Topic 6: Organic Chemistry I

Edexcel A Level Chemistry • Paper 1 (9CH0/01)

6.1	Know that a hydrocarbon is a compound of hydrogen and carbon only. A hydrocarbon contains only carbon and hydrogen atoms. Examples: alkanes (e.g. CH_4), alkenes (e.g. C_2H_4), arenes (e.g. C_6H_6). No other elements are present.
6.2	Be able to represent organic molecules using empirical, molecular, general, structural, displayed and skeletal formulae. Empirical formula: simplest whole number ratio (e.g. CH_2 for ethene). Molecular formula: actual number of atoms (e.g. C_2H_4). General formula: formula for a homologous series (e.g. C_nH_{2n+2} for alkanes). Structural formula: shows how atoms are grouped (e.g. CH_3CH_3). Displayed formula: shows every bond between every atom. Skeletal formula: carbon backbone as zigzag lines; C and H atoms on the chain are not shown; functional groups and heteroatoms are shown.
6.3	Know what is meant by the terms 'homologous series' and 'functional group'. Homologous series: a family of compounds with the same functional group and same general formula, differing by CH_2 between successive members. They show a gradual trend in physical properties and similar chemical properties. Functional group: the atom or group of atoms responsible for the characteristic chemical reactions of a compound (e.g. C=C in alkenes, –OH in alcohols).
6.4	Be able to name compounds using IUPAC nomenclature rules (prefixes up to C10). IUPAC naming rules: (1) Find the longest carbon chain → parent name. (2) Number from the end nearest the functional group/branch. (3) Name branches as prefixes (methyl, ethyl, etc.). (4) Use di-, tri- for multiple identical groups. (5) Functional group determines the suffix. Prefixes: meth- (1), eth- (2), prop- (3), but- (4), pent- (5), hex- (6), hept- (7), oct- (8), non- (9), dec- (10).

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6.5 Be able to classify reactions as addition, elimination, substitution, oxidation, reduction, hydrolysis or polymerisation.

Addition: two molecules combine to form one product (no atoms lost).

Elimination: a small molecule (e.g. H_2O, HBr) is removed from one molecule.

Substitution: one atom/group is replaced by another.

Oxidation: gain of oxygen / loss of hydrogen / loss of electrons.

Reduction: loss of oxygen / gain of hydrogen / gain of electrons.

Hydrolysis: a bond is broken by reaction with water (or aqueous OH^-/H^+).

Polymerisation: many small molecules (monomers) join to form a long chain (polymer).

6.6 Understand the term 'structural isomerism' and determine possible structural, displayed and skeletal formulae of an organic molecule.

Structural isomers have the same molecular formula but different structural formulae (different connectivity of atoms).

Types: chain isomerism (different carbon skeleton), position isomerism (same functional group in different positions), functional group isomerism (different functional groups, e.g. alcohol vs ether for C_2H_6O).

6.7 Understand the term 'stereoisomerism', as illustrated by E/Z isomerism (including cis-trans isomerism).

Stereoisomers have the same structural formula but a different arrangement of atoms in space.

E/Z isomerism occurs in alkenes where there is restricted rotation about the C=C and two different groups on each carbon of the double bond.

Z (cis): higher priority groups on the same side of the double bond.

E (trans): higher priority groups on opposite sides.

Priority is assigned by atomic number (Cahn-Ingold-Prelog rules).

6.8 Know the general formula for alkanes.

C_nH_{2n+2} (where n = number of carbon atoms). E.g. methane CH_4, ethane C_2H_6, propane C_3H_8.

Cycloalkanes have the general formula C_nH_{2n}.

6.9 Know that alkanes and cycloalkanes are saturated hydrocarbons.

Saturated means the molecule contains only single (sigma) bonds between carbon atoms – no C=C double bonds. All bonds are C–C or C–H. This makes alkanes relatively unreactive compared to alkenes.

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6.10 Understand that alkane fuels are obtained from fractional distillation, cracking and reforming of crude oil.

Fractional distillation: crude oil is heated and separated into fractions based on boiling point range. Shorter chains have lower b.p. and are collected near the top of the column.

