

Organic Chemistry

IB SL Study Guide

IB Chemistry SL — Organic Chemistry

Complete Study Guide

Topics Covered

1. Functional Groups & Homologous Series
2. IUPAC Naming
3. Structural Isomers
4. Combustion Reactions
5. Addition Reactions (Alkenes)
6. Oxidation of Alcohols
7. Free Radical Substitution
8. Polymerization
9. Properties of Organic Compounds

1. Functional Groups & Homologous Series

Organic chemistry is the study of carbon-containing compounds. Carbon is unique because it can form four bonds and chain together almost indefinitely, creating an enormous variety of molecules. To make sense of this variety, chemists group organic molecules into **homologous series** — families of molecules that share the same **functional group**. The functional group is the reactive part of the molecule — it determines how the compound behaves chemically. For example, all alcohols contain -OH and react similarly, regardless of how long their carbon chain is. Understanding functional groups is the foundation of everything else in organic chemistry: once you know what functional group is present, you can predict the reactions, the products, and even the physical properties.

Key Definitions

Term	Definition / Notes
Functional group	An atom or group of atoms that gives an organic molecule its characteristic chemical properties
Homologous series	A family of compounds with the same functional group, differing by CH_2 each time. Same general formula, similar chemical properties, gradually changing physical properties
Homologue	A member of a homologous series (e.g. methane, ethane, propane are all alkane homologues)

The Main Functional Groups You Must Know

Functional Group	Description & Example
Alkane	Single C-C bonds only. General formula: $\text{C}_n\text{H}_{2n+2}$. e.g. CH_3CH_3 (ethane)
Alkene	Contains a C=C double bond. General formula: C_nH_{2n} . e.g. $\text{CH}_2=\text{CH}_2$ (ethene)
Alcohol (-OH)	Contains an -OH group. e.g. $\text{CH}_3\text{CH}_2\text{OH}$ (ethanol). Suffix: -ol
Aldehyde (-CHO)	Contains -CHO at the END of the chain. e.g. CH_3CHO (ethanal). Suffix: -al
Ketone (C=O)	Contains C=O in the MIDDLE of the chain. e.g. CH_3COCH_3 (propanone). Suffix: -one
Carboxylic acid (-COOH)	Contains -COOH at the end. e.g. CH_3COOH (ethanoic acid). Suffix: -oic acid
Halogenoalkane	Contains a halogen (F, Cl, Br, I) bonded to carbon. e.g. $\text{CH}_3\text{CH}_2\text{Br}$ (bromoethane)
Ester (-COO-)	Contains a -COO- group. Formed from carboxylic acid + alcohol. e.g. $\text{CH}_3\text{COOCH}_2\text{CH}_3$ (ethyl ethanoate). Sweet/fruity smell. Suffix: -yl -anoate
Amine (-NH₂)	Contains an -NH ₂ group bonded to carbon. e.g. CH_3NH_2 (methylamine). Suffix: -amine

Complete Homologous Series Reference

Series	General Formula	Functional Group	Suffix	Example
Alkanes	C_nH_{2n+2}	C-C single bonds only	-ane	CH ₄ (methane), C ₂ H ₆ (ethane)
Alkenes	C_nH_{2n}	C=C double bond	-ene	C ₂ H ₄ (ethene), C ₃ H ₆ (propene)
Alcohols	$C_nH_{2n+1}OH$	-OH (hydroxyl)	-ol	CH ₃ OH (methanol), C ₂ H ₅ OH (ethanol)
Aldehydes	$C_nH_{2n}O$	-CHO (at chain end)	-al	HCHO (methanal), CH ₃ CHO (ethanal)
Ketones	$C_nH_{2n}O$	C=O (in chain middle)	-one	CH ₃ COCH ₃ (propanone)
Carboxylic acids	$C_nH_{2n}O_2$	-COOH	-oic acid	HCOOH (methanoic acid), CH ₃ COOH (ethanoic acid)
Esters	$C_nH_{2n}O_2$	-COO-	-yl -anoate	CH ₃ COOCH ₃ (methyl ethanoate)
Halogenoalkanes	$C_nH_{2n+1}X$	C-X (X = F, Cl, Br, I)	prefix: fluoro/chloro/bromo/iodo	CH ₃ Cl (chloromethane)
Amines	$C_nH_{2n+1}NH_2$	-NH ₂	-amine	CH ₃ NH ₂ (methylamine)

MEMORISE THIS

Key properties of homologous series:

- Members differ by CH₂ (one carbon and two hydrogens)
- All share the same general formula
- All share the same functional group → similar chemical properties
- Physical properties (boiling point, solubility) change gradually with chain length
- Longer chain → higher boiling point (stronger London dispersion forces)

IB TIP

In the IB, you must be able to identify the functional group from a structural formula AND know which homologous series a compound belongs to.

EXAM ALERT

Aldehydes have -CHO at the END; ketones have C=O in the MIDDLE. This is a very common trick question! Also: aldehydes and ketones share the same general formula ($C_nH_{2n}O$) — they are functional group isomers.

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. Which compound belongs to the same homologous series as $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$?

A. CH_3OCH_3

B. CH_3CHO

C. CH_3OH ← CORRECT

D. CH_3COOH

Why: $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ is propan-1-ol, an alcohol. Members of the same homologous series share the same functional group (-OH). CH_3OH (methanol) is also an alcohol. Option A is an ether, B is an aldehyde, and D is a carboxylic acid.

WORKED EXAMPLE

Q2. Ethanal and propanone both have the general formula $\text{C}_n\text{H}_{2n}\text{O}$. What is the correct term for the relationship between these two compounds?

A. Structural isomers

B. Homologues

C. **Functional group isomers** ← CORRECT

D. Members of the same homologous series

Why: Ethanal (CH_3CHO , an aldehyde) and propanone (CH_3COCH_3 , a ketone) share the same general formula but have different functional groups. They are functional group isomers. They are NOT structural isomers (different molecular formulas: $\text{C}_2\text{H}_4\text{O}$ vs $\text{C}_3\text{H}_6\text{O}$) and NOT homologues (different functional groups).

