Topic 4: Organic and Biological Chemistry

Most chemicals are compounds of carbon with other elements, mainly hydrogen, oxygen, and nitrogen, with many more being synthesised each year. The variety and importance of carbon compounds are so great that there is a specific branch of chemistry known as ‘organic chemistry’. In this topic students are introduced to the chemistry of the more common organic compounds.

Biological chemistry is a growing area of research; it includes medical technology, genetic engineering, and the development of pharmaceuticals. In this topic students are introduced to the major groups of compounds of biological significance.

The reactions of the larger macromolecules can often be explained by referring to the reactions and properties of smaller molecules with the same functional groups.

4.1 Systematic Nomenclature

Key Ideas	Intended Student Learning
The presence or absence of functional groups in an organic compound determines its physical and chemical properties.	Identify the functional groups in the structural formulae of alcohols, aldehydes, ketones, carboxylic acids, amines, esters, and amides.
Organic compounds are named systematically to provide unambiguous identification.	State, given its structural formula, the systematic name of an organic compound containing: • up to eight carbon atoms arranged as either a straight chain or a branched chain • one or more of the same functional groups (with these limited to hydroxyl, aldehyde, ketone, carboxyl, or primary amino groups).
The structural formula of an organic compound can be deduced from its systematic name.	Given its systematic name, draw the structural formula of an organic compound containing: • up to eight carbon atoms arranged as either a straight chain or a branched chain • one or more of the same functional groups (with these limited to hydroxyl, aldehyde, ketone, carboxyl, or primary amino groups).
Esters are named as derivatives of a carboxylic acid.	State the systematic names of methyl and ethyl esters of straight-chain acids containing up to eight carbon atoms.
The structural formula of an ester can be deduced from its systematic name.	Given its systematic name, draw the structural formula of an organic methyl or ethyl ester of a straight-chain acid containing up to eight carbon atoms.

4.2 Physical Properties

Key Ideas	Intended Student Learning
The melting points and boiling points of organic compounds that contain the same functional group increase with the length of carbon chain.	Predict and explain the melting points and boiling points of an organic compound in comparison with those of other compounds that contain the same functional group.
The boiling points of organic compounds that display hydrogen bonding between molecules are higher than those of compounds of similar molar mass that do not display hydrogen bonding.	Predict and explain the boiling points of alcohols in comparison with those of aldehydes and ketones of similar molar mass.
The boiling points of esters are lower than those of isomeric acids because of the absence of hydrogen bonding between molecules of the ester.	Predict and explain the boiling points of esters in comparison with those of isomeric acids.
Organic compounds are generally insoluble in water.	Explain the insolubility in water of most organic compounds.
Hydrogen bonding between functional groups and water can explain the solubility in water of some smaller organic compounds.	Predict and explain the solubility in water of the smaller amino acids, carboxylic acids, alcohols, aldehydes, and ketones.
The solubility in water of an organic compound depends on its molar mass and the functional groups present.	Predict and explain the relative solubilities in water of two organic compounds, given their structural formulae.

4.3 Alcohols

Key Ideas	Intended Student Learning
Ethanol is produced by the fermentation of glucose, which can be derived by the hydrolysis of complex carbohydrates.	Describe the conditions, and write equations, for the hydrolysis of polysaccharides and disaccharides, and the production of ethanol by the fermentation of glucose.
Alcohols are classified as primary, secondary, or tertiary.	Identify a hydroxyl group in an alcohol as primary, secondary, or tertiary, given the structural formula.
Primary and secondary alcohols can be distinguished from tertiary alcohols by their reaction with acidified dichromate solution.	Describe how primary and secondary alcohols can be distinguished from tertiary alcohols by their reaction with acidified dichromate solution.
The type of product obtained by oxidising an alcohol depends on whether the alcohol is primary or secondary.	Predict the structural formula(e) of the product(s) of dichromate oxidation of a primary or secondary alcohol, given its structural formula.

4.4 Aldehydes and Ketones

Key Ideas	Intended Student Learning
Aldehydes and ketones are produced by the oxidation of the corresponding primary and secondary alcohols respectively. Aldehydes are readily oxidised and so must be distilled off from the reaction mixture as they are formed.	Given the structural formula of the aldehyde or ketone, draw the structural formula of the alcohol from which it could be produced by oxidation, and describe the necessary reaction conditions.
Aldehydes can be oxidised to form carboxylic acids or, in alkaline solutions, carboxylate ions.	Draw the structural formula of the oxidation product of a given aldehyde in either acidic or alkaline conditions.
Ketones cannot readily be oxidised. This difference in properties between aldehydes and ketones can be used to distinguish one from the other.	Describe how acidified dichromate solution and Tollens' reagent (ammoniacal silver nitrate solution) can be used to distinguish between aldehydes and ketones.

4.5 Carboxylic Acids

Key Ideas	Intended Student Learning
Carboxylic acids can be produced by the oxidation of aldehydes or primary alcohols.	Identify the aldehyde or primary alcohol from which a carboxylic acid could be produced by oxidation, given its structural formula.
Carboxylic acids are weak acids and, to a small extent, ionise in water.	Write an equation for the ionisation of a carboxylic acid in water.
Carboxylic acids react with bases to form ionic carboxylate salts.	Write equations for the reactions of carboxylic acids with hydroxides, carbonates, and hydrogencarbonates, and describe changes that accompany these reactions.
The salts of sodium and potassium carboxylates are soluble in water because of the ion–dipole attraction between the ions and water.	Explain why some drugs with carboxyl groups are usually taken in the form of their salts.