Cracking: long-chain alkanes are broken into shorter, more useful molecules (shorter alkanes + alkenes). Thermal cracking (high T, high P) or catalytic cracking (zeolite catalyst, lower T).

Reforming: straight-chain alkanes are converted into branched-chain alkanes and cyclic hydrocarbons for more efficient combustion (higher octane rating).

6.11 Know that pollutants are formed during combustion of alkane fuels, including CO, NOx, SOx, carbon particulates and unburned hydrocarbons.

Carbon monoxide (CO): from incomplete combustion (insufficient O_2). Toxic.

Nitrogen oxides (NO_x): formed at high temperatures when N_2 and O_2 from the air react.

Sulfur dioxide (SO_2): from combustion of sulfur impurities in the fuel.

Carbon particulates (soot): from incomplete combustion.

Unburned hydrocarbons: from incomplete combustion; contribute to smog.

6.12 Understand problems from pollutants: toxicity of CO, acidity of NOx and SOx.

CO is toxic: it binds to haemoglobin more strongly than O_2, forming carboxyhaemoglobin, preventing oxygen transport in the blood. CO is colourless and odourless, making it especially dangerous.

NO_x and SO_x cause acid rain: they dissolve in atmospheric water to form nitric acid (HNO_3) and sulfuric acid (H_2SO_4), which damage buildings, ecosystems and aquatic life.

6.13 Understand how a catalytic converter solves some pollutant problems.

A catalytic converter (Pt/Pd/Rh catalyst on a ceramic honeycomb) converts toxic exhaust gases:

$2CO + 2NO \rightarrow 2CO_2 + N_2$ (removes both CO and NO simultaneously).

CO is oxidised to CO_2; NO is reduced to N_2. The catalyst provides a surface for adsorption, weakening bonds and enabling reaction at lower activation energy.

6.14 Understand the use of alternative fuels, including biodiesel and alcohols from renewable sources.

Biofuels (biodiesel, bioethanol) are made from renewable plant sources.

Advantages: carbon-neutral in theory (CO_2 released = CO_2 absorbed during growth); reduce dependence on finite fossil fuels.

Disadvantages: large land area needed (competition with food crops); energy input for farming/processing; not truly carbon-neutral when full lifecycle is considered.

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6.15 Know that a radical: (i) is a species with an unpaired electron, (ii) is formed by homolytic fission.

(i) A radical (free radical) has an unpaired electron, shown as a single dot (e.g. Cl•). Radicals are very reactive because they seek to pair their unpaired electron.

(ii) Homolytic fission: a covalent bond breaks so that each atom takes one electron from the bond. This produces two radicals. Requires energy (UV light or heat). E.g. $Cl_2 \rightarrow 2Cl•$

6.16 Understand reactions of alkanes with: (i) oxygen (combustion), (ii) halogens (radical substitution mechanism).

(i) Complete combustion: alkane + $O_2 \rightarrow CO_2 + H_2O$. Incomplete combustion: CO, C (soot), or H_2O.

(ii) Radical substitution (e.g. $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ in UV light):

Initiation: $Cl_2 \rightarrow 2Cl•$ (UV light breaks Cl–Cl bond homolytically)

Propagation: $Cl• + CH_4 \rightarrow CH_3• + HCl$, then $CH_3• + Cl_2 \rightarrow CH_3Cl + Cl•$

Termination: any two radicals combine, e.g. $Cl• + Cl• \rightarrow Cl_2$, or $CH_3• + Cl• \rightarrow CH_3Cl$

Curly half-arrows are NOT needed for radical mechanisms.

6.17 Understand limitations of radical substitution in synthesis: further substitution and mixture of products.

Radical substitution is not useful in synthesis because:

- Further substitution occurs: CH_3Cl can react again to form CH_2Cl_2, $CHCl_3$, CCl_4.
- A mixture of products is obtained, making it difficult to isolate the desired product.
- Different hydrogen atoms can be substituted, giving positional isomers.

6.18 Know the general formula for alkenes.

C_nH_{2n} (where $n \geq 2$). E.g. ethene C_2H_4, propene C_3H_6.