Written Questions (answers at end of guide):

W1. Define the term “homologous series” and explain why members of a homologous series have similar chemical properties but gradually changing physical properties. [3 marks]

2. IUPAC Naming

With millions of organic compounds known to science, a universal naming system is essential. The **IUPAC (International Union of Pure and Applied Chemistry)** system gives every compound a unique, systematic name that tells you exactly what the molecule looks like — the length of the carbon chain, the location and type of any branches, and the functional group present. The name is like an address: it pinpoints the structure precisely. The key insight is that IUPAC names are built in layers: first identify the longest chain (the parent), then number it to give branches and functional groups the lowest possible position numbers, then add prefixes and suffixes. Once you master this logic, you can name — or draw — any organic molecule from its name.

Prefix = Number of Carbon Atoms

Prefix	# of Carbons
meth-	1 carbon
eth-	2 carbons
prop-	3 carbons
but-	4 carbons
pent-	5 carbons
hex-	6 carbons

Naming Rules — Step by Step

- **Step 1:** Find the longest carbon chain — this gives the parent name (e.g. 'pentane' for 5 carbons)
- **Step 2:** Number the chain from the end closest to the functional group or branch
- **Step 3:** Name any branches (methyl, ethyl) with their position number (e.g. 2-methyl)
- **Step 4:** Add the suffix for the functional group (-ol, -al, -one, -oic acid)

Common Examples

Name	Explanation
2-methylbutane	Butane (4C) with a methyl branch on carbon 2. NOT 3-methylbutane (number from closest end)
2-methylpentane	Pentane (5C) with methyl on carbon 2
propan-1-ol	3-carbon chain, OH group on carbon 1 (primary alcohol)
propan-2-ol	3-carbon chain, OH group on carbon 2 (secondary alcohol)
1,2-dibromoethane	2-carbon chain with Br on carbons 1 and 2
2-methylpropan-2-ol	4C chain, OH on C2, methyl on C2 (tertiary alcohol)

IB TIP

Always number from the end that gives the substituent the LOWEST possible number. So 2-methylbutane, never 3-methylbutane.

EXAM ALERT

The IB often tests whether you can distinguish 1,1- from 1,2- or 2,3- isomers. Read position numbers carefully!

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. What is the correct IUPAC name for $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$?

- A. 3-methylbutane
- B. 2-ethylpropane
- C. 2-methylbutane ← CORRECT**
- D. 1,1-dimethylpropane

Why: The longest continuous chain has 4 carbons (butane). Numbering from the end closest to the branch gives a methyl group on carbon 2. The name is 2-methylbutane, not 3-methylbutane (always use the lowest locant).

WORKED EXAMPLE

Q2. An organic compound has the structure $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3$. What is its IUPAC name?

- A. 2-methylpropan-1-ol
- B. Butan-2-ol ← CORRECT**
- C. Butan-3-ol
- D. 2-butanol

Why: The longest chain with -OH has 4 carbons (butane). The -OH group is on carbon 2 (numbering from the end nearest to -OH). The correct IUPAC name is butan-2-ol. Option C uses incorrect numbering; option D uses an older naming convention.

Written Questions (answers at end of guide):

W1. Draw the structural formula and give the IUPAC name for the following compound: a 5-carbon alcohol with the hydroxyl group on carbon 3 and a methyl branch on carbon 2. [3 marks]

3. Structural Isomers & Primary/Secondary/Tertiary

Because carbon can bond in so many ways, two molecules can share the same molecular formula (the same atoms) yet have completely different structures — and therefore different names, properties, and reactions. These are called **structural isomers**. Think of it like having the same Lego bricks but building different models. For example, C_4H_{10} can be a straight chain (butane) or a branched chain (2-methylpropane) — same formula, different structure, different boiling point. Within alcohols and halogenoalkanes, a further important classification is whether the carbon bearing the functional group is bonded to one, two, or three other carbons — giving us primary, secondary, and tertiary compounds. This classification is critical

because it completely determines **which reactions are possible** (e.g. tertiary alcohols cannot be oxidised).

Structural Isomers

Structural isomers have the SAME molecular formula but DIFFERENT structural arrangements.

Example: C_4H_{10} has 2 structural isomers:

- $CH_3CH_2CH_2CH_3$ — butane (straight chain)
- $(CH_3)_2CHCH_3$ — 2-methylpropane (branched)

IB TIP

For C_5H_{12} , there are 3 isomers. For C_4H_8 (cyclobutane not required at SL) there are several. Practice drawing all isomers systematically.

Primary, Secondary & Tertiary

This classification depends on how many carbon atoms are bonded to the carbon that carries the functional group:

Type	Description & Example
Primary (1°)	The carbon with the -OH or -X is bonded to only 1 other carbon. e.g. propan-1-ol, 1-bromopropane
Secondary (2°)	The carbon with the -OH or -X is bonded to 2 other carbons. e.g. propan-2-ol, 2-bromopropane
Tertiary (3°)	The carbon with the -OH or -X is bonded to 3 other carbons. e.g. 2-methylpropan-2-ol, $(CH_3)_3CBr$

EXAM ALERT

Tertiary alcohols CANNOT be oxidised by acidified $K_2Cr_2O_7$.
Secondary \rightarrow ketone. Primary \rightarrow aldehyde \rightarrow carboxylic acid.

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. How many structural isomers exist with the molecular formula C_4H_{10} ?

A. 1

B. 2 ← CORRECT

C. 3

D. 4

Why: C_4H_{10} (an alkane) has exactly 2 structural isomers: butane ($CH_3CH_2CH_2CH_3$, straight chain) and 2-methylpropane ($(CH_3)_3CH$, branched). There are no other ways to arrange 4 carbons and 10 hydrogens.

WORKED EXAMPLE

Q2. 2-Methylpropan-2-ol is classified as a tertiary alcohol. What does this mean?

A. The -OH group is on the third carbon in the chain

B. The molecule has three -OH groups

C. The molecule has three carbon atoms in total

D. The carbon bonded to -OH is attached to three other carbon atoms ← CORRECT

Why: The classification primary/secondary/tertiary refers to how many other carbon atoms are bonded to the carbon carrying the functional group. In 2-methylpropan-2-ol, the carbon bearing -OH is bonded to three methyl groups, making it tertiary. This is critical because tertiary alcohols cannot be oxidised.

