Chemistry with Chloe

Expert A Level Chemistry Tuition

OCR A Level Chemistry A

Component 02: Synthesis and Analytical Techniques

H432/02 • 2 hours 15 minutes • 100 marks • 37% of A-level

COMPLETE REVISION GUIDE

Modules 4 and 6

Core Organic Chemistry • Organic Chemistry and Analysis

Module 2 (Foundations) is also assessed – see Component 01 guide

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How to Use This Guide

This revision guide covers every specification point examined in OCR A Level Chemistry A Component 02 (H432/02), including Module 4 (Core Organic Chemistry) and Module 6 (Organic Chemistry and Analysis).

Module 2 (Foundations in Chemistry) is also assessed in Component 02 – refer to the Component 01 guide for those topics.

PAG practicals are included inline where they appear in the specification, with full methods, uncertainties, errors and improvements.

Use this guide alongside past papers. Good luck! – Chloe

MODULE 4: CORE ORGANIC CHEMISTRY

4.1 Basic Concepts and Hydrocarbons

4.1.1 Basic Concepts of Organic Chemistry

4.1.1a-b	*IUPAC nomenclature. Structural, displayed, skeletal and general formulae. Know names of first ten alkanes and their alkyl groups.*
	IUPAC naming: longest chain = parent name. Number substituents from the end giving lowest locants. E.g. 2-methylbutan-1-ol. **General formula:** algebraic formula for a homologous series (e.g. alkanes: C_nH_{2n+2}). **Structural formula:** minimal detail showing arrangement (e.g. $CH_3CH_2CH_2CH_3$). **Displayed formula:** shows all atoms and bonds. **Skeletal formula:** carbon skeleton only; C and H on chain not shown; heteroatoms and functional groups shown. **First ten alkanes:** methane, ethane, propane, butane, pentane, hexane, heptane, octane, nonane, decane.

4.1.1c-d	*Homologous series, functional group, alkyl group. Terms: aliphatic, alicyclic, aromatic, saturated, unsaturated. General formula to predict formulae.*
	Homologous series: same functional group, differ by CH_2, same general formula. Similar chemical properties, gradual trend in physical properties. **Functional group:** group of atoms responsible for characteristic reactions. **Aliphatic:** straight/branched chains or non-aromatic rings. **Alicyclic:** non-aromatic ring (e.g. cyclohexane). **Aromatic:** contains benzene ring. **Saturated:** single C–C bonds only. **Unsaturated:** contains C=C, C≡C or aromatic ring.

4.1.1e	*Structural isomers: same molecular formula, different structural formula. Determine possible structural formulae.*
	Structural isomers: same molecular formula, different structural formula. Types: **chain** (different carbon skeleton), **position** (same group, different location), **functional group** (different functional group, e.g. alcohol vs ether).

4.1.1f-i	*Homolytic and heterolytic fission. Radicals (dot notation). Curly arrows from lone pairs, bonds or negative charges. Mechanism diagrams with dipoles.*
	Homolytic fission: bond breaks evenly → each atom gets one electron → two **radicals** (shown with a dot •). **Heterolytic fission:** bond breaks unevenly → one atom gets both electrons → ions formed. **Curly arrow:** shows movement of an **electron pair**. Must start from: a lone pair, a bond, or a negative charge. Points to where electrons move to. OCR note: half curly arrows are NOT required. Include relevant dipoles (δ+ and δ–) on mechanism diagrams.

4.1.2 Alkanes

4.1.2a-c	*Alkanes: saturated hydrocarbons with C–C and C–H σ-bonds. Free rotation. Tetrahedral shape (109.5°). Boiling points explained by London forces (chain length and branching).*
	Alkanes: general formula C_nH_{2n+2}. Saturated hydrocarbons. Only **σ-bonds** (head-on orbital overlap). Free rotation about C–C. Each carbon is **tetrahedral** (109.5°) – 4 bonding pairs, no lone pairs. **Boiling points increase** with chain length (more electrons → stronger London forces). **Branching decreases b.p.** (more compact shape → less surface contact → weaker London forces).

4.1.2d-e	*Low reactivity of alkanes (high bond enthalpy, low polarity). Combustion: complete and incomplete (CO danger).*
	Alkanes are **unreactive** because: C–H and C–C bonds have **high bond enthalpy** (hard to break) and **very low polarity** (not attacked by nucleophiles/electrophiles). **Complete combustion:** alkane + O_2 → CO_2 + H_2O. **Incomplete combustion** (limited O_2): produces **CO** (toxic, binds to haemoglobin) and/or **C** (soot/particulates).