4.6 Amines

Key Ideas	Intended Student Learning
Owing to the presence of an unbonded electron pair, amines are able to act as bases and accept H^+ ions.	Draw the structural formula of the protonated form of an amine, given the structural formula of its molecular form, and vice versa.
Amines are classified as primary, secondary, or tertiary.	Identify an amino group in an amine as primary, secondary, or tertiary, given the structural formula.
The salts of amines are soluble in water because of the ion–dipole attraction between the ions and water.	Explain why some drugs with amine groups are usually taken in the form of their salts.

4.7 Esters

Key Ideas	Intended Student Learning
An ester can be produced by a condensation reaction between an alcohol and a carboxylic acid.	Draw the structural formula of the ester that could be produced by the condensation reaction between an alcohol and a carboxylic acid, given their structural formulae, and write an equation for the reaction.
The production of an ester from the reaction of an alcohol and a carboxylic acid is slow at 25°C.	Explain the use of heating under reflux and the presence of a trace of concentrated sulfuric acid in the laboratory production of esters.
Esters may be hydrolysed under acidic or alkaline conditions.	Identify the products of hydrolysis of an ester, given its structural formula.

4.8 Amides

Key Ideas	Intended Student Learning
An amide can be produced by a condensation reaction between an amine and a carboxylic acid.	Draw the structural formula of the amide that could be produced by the condensation reaction between an amine and a carboxylic acid, given their structural formulae.
Amides may be hydrolysed under acidic or alkaline conditions.	Identify the products of hydrolysis of an amide, given its structural formula.

4.9 Proteins

Key Ideas	Intended Student Learning
Amino acids contain a carboxyl group and an amino group.	Determine whether or not a compound is an amino acid, given its structural formula.
Amino acids can self-ionise to produce an ion.	Draw the structural formula of the product formed when an amino acid self-ionises.
Proteins are large molecules in which amide groups link monomer units. In proteins the amide group is called a 'peptide link' or a 'peptide bond'.	Identify the amide group and deduce the structural formula(e) of the monomer(s), given the structural formula of a section of a protein.
Proteins are polyamides consisting of covalently bonded long chains of amino acid units.	Write the general formula of amino acids and recognise their structural formulae.
Proteins have sites that allow hydrogen bonding between sections of chains and between the chain and water.	Identify where hydrogen bonding can occur between protein chains or between the chain and water, given the structural formula of a section of the chain.
The biological function of a protein is a consequence of its unique spatial arrangement.	Explain why the biological function of a protein (e.g. an enzyme) is altered if its spatial arrangement is altered.

Key Ideas	Intended Student Learning
Changes in pH and temperature disrupt the secondary interactions, and hence the spatial arrangements, of a protein chain.	Explain why proteins are sensitive to changes in pH and temperature.

4.10 Triglycerides

Key Ideas	Intended Student Learning
Edible oils and fats are esters of propane-1,2,3-trio (glycerol) and various carboxylic acids. The carboxylic acids are unbranched and usually contain an even number of carbon atoms between twelve and twenty.	Draw the structural formula of an edible oil or fat, given the structural formula(e) of the carboxylic acid(s) from which it is derived.
Triglycerides can be hydrolysed to produce propane-1,2,3-triol and various carboxylic acids.	Identify the alcohol and acid(s) from which a triglyceride is derived, given its structural formula.
Edible oils are liquids at 25°C and are commonly obtained from plants and fish. Edible fats are solids at 25°C and are commonly obtained from land animals.	Identify the most likely source of a triglyceride, given its state at 25°C.
Most liquid triglycerides contain a larger proportion of unsaturated carbon chains than solid triglycerides contain.	Describe and explain the use of a solution of bromine or iodine to determine the degree of unsaturation of a compound. Draw the structural formula of the reaction product.
Liquid triglycerides can be converted into triglycerides of higher melting point by a process that involves the addition of hydrogen under pressure and at increased temperature, in the presence of a catalyst.	Explain the role of pressure, temperature, and a catalyst in the hydrogenation of liquid triglycerides.

4.11 Carbohydrates

Key Ideas	Intended Student Learning
Carbohydrates are naturally occurring sugars and their polymers. They usually have the general formula $C_xH_{2y}O_y$. They are defined more precisely as either polyhydroxy aldehydes or polyhydroxy ketones, or their polymers.	Given its structural formula, determine the molecular formula of an organic compound, and whether or not it is a carbohydrate.
Carbohydrates can be classified as monosaccharides, disaccharides, or polysaccharides.	Write molecular formulae for glucose, and for disaccharides and polysaccharides based on glucose monomers.
Polysaccharides are produced by the condensation of many monosaccharide units linked in chains by covalent bonds.	Identify the repeating unit and draw the structural formula of the monomer, given the structural formula of a section of a polysaccharide derived from one monomer.

Key Ideas	Intended Student Learning
Glucose molecules can occur in either a chain form or a ring form. There is equilibrium between the two structures. In the chain form an aldehyde group is present.	Explain the ability of glucose to react as an aldehyde when in chain form but not when in ring form.
Many simple carbohydrates are soluble in water, whereas polysaccharides are insoluble in water.	Explain the differences in solubility in water of simple carbohydrates and polysaccharides in terms of the size of the molecules and the number of hydroxyl groups.