Written Questions (answers at end of guide):

W1. Draw all the structural isomers of C_3H_7Br and classify each as primary, secondary, or tertiary. Predict which isomer would react faster with aqueous NaOH and explain why. [4 marks]

4. Combustion Reactions

Combustion is the reaction of an organic compound with oxygen, releasing energy as heat and light — it is the basis of fuels, from petrol engines to gas cookers. All hydrocarbons (and most organic compounds) combust, but the **products depend on how much oxygen is available**.

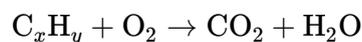
With plenty of oxygen, combustion is complete and clean — every carbon becomes CO_2 and every hydrogen becomes H_2O . With limited oxygen (such as in a poorly ventilated engine), combustion is incomplete, and more dangerous products form: carbon monoxide (CO), which is a colourless, odourless, highly toxic gas that binds to haemoglobin and prevents oxygen transport in the blood, and carbon soot (C). This is why car engines, boilers, and fires in

enclosed spaces can be lethal. Being able to write balanced equations for both types — and know which products form under which conditions — is an essential IB skill.

Complete Combustion

Occurs with excess oxygen. Products are ONLY CO₂ and H₂O.

Complete Combustion General Equation:

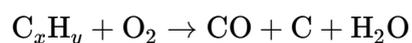


Example: C₃H₈ + 5O₂ → 3CO₂ + 4H₂O (propane)

Incomplete Combustion

Occurs with LIMITED oxygen. Produces some or all of: carbon monoxide (CO), carbon (soot/C), and water.

Incomplete Combustion (limited O₂):



The IB may ask: 'which products are formed?' — answer includes CO and/or C (soot), but NOT CO₂ if very limited O₂

Concept	Details
Products of complete combustion	CO ₂ and H ₂ O only
Products of incomplete combustion	CO (carbon monoxide), C (carbon/soot), H ₂ O — but NOT CO ₂ in very limited O ₂
Why incomplete combustion is dangerous	CO is colourless, odourless, and toxic (binds to haemoglobin)

IB TIP

The IB loves asking about incomplete combustion products. The answer is almost always II and III only (Carbon monoxide + Carbon), NOT hydrogen.

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. Which products are formed during the incomplete combustion of propane?

- A. CO₂ and H₂O only
- B. CO₂, CO, and H₂
- C. CO, C, and H₂O ← CORRECT
- D. CO and H₂ only

Why: Incomplete combustion occurs with limited oxygen. Carbon forms CO (carbon monoxide) and/or C (soot/carbon) instead of CO₂. Water is still produced. Hydrogen gas (H₂) is NOT a product of combustion.

WORKED EXAMPLE

Q2. What is the balanced equation for the complete combustion of butane (C₄H₁₀)?

- A. C₄H₁₀ + 4O₂ → 4CO₂ + 5H₂O
- B. C₄H₁₀ + 5O₂ → 4CO₂ + 5H₂O
- C. 2C₄H₁₀ + 13O₂ → 8CO₂ + 10H₂O ← CORRECT
- D. C₄H₁₀ + 6O₂ → 4CO₂ + 4H₂O

Why: Balancing C₄H₁₀ + O₂: 4 carbons need 4 CO₂; 10 hydrogens need 5 H₂O (requiring 8 + 5 = 13 oxygen atoms, so 6.5 O₂). Multiply through by 2 to get whole numbers:
2C₄H₁₀ + 13O₂ → 8CO₂ + 10H₂O.

Written Questions (answers at end of guide):

W1. Explain why incomplete combustion of hydrocarbons in enclosed spaces is dangerous. In your answer, identify the toxic product formed and describe how it affects the human body. [3 marks]

5. Addition Reactions of Alkenes

Alkenes are significantly more reactive than alkanes, and the reason comes down to one structural feature: the **C=C double bond**. A double bond consists of a strong sigma (σ) bond and a weaker pi (π) bond. It is this pi bond that is electron-rich and relatively easy to break, making alkenes attractive targets for molecules looking to gain electrons. In an addition reaction, the double bond opens up and two new groups are added across the two carbons — no atoms are lost. This is fundamentally different from substitution (where one atom replaces another) or elimination (where atoms are removed). Addition reactions are the key to understanding how alkenes are converted into alcohols, alkanes, halogenoalkanes, and ultimately polymers — making them one of the most commercially important reaction types in chemistry.

Key Addition Reactions

Reaction Type	Equation & Notes
Hydrogenation (+ H ₂)	Alkene + H ₂ → Alkane. Catalyst: Ni, heat. CH ₂ =CH ₂ + H ₂ → CH ₃ CH ₃
Halogenation (+ Br ₂)	Alkene + Br ₂ → dibromoalkane. No catalyst needed. CH ₂ =CH ₂ + Br ₂ → CH ₂ BrCH ₂ Br. Test: bromine water turns from orange/brown to colourless
Hydrohalogenation (+ HBr)	Alkene + HBr → bromoalkane. CH ₂ =CH ₂ + HBr → CH ₃ CH ₂ Br
Hydration (+ H ₂ O)	Alkene + H ₂ O → Alcohol. Catalyst: H ₃ PO ₄ , high temp & pressure. CH ₂ =CH ₂ + H ₂ O → CH ₃ CH ₂ OH (important!)

IB TIP

Bromine water (orange) going colourless is the standard test for an alkene. Memorise this — it comes up frequently.

EXAM ALERT

Addition reactions always produce ONE product from ONE reactant + one small molecule. Do not confuse with substitution (which produces two products).

Reaction Type = Addition

When an alkene reacts, the reaction type is ALWAYS called addition (or electrophilic addition at HL). At SL, just say ‘addition reaction.’

Terminal vs Internal Alkenes — Alkene 1 and Alkene 2

IB questions often refer to ‘compound A’ and ‘compound B’ being different alkenes. The key distinction is whether the C=C double bond is at the **end** of the chain (terminal alkene, e.g. but-1-ene) or in the **middle** (internal alkene, e.g. but-2-ene). The number in the IUPAC name tells you the position of the double bond.