4.1.2f-g	*Radical substitution with Cl_2/Br_2 and UV: initiation, propagation, termination. Limitations: mixture of products.*
	Initiation: Cl_2 → 2Cl• (UV, homolytic fission). **Propagation:** Cl• + CH_4 → CH_3• + HCl, then CH_3• + Cl_2 → CH_3Cl + Cl•. **Termination:** two radicals combine (Cl• + Cl•, CH_3• + Cl•, CH_3• + CH_3•). OCR: use dots • for all radical species. Half curly arrows NOT required. **Limitations:** further substitution (CH_2Cl_2, $CHCl_3$, CCl_4) and substitution at different positions → **mixture of products** → poor for synthesis.

4.1.3 Alkenes

4.1.3a-b	*Alkenes: unsaturated, C=C with π-bond (sideways p-orbital overlap) and σ-bond. Restricted rotation. Trigonal planar shape (120°).*
	Alkenes: general formula C_nH_{2n}. Unsaturated. C=C bond = **σ-bond** (head-on overlap) + **π-bond** (sideways p-orbital overlap above and below). **Restricted rotation** about C=C (p-orbitals must stay aligned) → gives rise to E/Z isomerism. Carbon atoms in C=C are **trigonal planar** (120°) – 3 regions of electron density.

4.1.3c-d	*E/Z and cis-trans isomerism. Stereoisomers. CIP priority rules. Determine possible stereoisomers.*
	Stereoisomers: same structural formula, different arrangement in space. **E/Z isomerism:** requires restricted rotation (C=C) + two different groups on each C of C=C. **CIP rules:** higher atomic number = higher priority. Z (zusammen) = higher priority groups on SAME side. E (entgegen) = OPPOSITE sides. **Cis-trans:** special case where two of the four substituents are the same. Cis = same side, trans = opposite.

4.1.3e-i	*Reactivity from low π-bond enthalpy. Addition reactions: H_2/Ni, halogens, HX, steam/H_3PO_4. Electrophile definition. Electrophilic addition mechanism. Markovnikov's rule and carbocation stability.*
	Alkene reactivity: π-bond has lower bond enthalpy than σ-bond → easier to break. C=C is a region of **high electron density** → attracts **electrophiles**. **Electrophile:** electron pair acceptor. **Addition reactions:** + H_2 (Ni catalyst) → alkane. + Br_2 → dibromoalkane (test: bromine water decolourised). + HBr → bromoalkane. + H_2O (H_3PO_4 catalyst, steam) → alcohol. **Mechanism:** curly arrow from C=C π-bond to δ+ atom of electrophile. Carbocation intermediate. Nucleophilic attack by –ve ion. **Markovnikov's rule:** H adds to C with more H's → more stable carbocation (3° > 2° > 1°) → **major product**. OCR: either carbocation or halonium intermediate acceptable for Br_2.

4.1.3j	*Addition polymerisation from alkenes and substituted alkenes. Repeat units: deduce from monomer and vice versa.*
	Addition polymerisation: many small alkene monomers join. C=C opens to form C–C backbone. No by-products (100% atom economy). **Repeat unit:** draw monomer with double bond opened; continuation bonds at each end. Can identify monomer from a section of polymer (close the C=C).

4.1.3k-l	*Waste polymer processing: combustion, feedstock recycling, removal of toxic by-products (e.g. HCl from PVC). Biodegradable and photodegradable alternatives.*
	Processing waste polymers: (1) combustion for energy (but CO_2 and toxic gases, e.g. HCl from PVC). (2) Feedstock recycling (break down to monomers/organic chemicals). (3) Remove toxic products (e.g. scrub HCl from PVC combustion). **Biodegradable polymers:** broken down by microorganisms. **Photodegradable:** broken down by light. Both reduce dependency on crude oil and problems of persistent plastic waste in landfill.