Cycloalkenes have the general formula C_nH_{2n-2}.

6.19 Know that alkenes and cycloalkenes are unsaturated hydrocarbons.

Unsaturated means the molecule contains at least one C=C double bond. This makes alkenes more reactive than alkanes, as the π-bond is a region of high electron density that can be attacked by electrophiles.

6.20 Understand the bonding in alkenes in terms of σ- and π-bonds.

The C=C double bond consists of:

- A σ-bond: formed by the head-on overlap of two sp^2 hybrid orbitals. Strong; allows free rotation.
- A π-bond: formed by the sideways overlap of two p-orbitals above and below the plane of the molecule. Weaker than the σ-bond; prevents rotation (causing E/Z isomerism). The π-bond has a region of high electron density above and below the bond, making it susceptible to electrophilic attack.

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6.21 Know what is meant by the term 'electrophile'.

An electrophile is an electron-pair acceptor – a species attracted to regions of high electron density (e.g. the π-bond in alkenes). Electrophiles are either positively charged (e.g. H^+, NO_2^+) or have a partial positive charge (e.g. δ+Br in Br_2).

6.22 Understand the addition reactions of alkenes with: (i) H_2/Ni, (ii) halogens, (iii) hydrogen halides, (iv) steam/acid catalyst, (v) $KMnO_4$ in acid.

(i) H_2 + Ni catalyst, 150°C: alkene → alkane (hydrogenation). Used in margarine manufacture.

(ii) Halogens (e.g. Br_2): alkene + Br_2 → dihalogenoalkane. Bromine water decolourises (test for C=C).

(iii) Hydrogen halides (e.g. HBr): alkene + HBr → halogenoalkane. Markovnikov's rule: H adds to the C with more H atoms (via the more stable carbocation).

(iv) Steam + H_3PO_4 catalyst (300°C, 60 atm): alkene + H_2O → alcohol. Industrial production of ethanol.

(v) $KMnO_4$ (acidified, cold, dilute): alkene → diol. Purple $KMnO_4$ decolourises.

6.23 Understand that heterolytic bond fission results in the formation of ions.

Heterolytic fission: a covalent bond breaks so that both electrons go to one atom, forming a cation and an anion. E.g. HBr → H^+ + Br^-. This is the opposite of homolytic fission. It occurs in polar molecules and in ionic bond formation.

6.24 Understand the mechanism of electrophilic addition between alkenes and: (i) halogens, (ii) hydrogen halides, (iii) other binary compounds.

(i) With Br_2: the π-bond repels electrons in Br_2, inducing a dipole (δ+Br–Brδ–). Curly arrow from C=C π-bond to δ+Br shows bond formation. Second curly arrow from Br–Br to departing Br shows heterolytic fission. Forms a carbocation intermediate + Br^-. Then Br^- attacks the carbocation.

(ii) With HBr: curly arrow from C=C to δ+H. The more stable secondary or tertiary carbocation forms preferentially (Markovnikov's rule). Br^- then attacks the carbocation.

Carbocation stability: tertiary > secondary > primary (due to the inductive effect of alkyl groups).

6.25 Know the qualitative test for a C=C double bond using bromine or bromine water.

Add bromine water (orange/brown) to the substance. If a C=C double bond is present, the bromine water is decolourised (turns from orange to colourless) because Br_2 undergoes electrophilic addition across the double bond. Alkanes do NOT decolourise bromine water.

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6.26 Know that alkenes form polymers through addition polymerisation. Be able to identify repeat units.

In addition polymerisation, many alkene monomers join together to form a long-chain polymer with no by-products (atom economy = 100%). The C=C double bond in each monomer opens up and the monomers link by single C–C bonds.

Repeat unit: draw the monomer with the double bond opened, and show the continuation bonds extending from each end. E.g. ethene → poly(ethene).

6.27 Know that waste polymers can be: (i) recycled, (ii) incinerated for energy, (iii) used as feedstock for cracking.

(i) Recycling: polymers are sorted by type and reprocessed. Reduces waste and use of raw materials.