Type	Explanation
Terminal alkene (e.g. but-1-ene)	C=C double bond starts at C1 — at the END of the chain. Structure: CH ₂ =CH-CH ₂ -CH ₃ . Adding HBr can give two possible products (different carbons get H and Br).
Internal alkene (e.g. but-2-ene)	C=C double bond starts at C2 — in the MIDDLE of the chain. Structure: CH ₃ -CH=CH-CH ₃ . but-2-ene is symmetrical, so adding HBr gives only ONE product.
How to identify which is which	The number in the name = position of the LOWER carbon of the C=C. but-1-ene: double bond at C1. but-2-ene: double bond at C2. Both are C ₄ H ₈ — they are structural isomers.
Why it matters in IB questions	In multi-step questions (e.g. Q33, Q35), ‘compound A’ is often one alkene and ‘compound B’ another. You must draw out the full structural formula for each and show different products.

Example — but-1-ene vs but-2-ene:

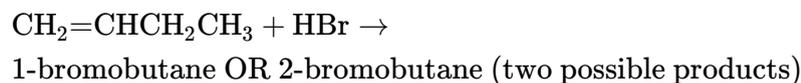
but-1-ene: $\text{CH}_2=\text{CHCH}_2\text{CH}_3$ (double bond at C1, terminal)

but-2-ene: $\text{CH}_3\text{CH}=\text{CHCH}_3$ (double bond at C2, internal, symmetrical)

Adding HBr to but-2-ene:



Adding HBr to but-1-ene:



Both are C_4H_8 — same molecular formula, different position of the $\text{C}=\text{C}$. They are structural isomers.

IB TIP

When a question says 'alkene A' and 'alkene B', draw them out fully. The position of the $\text{C}=\text{C}$ changes which products form.

EXAM ALERT

But-1-ene and but-2-ene have the same molecular formula (C_4H_8) but different structures — structural isomers. Do not confuse position isomers with chain isomers.

Electrophilic Addition — Why It Is Called That HL

At SL you call it 'addition reaction'. The full name is **electrophilic addition** — because the reagent that attacks the alkene is an **electrophile** (electron-seeking species). The $\text{C}=\text{C}$ π bond is electron-rich, attracting electrophiles. Understanding this helps you answer 'explain' questions.

Term	Explanation
Electrophile	Electron-deficient species — ACCEPTS electrons. Has $\delta+$ or full + charge. Examples: H^+ (in HBr), Br_2 , carbocations
Nucleophile	Electron-rich species — DONATES electrons. Has lone pairs or negative charge. Examples: OH^- , CN^- , NH_3 , Br^-
Why $\text{C}=\text{C}$ is attacked	The π bond electrons sit above/below the bond axis — this negative cloud attracts electrophiles.
What 'addition' means	Electrophile adds ACROSS the double bond. Both carbons of $\text{C}=\text{C}$ get a new bond. No atoms lost.

Mechanism: Electrophilic Addition of HBr to Ethene

Step	Detail
Step 1	HBr approaches. Br is electronegative, pulling electron density from H, making H δ^+ . H is the electrophile.
Step 2	π electrons attack H. C-H bond forms on one carbon. Other carbon becomes carbocation (C^+). Br^- released.
Step 3	Br^- (nucleophile) attacks the carbocation. C-Br bond forms. Product: bromoethane.
Overall	$CH_2=CH_2 + HBr \rightarrow CH_3CH_2Br$. Type: addition (electrophilic addition at HL, just 'addition' at SL).

EXAM ALERT

Do not confuse addition with substitution. Addition produces one product (C=C opens); substitution produces two products (one atom replaces another).

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. Bromine water is added to a sample of an unknown hydrocarbon. The solution changes from orange to colourless. What can be concluded?

- A. The compound is an alkane
- B. The compound contains a -OH group
- C. The compound contains a C=C double bond ← CORRECT**
- D. The compound is saturated

Why: Bromine water decolourises when Br_2 adds across a C=C double bond (addition reaction). This is the standard test for unsaturation. Alkanes are saturated and would not decolourise bromine water.

WORKED EXAMPLE

Q2. What is the product when propene ($CH_3CH=CH_2$) reacts with H_2O in the presence of H_3PO_4 ?

- A. Propanal
- B. Propan-2-ol ← CORRECT**
- C. Propan-1-ol
- D. Propanoic acid

Why: This is a hydration reaction (addition of water across C=C). The water adds across the double bond to form an alcohol. In propene, the -OH preferentially bonds to the more substituted carbon (carbon 2), giving propan-2-ol as the major product (Markovnikov's rule).

WORKED EXAMPLE

Q3. But-2-ene reacts with HBr. How many distinct organic products are formed?

A. 1 ← CORRECT

B. 2

C. 3

D. 4

Why: But-2-ene ($\text{CH}_3\text{CH}=\text{CHCH}_3$) is a symmetrical internal alkene. Adding HBr across the double bond gives only one product: 2-bromobutane ($\text{CH}_3\text{CHBrCH}_2\text{CH}_3$). In contrast, but-1-ene (a terminal, asymmetric alkene) would give two possible products.

Written Questions (answers at end of guide):

W1. Describe a chemical test you could use to distinguish between ethane and ethene. State the reagent, the procedure, and the expected observations for each compound. [3 marks]

W2. But-1-ene and but-2-ene are structural isomers with the molecular formula C_4H_8 . When each reacts with HBr, a different number of organic products is possible. Draw the structural formula of but-1-ene and but-2-ene, show the products formed with HBr in each case, and explain why the number of products differs. [4 marks]

6. Oxidation of Alcohols

Oxidation in organic chemistry generally means the addition of oxygen (or removal of hydrogen) to a molecule. Alcohols are particularly interesting because **how far they can be oxidised depends entirely on their structure**. The -OH group in an alcohol sits on a carbon atom. If that carbon still has a hydrogen attached (as in primary and secondary alcohols), oxidation can remove that hydrogen and form a new C=O bond. Primary alcohols can be oxidised in two stages: first to an aldehyde (still has that C-H bond next to the C=O), and then all the way to a carboxylic acid if excess oxidising agent is used. Secondary alcohols can only be oxidised to a ketone, because ketones have no adjacent C-H to lose. Tertiary alcohols have no such hydrogen at all — so they simply cannot be oxidised under normal conditions.