4.2 Alcohols, Haloalkanes and Analysis

4.2.1 Alcohols

4.2.1a	*Polarity of alcohols and H-bonding. Water solubility and low volatility compared with alkanes. Classification: primary, secondary, tertiary.*
	Alcohols contain the **–OH** functional group. The O–H bond is polar → can form **hydrogen bonds** with water and other alcohol molecules. **Water solubility:** short-chain alcohols are soluble (H-bonding with water). Solubility decreases as chain length increases (non-polar hydrocarbon chain dominates). **Lower volatility** than alkanes of similar Mr (H-bonds between alcohol molecules require more energy to overcome). **Primary (1°):** OH on a carbon bonded to 1 other C. **Secondary (2°):** OH on C bonded to 2 other C's. **Tertiary (3°):** OH on C bonded to 3 other C's.

4.2.1b-c	*Combustion of alcohols. Oxidation with $Cr_2O_7^{2-}/H^+$: primary → aldehyde (distil) or carboxylic acid (reflux). Secondary → ketone. Tertiary → no reaction.*
	Combustion: alcohols burn to give CO_2 + H_2O. **Oxidation (acidified $K_2Cr_2O_7$):** **Primary → aldehyde:** distil immediately (remove product before further oxidation). Orange → green. **Primary → carboxylic acid:** reflux with excess oxidising agent. Orange → green. **Secondary → ketone:** reflux or distil. Orange → green. **Tertiary → no reaction** (no H on C bearing OH). Orange stays orange. Use [O] in equations. E.g. $CH_3CH_2OH + [O] \rightarrow CH_3CHO + H_2O$.

4.2.1d-e	*Elimination of H_2O (acid catalyst, heat) to form alkenes. Substitution with halide ions/H_2SO_4 to form haloalkanes.*
	Dehydration (elimination): alcohol + conc. H_3PO_4 (or H_2SO_4), heat → alkene + H_2O. Mechanism not required at this stage. **Substitution to haloalkane:** alcohol + NaBr/H_2SO_4 → bromoalkane + $NaHSO_4$ + H_2O. Mechanism not required.

4.2.2 Haloalkanes

4.2.2a-d	*Hydrolysis of haloalkanes: by aqueous alkali and by $AgNO_3$/ethanol. Nucleophile definition. SN2 mechanism for primary haloalkanes. Trend in hydrolysis rate (C–F to C–I) from bond enthalpies.*
	Hydrolysis: $R–X + OH^- \rightarrow R–OH + X^-$ (substitution). **$AgNO_3$ test:** haloalkane + $AgNO_3$ in ethanol/water, warm. Rate of precipitate formation shows: **C–I fastest** > C–Br > C–Cl > C–F slowest. **Nucleophile:** electron pair donor. **SN2 mechanism (primary):** curly arrow from OH^- lone pair to δ+C. Simultaneously, C–X bond breaks (curly arrow from bond to X). **Rate trend:** C–I bond has **lowest bond enthalpy** (weakest, easiest to break) → fastest hydrolysis. C–F has highest (strongest) → slowest.

4.2.2e	*CFCs: UV breaks C–Cl bonds forming radicals. Cl• catalyses ozone decomposition. Include •NO as another ozone-depleting radical. Legislation and alternatives.*
	CFCs release Cl• radicals in the upper atmosphere (UV homolytic fission of C–Cl). **Ozone depletion:** $Cl• + O_3 \rightarrow ClO• + O_2$, then $ClO• + O \rightarrow Cl• + O_2$. Cl• regenerated (catalyst). OCR also requires: **•NO** as another radical catalyst: $•NO + O_3 \rightarrow •NO_2 + O_2$. Scientific evidence led to legislation banning CFCs. Replaced by chlorine-free alternatives (HFCs).

4.2.3 Organic Synthesis

4.2.3a	*Practical skills: Quickfit apparatus for distillation and reflux. Preparation and purification of organic liquids: separating funnel, drying with anhydrous salt, redistillation.*
	Quickfit apparatus: ground-glass joints for leak-free connections. **Distillation:** to separate/collect a liquid product at its boiling point. **Reflux:** to heat a reaction mixture for a prolonged time without losing volatile reactants/products. **Purification of organic liquids:** (1) Separating funnel: remove aqueous layer from organic layer. (2) Wash organic layer (e.g. with Na_2CO_3 to remove acid). (3) Dry with anhydrous salt (e.g. $MgSO_4$ or $CaCl_2$). (4) Filter off drying agent. (5) Redistil, collecting at correct b.p.