(ii) Incineration: burning polymers releases energy that can generate electricity. Produces CO_2 and may release toxic gases (e.g. HCl from PVC).

(iii) Feedstock recycling/cracking: polymers are broken down into monomers or other useful small molecules (e.g. for fuel or chemical synthesis).

6.28 Understand, in terms of energy and resources over the life cycle of polymer products, that chemists can contribute to more sustainable use of materials.

Chemists consider the entire life cycle of a polymer: raw material extraction, manufacture, use, and disposal. Sustainable approaches include: using renewable feedstocks, reducing energy in production, designing polymers for easier recycling, and extending product lifetimes.

6.29 Understand how chemists limit polymer disposal problems by: (i) developing biodegradable polymers, (ii) removing toxic waste gases from incineration.

(i) Biodegradable polymers (e.g. PLA from corn starch) can be broken down by microorganisms, reducing landfill waste.

(ii) Toxic gases from incineration (e.g. HCl from PVC, dioxins) can be removed by scrubbers (e.g. using $Ca(OH)_2$ to neutralise acidic gases) or filters to trap particulates.

6.30 Know that halogenoalkanes can be classified as primary, secondary or tertiary.

Classification depends on the carbon bonded to the halogen:

Primary (1°): the C bonded to the halogen is attached to one other carbon (or none, e.g. CH_3Br).

Secondary (2°): the C bonded to the halogen is attached to two other carbons.

Tertiary (3°): the C bonded to the halogen is attached to three other carbons.

6.31 Understand what is meant by the term 'nucleophile'.

A nucleophile is an electron-pair donor – a species attracted to regions of positive charge (δ+ or +). Nucleophiles have a lone pair of electrons which they donate to form a new covalent bond. Examples: OH^-, CN^-, NH_3, H_2O.

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6.32 Understand the reactions of halogenoalkanes with: (i) aqueous KOH → alcohols, (ii) aqueous $AgNO_3$ in ethanol, (iii) KCN → nitriles, (iv) NH_3 → primary amines, (v) ethanolic KOH → alkenes.

(i) Aqueous KOH (nucleophilic substitution): R–X + OH^- → R–OH + X^-. OH^- acts as a nucleophile. Produces an alcohol. Reflux with aqueous KOH.

(ii) Aqueous $AgNO_3$ in ethanol: H_2O acts as the nucleophile. The halide ion released reacts with Ag^+ to form a silver halide precipitate: AgCl (white), AgBr (cream), AgI (yellow). Used to test for and compare rates of hydrolysis.

(iii) KCN (nucleophilic substitution): R–X + CN^- → R–CN + X^-. Increases the carbon chain by one C. Reflux with ethanolic KCN.

(iv) NH_3 (nucleophilic substitution): R–X + $2NH_3$ → R–NH_2 + NH_4X. Produces a primary amine. Heat with excess concentrated ammonia in a sealed tube.

(v) Ethanolic KOH (elimination): R–X + KOH → alkene + H_2O + KX. OH^- acts as a base (removes H^+). Reflux with ethanolic (not aqueous) KOH.

6.33 Understand that experimental observations can compare rates of hydrolysis of: (i) primary, secondary, tertiary halogenoalkanes, (ii) chloro-, bromo-, iodoalkanes, using aqueous $AgNO_3$ in ethanol.

Add aqueous $AgNO_3$ in ethanol to the halogenoalkane and time how long until a precipitate appears.

(i) Tertiary fastest, primary slowest. Tertiary undergoes SN1 (stable carbocation intermediate).

(ii) Iodoalkanes fastest, chloroalkanes slowest. The C–I bond has the lowest bond enthalpy (weakest, easiest to break). C–Cl is strongest, so slowest.

Precipitate colour identifies the halide: AgCl (white), AgBr (cream), AgI (yellow).

6.34 Know the trend in reactivity of primary, secondary and tertiary halogenoalkanes.

Tertiary > secondary > primary for hydrolysis rate.

Tertiary halogenoalkanes react via an SN1 mechanism (carbocation intermediate stabilised by three alkyl groups). Primary halogenoalkanes react via an SN2 mechanism (direct attack by nucleophile, backside attack).