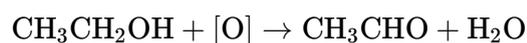
The reagent used in IB is **acidified potassium dichromate(VI)**, written as $\text{K}_2\text{Cr}_2\text{O}_7 / \text{H}_2\text{SO}_4$. The chromium in this reagent starts as Cr^{6+} (orange dichromate ion) and is reduced to Cr^{3+} (green chromium ion) as it oxidises the alcohol. This colour change — orange to green — is your experimental proof that oxidation has occurred. If the solution stays orange, no oxidation has taken place (this is what happens with tertiary alcohols).

What Gets Oxidised to What? — Full Breakdown

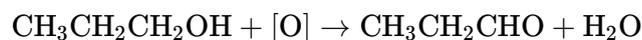
Alcohol Type	Products, Steps & Colour
Primary alcohol (1°) e.g. ethanol, propan-1-ol	STEP 1 — Mild oxidation (limited $K_2Cr_2O_7$, distil off product immediately): → Aldehyde (still has a C-H on the carbonyl carbon). STEP 2 — Further oxidation (excess $K_2Cr_2O_7$, reflux): → Carboxylic acid (no more C-H to remove). Colour change: orange → green at BOTH steps
Secondary alcohol (2°) e.g. propan-2-ol, butan-2-ol	ONE STEP ONLY: → Ketone (C=O in middle of chain, NO adjacent H). Ketones CANNOT be oxidised further at SL conditions. Colour change: orange → green
Tertiary alcohol (3°) e.g. 2-methylpropan-2-ol	NO REACTION — the central carbon has NO hydrogen to remove. Solution STAYS ORANGE — this is the negative result. No colour change = proof it is tertiary

Full Worked Examples — Equations

Primary alcohol → Aldehyde (mild oxidation, distillation):



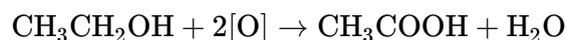
ethanol → ethanal



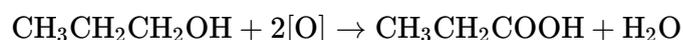
propan-1-ol → propanal

Use [O] to represent the oxidising agent in equations. Distil off the aldehyde immediately to prevent further oxidation.

Primary alcohol → Carboxylic acid (excess oxidising agent, reflux):



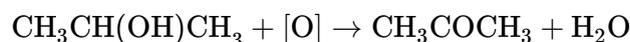
ethanol → ethanoic acid



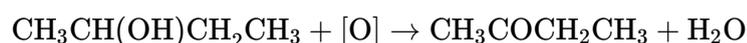
propan-1-ol → propanoic acid

Use excess $K_2Cr_2O_7/H_2SO_4$ under reflux conditions. The aldehyde intermediate is oxidised again before it can escape.

Secondary alcohol → Ketone:



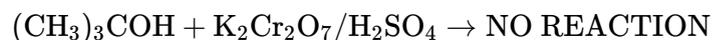
propan-2-ol → propanone



butan-2-ol → butanone

Colour change: orange → green. But if you add MORE $K_2Cr_2O_7$, nothing further happens – solution stays green.

Tertiary alcohol – NO reaction:



2-methylpropan-2-ol (solution stays orange)

The carbon bonded to -OH already has 3 carbon groups attached and NO hydrogen. There is nothing for the oxidising agent to remove.

How to Control Whether You Get Aldehyde or Carboxylic Acid

Goal	Conditions & Method
To get the ALDEHYDE (stop at first stage)	Use LIMITED $K_2Cr_2O_7/H_2SO_4$. Heat gently and DISTIL the product off immediately as it forms. The aldehyde has a lower boiling point than the alcohol — it escapes before it can be oxidised further. Practical setup: distillation apparatus, gentle heat
To get the CARBOXYLIC ACID (go all the way)	Use EXCESS $K_2Cr_2O_7/H_2SO_4$. Heat under REFLUX (the condenser returns vapours back to the flask). The aldehyde is trapped in the flask and oxidised again. Practical setup: reflux condenser, prolonged heating

IB TIP

Distillation = removes product early = stops at aldehyde. Reflux = keeps product in flask = goes all the way to carboxylic acid. The IB loves asking which conditions give which product.

How Do You PROVE Oxidation Has Occurred? — Experimental Tests

This is a key IB skill: not just knowing what happens, but being able to describe a **test and its expected result** that proves a reaction has occurred. For oxidation of alcohols you have several options:

Test	How to Do It & What It Proves
Test 1: Acidified $K_2Cr_2O_7$ (potassium dichromate)	Reagent: orange $K_2Cr_2O_7$ solution + dilute H_2SO_4 . Positive result (oxidation occurred): solution turns GREEN. Negative result (no oxidation): solution stays ORANGE. Proves: the alcohol has been oxidised (e.g. primary or secondary alcohol present). Does NOT prove: which product formed (aldehyde or carboxylic acid)
Test 2: Tollens' Reagent (silver mirror test)	Reagent: ammoniacal silver nitrate solution ($Ag(NH_3)_2^+$). Positive result: silver mirror forms on inside of test tube. Negative result: no change, solution stays colourless. Proves: an ALDEHYDE is present (distinguishes aldehyde from ketone). Why: aldehydes reduce Ag^+ to Ag metal. Ketones cannot do this.
Test 3: Fehling's / Benedict's Solution	Reagent: blue copper(II) solution (Cu^{2+}). Positive result: blue \rightarrow brick-red precipitate (Cu_2O formed). Negative result: stays blue. Proves: an ALDEHYDE is present. Why: aldehydes reduce Cu^{2+} to Cu^+ (copper(I) oxide). Ketones cannot.
Test 4: pH / litmus test	Reagent: universal indicator or pH paper. Positive result: low pH (acidic, pH 1-4), indicator turns red. Negative result: neutral or slightly acidic. Proves: a CARBOXYLIC ACID has formed (from full oxidation of primary alcohol). Cross-check: also check for sharp, vinegar-like smell
Test 5: Smell / physical observation	Not an official IB test, but useful to describe: Aldehydes: often sweet, fruity smell. Carboxylic acids: sharp, vinegar-like smell (ethanoic acid = vinegar). Alcohols: distinctive alcoholic smell. Note: never rely on smell alone in an IB answer — always use a chemical test

WORKED EXAMPLE

Worked Example: Proving a Primary Alcohol Has Been Oxidised to a Carboxylic Acid

Scenario: You heat ethanol with excess acidified $K_2Cr_2O_7$ under reflux. How do you prove the product is ethanoic acid (not just that oxidation occurred)?