⭐ PAG5: Preparation and Purification of an Organic Liquid

Method:

1. Set up Quickfit apparatus for reflux. Add reactants (e.g. cyclohexanol + conc. H_3PO_4 for dehydration to cyclohexene, or alcohol + NaBr/H_2SO_4 for substitution).
2. Heat under reflux for the required time to ensure complete reaction.
3. Rearrange apparatus for distillation. Collect the product at the correct boiling point range.
4. Transfer distillate to a separating funnel. Wash with sodium carbonate solution (removes acid impurities). Vent regularly to release CO_2.
5. Separate the organic layer. Wash with distilled water. Separate again.
6. Dry the organic layer with anhydrous drying agent (e.g. $MgSO_4$ or $CaCl_2$). Leave for ~10 minutes.
7. Filter off the drying agent (gravity filtration).
8. Redistil, collecting the fraction at the correct boiling point. Record b.p. and compare with literature.
9. Calculate percentage yield.

Sources of Uncertainty:

- Thermometer: ±0.5°C
- Measuring cylinder: ±0.5 cm^3
- Balance: ±0.01 g

Common Errors:

- Not refluxing for long enough (incomplete reaction)
- Loss of product during transfers between vessels
- Incomplete drying (water contamination)
- Collecting fractions at wrong temperature range
- Not venting the separating funnel (pressure build-up)

Improvements:

- Reflux for the full specified time
- Minimise transfers to reduce losses
- Allow sufficient time for drying agent to work
- Collect only the fraction at the correct b.p. range
- Record boiling point – sharp b.p. near literature = pure
- Calculate % yield = (actual mass / theoretical mass) × 100%

4.2.3b-c	*Identify functional groups in molecules with multiple groups. Predict properties and reactions. Two-stage synthetic routes.*
	You must be able to identify all functional groups from Module 4 in an unfamiliar molecule and predict how each would react. **Two-stage synthesis:** chain together two reactions from the specification. E.g. alkene → alcohol (hydration) → haloalkane (substitution). Or alcohol → aldehyde (oxidation) → carboxylic acid (further oxidation).

4.2.4 Analytical Techniques (IR and MS)

4.2.4a-e	*IR spectroscopy: bond vibrations absorb IR. Greenhouse gases (CO_2, H_2O, CH_4). Identify O–H (alcohol), C=O, O–H (acid) from IR spectra. Interpret unfamiliar spectra. Air pollution monitoring.*
	IR spectroscopy: covalent bonds absorb IR at characteristic wavenumbers, causing vibrations. **Key absorptions:** C–H ~3000 cm^{-1} (most organic compounds); O–H alcohol: broad ~3200–3600 cm^{-1}; O–H acid: very broad ~2500–3300 cm^{-1}; C=O: strong ~1680–1750 cm^{-1}. **Fingerprint region** (< ~1500 cm^{-1}): unique to each compound. **Greenhouse gases:** CO_2, CH_4, H_2O absorb IR (C=O, C–H, O–H bonds vibrate at IR frequencies) → trap heat. **Applications:** monitoring air pollution (CO, NO from car exhausts); breathalyser (ethanol detection).

4.2.4f-h	*Mass spectrometry: molecular ion peak gives Mr. Fragmentation peaks identify structural parts. Combined techniques: elemental analysis + MS + IR to deduce structures.*
	Molecular ion peak (M^+): highest m/z peak (ignore small M+1 from ^{13}C) → gives Mr. **Fragmentation:** molecule breaks into fragments. Common losses: −15 (CH_3), −17 (OH), −28 (CO or C_2H_4), −29 (CHO), −31 (CH_2OH), −45 (OC_2H_5). OCR: will not test mass spectra of organic halogen compounds. **Combined techniques:** use all data together – empirical formula (from elemental analysis) + Mr (from MS) → molecular formula. IR identifies functional groups. Piece together the structure.

MODULE 6: ORGANIC CHEMISTRY AND ANALYSIS

6.1 Aromatic Compounds, Carbonyls and Acids

6.1.1 Aromatic Compounds

6.1.1a-c	*Benzene: Kekulé vs delocalised model. p-orbital overlap forming delocalised π-system. Evidence: bond lengths, enthalpy of hydrogenation. IUPAC naming of substituted aromatics.*
	Benzene (C_6H_6): planar hexagonal ring. Each C is sp^2 hybridised with one p-orbital perpendicular to the ring. **Kekulé model:** alternating single/double bonds. **Problems:** would predict two different C–C lengths and three additions of Br_2. **Delocalised model:** p-orbitals overlap to form a **delocalised π-system** above and below the ring. All C–C bonds equal length (140 pm). **Enthalpy of hydrogenation** is ~152 kJ mol^{-1} less exothermic than expected for cyclohexatriene → benzene is more stable (delocalisation energy). **Naming:** use locant numbers for substituent positions (e.g. 2,4-dinitromethylbenzene).