6.35 Understand, in terms of bond enthalpy, the trend in reactivity of chloro-, bromo- and iodoalkanes.

Reactivity: iodoalkanes > bromoalkanes > chloroalkanes.

Bond enthalpy: C–Cl > C–Br > C–I. The C–I bond is the weakest (lowest bond enthalpy), so it is easiest to break, making iodoalkanes the most reactive. The C–Cl bond is the strongest, so chloroalkanes are the least reactive.

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6.36 Understand the mechanisms of nucleophilic substitution between primary halogenoalkanes and: (i) aqueous KOH, (ii) ammonia.

Both are SN2 mechanisms (one step, bimolecular).

(i) With OH^-: curly arrow from the lone pair on OH^- to the δ+C. Simultaneously, curly arrow from the C–X bond to the halogen. The nucleophile attacks from the opposite side to the leaving group (backside attack). Transition state has 5 bonds to C. Configuration is inverted.

(ii) With NH_3: curly arrow from the lone pair on N to the δ+C. C–X bond breaks. An intermediate forms, then a second NH_3 molecule removes an H^+ to give the amine + NH_4^+. Show the lone pair on N, the δ+ on C, and the δ– on X.

6.37 Know that alcohols can be classified as primary, secondary or tertiary.

Classification depends on the carbon bonded to the –OH group:

Primary (1°): the C bearing –OH has one (or zero) other C atoms attached.

Secondary (2°): the C bearing –OH has two other C atoms.

Tertiary (3°): the C bearing –OH has three other C atoms.

This classification determines the oxidation products.

6.38 Understand the reactions of alcohols with: (i) oxygen, (ii) halogenating agents, (iii) $K_2Cr_2O_7/H_2SO_4$, (iv) conc. H_3PO_4.

(i) Combustion: alcohol + O_2 → CO_2 + H_2O. Clean-burning fuels.

(ii) Halogenating agents: PCl_5 + alcohol → chloroalkane + $POCl_3$ + HCl (steamy white fumes of HCl confirm –OH). KBr + 50% H_2SO_4 + alcohol → bromoalkane. Red phosphorus + I_2 + alcohol → iodoalkane.

(iii) Oxidation with acidified $K_2Cr_2O_7$:

Primary alcohol → aldehyde (distil immediately) → carboxylic acid (reflux).

Secondary alcohol → ketone (reflux or distil).

Tertiary alcohol → no reaction (cannot be oxidised).

Orange dichromate turns green (Cr^{3+}) if oxidation occurs. Test aldehydes with Fehling's (brick-red ppt) or Tollens' (silver mirror).

(iv) Elimination with conc. H_3PO_4: alcohol + H_3PO_4 (heat) → alkene + H_2O. This is a dehydration/elimination reaction.

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6.39 Understand techniques used in preparation and purification of a liquid organic compound: (i) reflux, (ii) extraction, (iii) distillation, (iv) drying, (v) boiling point determination.

(i) Reflux: heating in a flask fitted with a vertical condenser. Vapour condenses and returns to the flask, allowing prolonged heating without loss of volatile substances.

(ii) Solvent extraction (separating funnel): shaking the product with an immiscible solvent to extract it. Drain the lower layer.

(iii) Distillation: heating to separate the product by boiling point. Collect the fraction boiling at the correct temperature.

(iv) Drying: add an anhydrous drying agent (e.g. anhydrous $MgSO_4$ or $CaCl_2$) to remove traces of water. Filter off the drying agent.

(v) Boiling point determination: compare the observed boiling point with the literature value to confirm identity and assess purity.

Investigation of the Rates of Hydrolysis of Some Halogenoalkanes

The Oxidation of Ethanol

Chlorination of 2-methylpropan-2-ol Using Concentrated Hydrochloric Acid

ABOUT THESE NOTES

Notes written by Chloe Archard (MSc Biochemistry, Oxford-trained chemist, 20+ years teaching experience at top UK independent schools). For 1-1 tuition, revision courses, and more free resources: chemistrywithchloe.com

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