Step	Test & Interpretation
Step 1: Prove oxidation occurred	Add acidified $K_2Cr_2O_7 \rightarrow$ solution turns orange to green. This proves electrons were transferred (oxidation happened).
Step 2: Prove it's not still an alcohol	Test with $K_2Cr_2O_7$: if orange goes green, something oxidisable is still present. If no more colour change, alcohol has been used up.
Step 3: Prove it's not an aldehyde	Add Tollens' reagent: if NO silver mirror forms, the product is NOT an aldehyde. This rules out ethanal. Test with litmus/pH paper: acidic pH (turns red) confirms a carboxylic acid is present.
Step 4: Prove it is a carboxylic acid	Add sodium carbonate solution: if CO_2 bubbles form, a carboxylic acid is confirmed (carboxylic acids react with Na_2CO_3 to release CO_2).
Conclusion	Orange \rightarrow green (oxidation occurred) + no silver mirror (not aldehyde) + acidic pH + CO_2 with $Na_2CO_3 \rightarrow$ confirms ethanoic acid (carboxylic acid) has formed.

Distinguishing Aldehydes from Ketones — Summary

Test	Aldehyde vs Ketone Result
Tollens' reagent (ammoniacal $AgNO_3$)	Aldehyde: silver mirror on glass. Ketone: no reaction, stays colourless. Proves: aldehyde present vs ketone
Fehling's / Benedict's (blue Cu^{2+} solution)	Aldehyde: blue \rightarrow brick-red precipitate (Cu_2O). Ketone: stays blue. Proves: aldehyde present vs ketone
Acidified $K_2Cr_2O_7$ (orange)	Aldehyde: orange \rightarrow green (can be further oxidised to carboxylic acid). Ketone: NO colour change — stays orange. Proves: whether further oxidation is possible
Na_2CO_3 solution	Carboxylic acid: fizzing / CO_2 bubbles produced. Aldehyde / ketone: no bubbles. Proves: carboxylic acid present (not just any carbonyl compound)

EXAM ALERT

In an IB 'describe a test to show' question, you must always state: (1) the name/description of the reagent, (2) the observation if the compound IS present (positive result), and (3) the observation if it is NOT present (negative result). A one-line answer will lose marks.

IB TIP

The silver mirror test (Tollens') is the most reliable and specific test for aldehydes. Fehling's is equally valid. Either is acceptable in an IB answer.

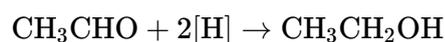
Reduction of Carbonyl Compounds — Back to Alcohol

Oxidation and reduction are reversible: just as alcohols are oxidised to carbonyls, carbonyl compounds can be **reduced back to alcohols** by adding hydrogen. The reducing agent used in IB is NaBH_4 (**sodium tetrahydridoborate**). In equations, write $[\text{H}]$ to represent the reducing agent. Reduction converts $\text{C}=\text{O}$ to $\text{C}-\text{OH}$.

Transformation	Product, Reagent & Example
Aldehyde + $[\text{H}] \rightarrow$ Primary alcohol	$\text{C}=\text{O}$ at the END of the chain is reduced to $\text{C}-\text{OH}$. Reagent: NaBH_4 (or $[\text{H}]$) in water. Example: $\text{CH}_3\text{CHO} + 2[\text{H}] \rightarrow \text{CH}_3\text{CH}_2\text{OH}$ (ethanal \rightarrow ethanol)
Ketone + $[\text{H}] \rightarrow$ Secondary alcohol	$\text{C}=\text{O}$ in the MIDDLE of the chain is reduced to $\text{C}-\text{OH}$. Reagent: NaBH_4 (or $[\text{H}]$) in water. Example: $\text{CH}_3\text{COCH}_3 + 2[\text{H}] \rightarrow \text{CH}_3\text{CH}(\text{OH})\text{CH}_3$ (propanone \rightarrow propan-2-ol)
Carboxylic acid + $[\text{H}] \rightarrow$ Primary alcohol	Requires stronger reducing agent (LiAlH_4 , more common at HL). Example: $\text{CH}_3\text{COOH} + 4[\text{H}] \rightarrow \text{CH}_3\text{CH}_2\text{OH} + \text{H}_2\text{O}$

Reduction Worked Examples

1. Aldehyde \rightarrow primary alcohol:

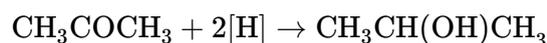


ethanal \rightarrow ethanol

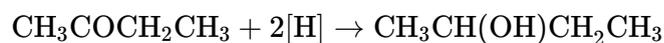


butanal \rightarrow butan-1-ol

2. Ketone \rightarrow secondary alcohol:



propanone \rightarrow propan-2-ol



butanone \rightarrow butan-2-ol

Reduction = add $[\text{H}]$. Oxidation = add $[\text{O}]$ or remove $[\text{H}]$. They are exact reverse operations.

Complete Oxidation-Reduction Pathway for a Primary Alcohol



Oxidation goes UP (more oxygen). Reduction goes DOWN (more hydrogen).

How to Prove Reduction Has Occurred

Stage	Test & Expected Result
Before reduction: test for aldehyde/ketone	Aldehyde: Tollens' → silver mirror. Fehling's → red precipitate. Ketone: $\text{K}_2\text{Cr}_2\text{O}_7$ stays orange. Tollens' gives no mirror.
After reduction: test for alcohol	$\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$: if primary or secondary alcohol formed → orange → green. This confirms the carbonyl has been converted to an alcohol.
Confirm aldehyde is gone	After reduction: Tollens' gives NO silver mirror. Fehling's stays blue. This proves the aldehyde has been consumed.