6.1.1d-g	*Electrophilic substitution: nitration (conc HNO_3/H_2SO_4), halogenation (halogen carrier), Friedel-Crafts (haloalkane or acyl chloride with halogen carrier). Mechanisms for nitration and halogenation. Resistance to bromination vs alkenes.*
	Nitration: $C_6H_6 + HNO_3 \rightarrow C_6H_5NO_2 + H_2O$ (conc. H_2SO_4 catalyst, <55°C). Electrophile: **NO_2^+** (nitronium ion). Generation: $HNO_3 + H_2SO_4 \rightarrow NO_2^+ + HSO_4^- + H_2O$. **Halogenation:** $C_6H_6 + Br_2 \rightarrow C_6H_5Br + HBr$ (halogen carrier: Fe, $FeBr_3$ or $AlBr_3$). Electrophile assumed to be Br^+ (or X^+). **Friedel-Crafts:** acylation ($RCOCl + AlCl_3$) or alkylation ($RCl + AlCl_3$). Important: forms **C–C bond** to aromatic ring. **Mechanism:** (1) E^+ attacks ring (curly arrow from ring to E^+). (2) Intermediate. (3) H^+ lost, ring restored. **Resistance:** benzene resists addition (would destroy stable delocalised system). Substitution preserves it. Alkenes react readily by addition (localised π-bond, no stabilisation).

6.1.1h-l	*Phenols: weak acidity (reacts NaOH but NOT carbonates). Electrophilic substitution of phenol with Br_2 and dilute HNO_3. Enhanced reactivity vs benzene. 2,4-directing (OH, NH_2) and 3-directing (NO_2) effects. Prediction of products.*
	Phenol (C_6H_5OH): weakly acidic. Reacts with NaOH → sodium phenoxide + H_2O. Does **NOT** react with Na_2CO_3 (too weak an acid). **Reactions:** + Br_2(aq) → **2,4,6-tribromophenol** (white precipitate, no catalyst needed). + dilute HNO_3 → mixture of 2-nitrophenol + 4-nitrophenol (no conc. acid or H_2SO_4 needed). **Enhanced reactivity:** O lone pair donates into the π-system → increased electron density in ring → more susceptible to electrophilic attack. **Directing effects:** electron-donating groups (OH, NH_2) direct to **positions 2 and 4**. Electron-withdrawing groups (NO_2) direct to **position 3**.

6.1.2 Carbonyl Compounds

6.1.2a	*Oxidation of aldehydes to carboxylic acids using $Cr_2O_7^{2-}/H^+$.*
	Aldehyde + [O] → carboxylic acid (acidified $K_2Cr_2O_7$, reflux). Orange dichromate → green Cr^{3+}. Ketones resist oxidation.

6.1.2b-c	*Nucleophilic addition: $NaBH_4$ → alcohols, HCN ($NaCN/H^+$) → hydroxynitriles. Mechanisms for both.*
	Reduction with $NaBH_4$: aldehyde → primary alcohol; ketone → secondary alcohol. Nucleophile = **H^-** (H^- ion from $NaBH_4$). Mechanism: H^- attacks δ+C of C=O (π-bond breaks, electrons to O). Then protonation by H_2O. **Reaction with HCN ($NaCN/H^+$):** carbonyl → **hydroxynitrile** (extends C chain by 1). Nucleophile = **CN^-**. Mechanism: CN^- attacks δ+C of C=O. Then protonation by H_2O or H^+. KCN/HCN is extremely toxic – fume cupboard, safety protocols.

6.1.2d-e	*Tests: 2,4-DNP to detect C=O (and identify by melting point of derivative). Tollens' reagent to detect aldehydes (silver mirror) and distinguish from ketones.*
	2,4-dinitrophenylhydrazine (2,4-DNP): forms orange/yellow precipitate with any carbonyl compound (aldehyde or ketone). Measure m.p. of precipitate to identify specific compound. **Tollens' reagent (ammoniacal $AgNO_3$): aldehyde → silver mirror** (Ag^+ reduced to Ag). **Ketone** → no reaction. Distinguishes aldehydes from ketones.

