uploaded:1A Chemistry for Biologists.pdf]. This creates regular structures, primarily the right-handed spiral **α-helix** or the pleated **β-sheet** [cite: uploaded:1A Chemistry for Biologists.pdf].
3. **Tertiary Structure:** The overall three-dimensional folding of the polypeptide chain into a complex shape, driven by interactions between the variable R groups [cite: uploaded:1A Chemistry for Biologists.pdf]. These bonds include strong covalent **disulfide bridges** (formed via oxidation between adjacent cysteine residues), **ionic bonds** between charged R groups, weak **hydrogen bonds**, and **hydrophobic interactions** where non-polar residues cluster away from surrounding water [cite: uploaded:1A Chemistry for Biologists.pdf].
4. **Quaternary Structure:** Exists only in proteins comprised of multiple polypeptide subunits working together as a single functional macromolecule, such as hemoglobin [cite: uploaded:1A Chemistry for Biologists.pdf, uploaded:1B Mamalian Transportation System.pdf].

EXAM HINT: THE MECHANICS OF DENATURATION

Changes in temperature or pH alter the tertiary structure of a protein by disrupting R-group interactions [cite: uploaded:1B Mamalian Transportation System.pdf]. Heating provides kinetic energy that breaks hydrogen and ionic bonds, causing the protein to unfold and lose its shape [cite: uploaded:1B Mamalian Transportation System.pdf]. This process, known as **denaturation**, is irreversible and destroys the protein's biological function [cite: uploaded:1B Mamalian Transportation System.pdf].

Fibrous vs. Globular Proteins

Property	Fibrous Proteins	Globular Proteins
General Shape	Long, parallel, extended polypeptide strands with minimal tertiary folding.	Spherical, highly folded, compact three-dimensional structural geometry [cite: uploaded:1B Mamalian Transportation System.pdf].
Solubility	Completely insoluble in water.	Dissolves easily or forms clear colloidal suspensions in water [cite: uploaded:1B Mamalian Transportation System.pdf].
R-Group Layout	Hydrophobic R groups project outward along the length of the strands.	Hydrophobic R groups tuck inward; hydrophilic R groups face outward.
Examples & Roles	**Collagen:** Three alpha chains wound into a tight triple helix, forming tough structural fibers for tendons and bone.	**Hemoglobin:** Four folded polypeptide subunits encasing iron-containing heme prosthetic groups to carry oxygen [cite: uploaded:1B Mamalian Transportation System.pdf].