EXAM ALERT

Reduction always uses [H] in the equation. You need 2[H] per carbonyl group. Do not confuse with hydrogenation of alkenes (which also adds H_2 but across $\text{C}=\text{C}$, not $\text{C}=\text{O}$).

IB TIP

OXIDATION = more C-O bonds (or fewer C-H bonds). REDUCTION = more C-H bonds (or fewer C-O bonds). Count the oxygens on carbon to check which direction you are going.

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. An unknown alcohol is heated with acidified $\text{K}_2\text{Cr}_2\text{O}_7$. The solution stays orange. What type of alcohol is the unknown compound?

- A. Primary
- B. Secondary
- C. Tertiary ← CORRECT**
- D. It is not an alcohol

Why: Primary and secondary alcohols are oxidised by acidified $\text{K}_2\text{Cr}_2\text{O}_7$, causing the solution to change from orange to green. If the solution stays orange, no oxidation has occurred. This is the characteristic result for a tertiary alcohol, which has no hydrogen on the carbon bearing -OH.

WORKED EXAMPLE

Q2. What are the conditions needed to oxidise ethanol to ethanoic acid (rather than stopping at ethanal)?

- A. Limited $\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$, distillation
- B. NaBH_4 in water, reflux
- C. Excess $\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$, reflux ← CORRECT**
- D. Excess $\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$, distillation

Why: To obtain the carboxylic acid, you need excess oxidising agent and reflux conditions. Reflux keeps the intermediate aldehyde in the flask so it is further oxidised. Distillation would remove the aldehyde before further oxidation can occur, stopping at ethanal.

WORKED EXAMPLE

Q3. Tollens' reagent is added to the product of oxidising propan-1-ol with limited $\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$. What is observed?

- A. No change — solution stays colourless
- B. Blue solution turns brick-red
- C. A silver mirror forms on the inside of the test tube ← CORRECT**
- D. The solution turns green

Why: Propan-1-ol is a primary alcohol. With limited oxidising agent and distillation, it is oxidised to propanal (an aldehyde). Tollens' reagent (ammoniacal silver nitrate) reacts with aldehydes: Ag^+ ions are reduced to metallic silver, forming a silver mirror. Ketones do not give this result.

Written Questions (answers at end of guide):

W1. Explain why tertiary alcohols cannot be oxidised by acidified potassium dichromate. [3 marks]

W2. A student has two unlabelled bottles, one containing ethanal (CH_3CHO) and one containing propanone (CH_3COCH_3). Describe two different chemical tests the student could use to identify which bottle contains the aldehyde. For each test, state the reagent, the expected positive result, and the expected negative result. [4 marks]

6A. Reduction of Carbonyl Compounds — The Reverse of Oxidation

Just as alcohols can be **oxidised** to carbonyl compounds (aldehydes, ketones, carboxylic acids), the reverse is also possible: carbonyl compounds can be **reduced** back to alcohols.

Reduction in organic chemistry means **addition of hydrogen** (or removal of oxygen). The C=O double bond in a carbonyl is reduced to a C-OH group. This is the reverse of the oxidation pathway — and understanding both directions together (oxidation up, reduction down) is a powerful tool for synthesis questions.

The Reducing Agent

The standard reducing agent in IB organic chemistry is NaBH₄ (**sodium tetrahydridoborate** / **sodium borohydride**), used in aqueous or alcoholic solution. It delivers a hydride ion (H⁻) to the carbonyl carbon, converting C=O to C-OH. Another reagent you may see is LiAlH₄ (**lithium aluminium hydride**) — a stronger reducing agent, used in dry ether solvent (more common at HL). At SL, the key is to know that [H] represents the reducing agent in equations, and to know what each carbonyl compound reduces to.

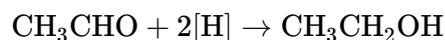
Reduction Reactions — What Reduces to What

Transformation	Product, Reagent & Example
Aldehyde → Primary alcohol	The C=O at the end of the chain gains H, becoming CH-OH. Reagent: NaBH ₄ (or [H] in equations). e.g. CH ₃ CHO + 2[H] → CH ₃ CH ₂ OH (ethanal → ethanol)
Ketone → Secondary alcohol	The C=O in the middle of the chain gains H, becoming CH-OH. Reagent: NaBH ₄ (or [H] in equations). e.g. CH ₃ COCH ₃ + 2[H] → CH ₃ CH(OH)CH ₃ (propanone → propan-2-ol)
Carboxylic acid → Primary alcohol	Requires a stronger reducing agent (LiAlH ₄). Not common at SL but worth knowing. e.g. CH ₃ COOH + 4[H] → CH ₃ CH ₂ OH + H ₂ O (ethanoic acid → ethanol)
Ester → Two alcohols	Full reduction of an ester gives two alcohols (HL topic mostly). e.g. CH ₃ COOCH ₂ CH ₃ + 4[H] → CH ₃ CH ₂ OH + CH ₃ CH ₂ OH

Full Worked Examples — Reduction Equations

WORKED EXAMPLE

Example 1 — Reduction of ethanal to ethanol (aldehyde → primary alcohol):

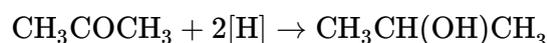


ethanal → ethanol

Reagent: NaBH_4 in water. What happened: the $\text{C}=\text{O}$ double bond became $\text{C}-\text{OH}$ (added 2H).
Reaction type: reduction.

Notice: this is the exact REVERSE of oxidising ethanol to ethanal with $\text{K}_2\text{Cr}_2\text{O}_7$.

Example 2 — Reduction of propanone to propan-2-ol (ketone → secondary alcohol):



propanone → propan-2-ol

Reagent: NaBH_4 in water. What happened: $\text{C}=\text{O}$ in middle of chain became $\text{C}-\text{OH}$. Reaction type: reduction.

The OH group ends up on the middle carbon — so the product is a SECONDARY alcohol.