6.1.3 Carboxylic Acids and Esters

6.1.3a-b	*Carboxylic acids: water solubility (H-bonding). Reactions with metals, bases, carbonates, metal oxides, alkalis.*
	Carboxylic acids (–COOH): soluble in water (H-bonding from both C=O and O–H). **Reactions:** with metals → salt + H_2. With bases (NaOH) → salt + H_2O. With carbonates (Na_2CO_3) → salt + H_2O + CO_2 (effervescence – a test for carboxylic acids).

6.1.3c-d	*Esterification: carboxylic acid + alcohol (acid catalyst); acid anhydride + alcohol. Hydrolysis of esters: acid (reversible) and alkaline (irreversible).*
	Esterification: RCOOH + R′OH ⇌ RCOOR′ + H_2O (conc. H_2SO_4 catalyst, reflux). Also: acid anhydride + alcohol → ester + carboxylic acid. OCR note: phenol is not readily esterified by carboxylic acids (use acyl chloride or anhydride instead). **Acid hydrolysis:** RCOOR′ + H_2O ⇌ RCOOH + R′OH (reversible). **Alkaline hydrolysis:** RCOOR′ + NaOH → RCOONa + R′OH (irreversible – goes to completion).

6.1.3e-f	*Acyl chlorides: formation from carboxylic acids using $SOCl_2$. Reactions: formation of esters, carboxylic acids, primary and secondary amides.*
	Formation: RCOOH + $SOCl_2$ → RCOCl + SO_2 + HCl. **Reactions of acyl chlorides:** + Water → carboxylic acid + HCl. + Alcohol → ester + HCl. + NH_3 → primary amide ($RCONH_2$) + HCl. + Primary amine ($R'NH_2$) → secondary amide (RCONHR′) + HCl. Acyl chlorides are very reactive – vigorous reactions, fumes of HCl.

6.2 Nitrogen Compounds, Polymers and Synthesis

6.2.1 Amines

6.2.1a-b	*Amines as bases (N lone pair accepts H^+). Reactions with dilute acids to form salts. Preparation: excess ethanolic NH_3 + haloalkane; reduction of nitroarenes (Sn/conc. HCl).*
	Amines are weak bases: lone pair on N accepts H^+. E.g. $CH_3NH_2 + HCl \rightarrow CH_3NH_3^+Cl^-$ (salt). **Preparation of aliphatic amines:** haloalkane + excess NH_3 in ethanol, heat in sealed tube → primary amine (+ further substitution to 2°, 3° amines). **Preparation of aromatic amines:** nitroarene + Sn + conc. HCl, reflux → $ArNH_2$ (reduction: $ArNO_2 + 6[H] \rightarrow ArNH_2 + 2H_2O$). Also: reduction of nitriles ($RCN + 4[H] \rightarrow RCH_2NH_2$) using H_2/Ni.

6.2.2 Amino Acids, Amides and Chirality

6.2.2a-b	*Amino acids: $RCH(NH_2)COOH$. Reactions: COOH group with alkalis/esters; NH_2 group with acids. Primary and secondary amide structures.*
	α-amino acids: general formula $RCH(NH_2)COOH$. Have both acidic (–COOH) and basic ($–NH_2$) groups. **Reactions:** –COOH reacts with NaOH → salt + H_2O; forms esters with alcohols. $–NH_2$ reacts with HCl → salt. **Primary amide:** $RCONH_2$ (from acyl chloride + NH_3). **Secondary amide:** RCONHR′ (from acyl chloride + $R'NH_2$).

6.2.2c-d	*Optical isomerism: non-superimposable mirror images about a chiral centre. Identify chiral centres.*
	Optical isomers (enantiomers): non-superimposable mirror images. Occur when a carbon has **4 different groups** attached (chiral centre). Enantiomers have identical physical properties but rotate plane-polarised light in opposite directions. **Racemic mixture:** 50:50 mix of enantiomers → no net rotation (optically inactive).

6.2.3 Polyesters and Polyamides

6.2.3a-c	*Condensation polymerisation: polyesters and polyamides. Hydrolysis of polyesters (ester groups) and polyamides (amide groups). Predict repeat units from monomers and vice versa. Identify polymerisation type.*
	Condensation polymerisation: monomers join with loss of a small molecule (**H_2O**). **Polyesters:** dicarboxylic acid + diol → ester linkage (–COO–) + H_2O. **Polyamides:** dicarboxylic acid + diamine (or acyl chloride + diamine) → amide linkage (–CONH–) + H_2O or HCl. **Hydrolysis:** acid or alkaline conditions break the ester/amide bonds → original monomers (or their salts). OCR: learners won't recall structures of synthetic polyesters/polyamides, but must draw repeat units from given monomers.

6.2.4 Carbon–Carbon Bond Formation

6.2.4a-d	*C–C bond formation in synthesis. Nitrile formation: haloalkane + CN^- (SN2 mechanism); carbonyl + HCN (nucleophilic addition mechanism). Nitrile reactions: reduction → amine; acid hydrolysis → carboxylic acid. Friedel-Crafts.*
	Extending carbon chains is vital in synthesis. Key methods: **Nitrile route:** RX + CN^- (ethanol) → RCN + X^- (SN2, **C chain +1**). Then: RCN + 4[H] → RCH_2NH_2 (amine, H_2/Ni) or RCN + H_2O + H^+ → RCOOH (carboxylic acid, acid hydrolysis). **HCN route:** carbonyl + HCN → hydroxynitrile (nucleophilic addition, C chain +1). **Friedel-Crafts:** alkylation (RCl + $AlCl_3$) or acylation (RCOCl + $AlCl_3$) attaches C chain to aromatic ring.

6.2.5 Organic Synthesis

6.2.5a-c	*Practical skills: Quickfit, distillation, reflux, filtration under reduced pressure, recrystallisation, melting points. Multi-stage synthetic routes using all functional groups.*
	Organic solid preparation/purification: (1) Carry out reaction (Quickfit, reflux). (2) Filter product under reduced pressure (Buchner funnel). (3) Recrystallise: dissolve in minimum hot solvent, cool slowly, filter, wash, dry. (4) Measure melting point – compare with literature (sharp m.p. = pure). **Multi-stage synthesis:** link all reactions in the spec. E.g. benzene → nitrobenzene (nitration) → phenylamine (reduction). Or: alcohol → aldehyde (oxidation) → hydroxynitrile (HCN) → hydroxy acid (hydrolysis).

⭐ PAG6: Preparation and Purification of an Organic Solid

Method:

1. Carry out the organic reaction (e.g. preparation of aspirin from 2-hydroxybenzoic acid + ethanoic anhydride, or nitration of methyl benzoate).
2. Use Quickfit apparatus: heat under reflux or in a water bath for the specified time.
3. Cool the mixture. Add cold water to precipitate the product (or decompose excess reagent). Cool in ice.
4. Filter under reduced pressure using a Buchner funnel. Wash the solid with cold water.
5. Recrystallise: dissolve in minimum volume of hot solvent (e.g. ethanol or water). Add hot water if needed. Cool slowly, then in ice. Crystals form.
6. Filter under reduced pressure. Wash with a small amount of cold solvent.
7. Dry the crystals (press between filter papers, or leave in a desiccator, or warm oven).
8. Measure the melting point using a melting point apparatus. Compare with literature value.
9. A sharp melting point close to the literature value = high purity. A broad range or lower m.p. = impure.

Sources of Uncertainty:

- Balance: ±0.001 g
- Thermometer/melting point apparatus: ±1°C
- Volume measurements for solvents

Common Errors:

- Incomplete reaction (not heated for long enough)
- Adding water too quickly to hot mixture (splattering)
- Not cooling sufficiently before filtering (product dissolves → lower yield)
- Using too much solvent during recrystallisation (product stays dissolved → lower yield)
- Product not fully dry (m.p. will be lower and broader than expected)

Improvements:

- Heat for the full specified time
- Cool thoroughly in ice before filtering
- Use minimum volume of hot solvent for recrystallisation
- Cool slowly (not rapidly) for better crystal formation
- Dry completely before measuring melting point
- Sharp m.p. close to literature value = high purity
- Calculate % yield

6.3 Analysis

6.3.1 Chromatography and Qualitative Analysis

6.3.1a-b	*TLC: interpret chromatograms using Rf values. GC: interpret retention times, amounts/proportions, external calibration curves.*
	TLC: Rf = distance by substance / distance by solvent front (0 to 1). Compare with standards. **GC:** retention time identifies the component (compare with standards). Peak area/integration values → amount of each component. **External calibration curves** confirm concentrations.

6.3.1c	*Test-tube tests for organic functional groups: alkenes (Br_2), haloalkanes ($AgNO_3$/ethanol), phenols (NaOH but not CO_3^{2-}), carbonyls (2,4-DNP), aldehydes (Tollens'), 1°/2° alcohols and aldehydes (acidified dichromate), carboxylic acids (CO_3^{2-}).*
	Alkene: bromine water decolourised (orange → colourless). **Haloalkane:** $AgNO_3$/ethanol, warm → precipitate (rate: I > Br > Cl). **Phenol:** dissolves in NaOH but does NOT react with Na_2CO_3. **Carbonyl (aldehyde or ketone):** 2,4-DNP → orange/yellow precipitate. **Aldehyde (not ketone):** Tollens' → silver mirror. **Primary/secondary alcohol and aldehyde:** acidified $K_2Cr_2O_7$ goes orange → green. **Carboxylic acid:** Na_2CO_3 → effervescence (CO_2). Or: turns blue litmus red.

⭐ PAG7: Qualitative Tests for Organic Functional Groups

Method:

1. Prepare small samples in clean, labelled test tubes.
2. ALKENE: add bromine water. Decolourised (orange → colourless) = C=C present.
3. HALOALKANE: add $AgNO_3$ in ethanol, warm in water bath. White/cream/yellow ppt indicates Cl/Br/I. Rate: I fastest, Cl slowest.
4. PHENOL: dissolve in water/NaOH. Add Br_2(aq) → white precipitate of 2,4,6-tribromophenol. Also: reacts with NaOH but NOT Na_2CO_3.
5. CARBONYL (aldehyde or ketone): add 2,4-DNP reagent. Orange/yellow precipitate = C=O present.
6. ALDEHYDE (not ketone): warm with Tollens' reagent (ammoniacal $AgNO_3$) in a clean glass tube. Silver mirror = aldehyde.
7. PRIMARY/SECONDARY ALCOHOL or ALDEHYDE: warm with acidified $K_2Cr_2O_7$. Orange → green = oxidation occurred. Tertiary alcohols and ketones: no change.
8. CARBOXYLIC ACID: add Na_2CO_3. Effervescence (CO_2) = COOH group. Or: turns blue litmus red.
9. Record all observations systematically in a table.

Sources of Uncertainty:

- Visual judgement of colour changes and precipitates
- Reaction times for rate comparisons

Common Errors:

- Cross-contamination (dirty test tubes)
- Not warming sufficiently for Tollens' or $AgNO_3$ tests
- Dirty glass for Tollens' (silver mirror won't form)
- Confusing colour changes with precipitates

Improvements:

- Use clean test tubes throughout – especially for Tollens'
- Warm gently in a water bath (not direct flame for Tollens')
- Use consistent small quantities of reagents
- Record observations immediately
- Carry out tests in a logical order

6.3.2 Spectroscopy (NMR and Combined Techniques)

6.3.2a-d	*^{13}C NMR: number of C environments, types from chemical shift, possible structures. ^{1}H NMR: proton environments, chemical shifts, integration, n+1 rule for splitting. Predict spectra. TMS standard, deuterated solvents, D_2O shake.*
	^{13}C NMR: number of peaks = number of different **carbon environments**. Chemical shift (δ) identifies type of C. Simpler spectra (no splitting). **^{1}H NMR:** number of peaks = number of **proton environments**. Integration/peak area = relative number of H atoms. **Splitting (n+1 rule):** n adjacent non-equivalent H → peak split into n+1 lines (singlet, doublet, triplet, quartet). OCR: aromatic protons identified by δ value but splitting patterns of aromatic H's not tested. **TMS ($Si(CH_3)_4$):** reference standard (δ = 0). 12 equivalent H (one strong peak), away from other signals, inert, volatile. **Deuterated solvents** (e.g. $CDCl_3$): D is NMR-inactive, no solvent peaks. **D_2O shake:** O–H and N–H peaks disappear (H exchanged for D).

6.3.2e	*Combined techniques: deduce structures from elemental analysis, MS, IR spectra, NMR spectra together.*
	Strategy for structure determination: (1) Empirical formula from elemental analysis. (2) Mr from MS molecular ion peak → molecular formula. (3) IR: identify functional groups. (4) ^{13}C NMR: number of C environments. (5) ^{1}H NMR: number of H environments, ratios, splitting. (6) Piece together the structure that is consistent with ALL the data.

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