Example 3 — Reduction of butanal to butan-1-ol:

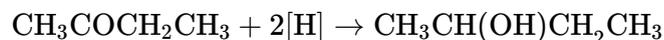


butanal → butan-1-ol

Reagent: NaBH_4 in water. Type: reduction (aldehyde → primary alcohol).

The CHO at the end becomes CH_2OH — the carbon count stays the same.

Example 4 — Reduction of butanone to butan-2-ol:



butanone → butan-2-ol

Reagent: NaBH_4 . Type: reduction (ketone → secondary alcohol).

The $\text{C}=\text{O}$ on carbon 2 becomes CHOH on carbon 2 — secondary alcohol.

The Full Oxidation-Reduction Pathway (Primary Alcohol)

Complete reversible pathway — primary alcohol family:

Primary alcohol $\xrightarrow{\text{oxidation, } \text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4, \text{ distil}}$ Aldehyde

Aldehyde $\xrightarrow{\text{oxidation, } \text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4, \text{ reflux}}$ Carboxylic acid

Carboxylic acid $\xrightarrow{\text{reduction, LiAlH}_4}$ Primary alcohol

Aldehyde $\xrightarrow{\text{reduction, NaBH}_4}$ Primary alcohol

Oxidation goes UP (more oxygen, less hydrogen). Reduction goes DOWN (more hydrogen, less oxygen).

How to Prove Reduction Has Occurred

Stage	Test & Expected Result
Before reduction: test for aldehyde or ketone	Aldehyde: Tollens' reagent gives silver mirror. Fehling's gives red precipitate. Ketone: $\text{K}_2\text{Cr}_2\text{O}_7$ stays orange. Tollens' gives no mirror.
After reduction: test for alcohol	Test with $\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$: if the product is a PRIMARY or SECONDARY alcohol, solution turns orange \rightarrow green. If TERTIARY alcohol formed (impossible from reduction), no colour change.
Confirm it is no longer an aldehyde	After reduction, Tollens' reagent should give NO silver mirror (aldehyde has been converted). Fehling's should stay blue (no aldehyde remaining).
Additional confirmation	IR spectroscopy (HL): the $\text{C}=\text{O}$ stretch at $\sim 1700\text{ cm}^{-1}$ disappears and broad O-H stretch appears at $\sim 3300\text{ cm}^{-1}$. At SL: smell changes (aldehydes are sweet/fruity; alcohols smell 'alcoholic').

EXAM ALERT

Reduction always uses [H] in the equation at SL. Make sure you balance: adding [H] to $\text{C}=\text{O}$ gives $\text{C}-\text{OH}$, and you need $2[\text{H}]$ per carbonyl group. Do not confuse with hydrogenation of alkenes (also adds $2[\text{H}]$ but across $\text{C}=\text{C}$, not $\text{C}=\text{O}$).

IB TIP

A useful way to remember oxidation vs reduction in organic: OXIDATION increases the number of C-O bonds (or removes C-H bonds). REDUCTION increases the number of C-H bonds (or removes C-O bonds). Count the oxygens and hydrogens on carbon to check.

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. What is the product when butanone ($\text{CH}_3\text{COCH}_2\text{CH}_3$) is reduced with NaBH_4 ?

A. Butan-1-ol

B. Butan-2-ol ← CORRECT

C. Butanal

D. Butanoic acid

Why: Butanone is a ketone ($\text{C}=\text{O}$ in the middle of the chain). Reduction with NaBH_4 converts $\text{C}=\text{O}$ to $\text{C}-\text{OH}$, giving a secondary alcohol. The $-\text{OH}$ ends up on carbon 2 (the same carbon that had the $\text{C}=\text{O}$), producing butan-2-ol. Ketones always reduce to secondary alcohols.

WORKED EXAMPLE

Q2. Which statement correctly describes the reduction of an aldehyde?

A. $\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$ is added and the solution turns green

B. $[\text{O}]$ is added to convert $\text{C}=\text{O}$ to $\text{C}-\text{OH}$

C. $[\text{H}]$ is added to convert $\text{C}=\text{O}$ to $\text{C}-\text{OH}$, using NaBH_4 as the reducing agent ← CORRECT

D. The aldehyde is heated under reflux to form a carboxylic acid

Why: Reduction means adding hydrogen (or $[\text{H}]$). The $\text{C}=\text{O}$ double bond in the aldehyde gains hydrogen to become $\text{C}-\text{OH}$. The reagent is NaBH_4 (sodium tetrahydridoborate). Options A and D describe oxidation, not reduction. Option B incorrectly uses $[\text{O}]$.

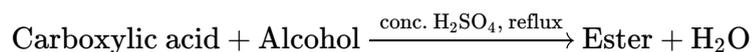
Written Questions (answers at end of guide):

W1. Propanal ($\text{CH}_3\text{CH}_2\text{CHO}$) can be reduced to an alcohol. Write the equation for this reaction using $[\text{H}]$, name the product, classify it as primary/secondary/tertiary, and state the reagent used. Describe how you could confirm that the reduction has occurred using a chemical test. [4 marks]

6C. Esterification — Making Esters

Esters are organic compounds with a distinctive **sweet, fruity smell** — they are responsible for the aromas of many fruits (banana, pineapple, pear) and are widely used in perfumes, food flavourings, and solvents. An ester is formed when a **carboxylic acid reacts with an alcohol** in the presence of an **acid catalyst** (concentrated H_2SO_4). This reaction is called **esterification** (or **condensation**), because a small molecule — water — is released as a by-product. The reaction is **reversible** and reaches an equilibrium, which is why an acid catalyst and **reflux** conditions are used to push the reaction forward and increase yield.

The Esterification Reaction



How Ester Names Work

Ester names have two parts: the **alcohol part** comes first (as an -yl group), and the **acid part** comes second (as an -anoate group).

Acid	Alcohol	Ester Produced	Ester Name
CH ₃ COOH (ethanoic acid)	CH ₃ OH (methanol)	CH ₃ COOCH ₃	Methyl ethanoate
CH ₃ COOH (ethanoic acid)	CH ₃ CH ₂ OH (ethanol)	CH ₃ COOCH ₂ CH ₃	Ethyl ethanoate
HCOOH (methanoic acid)	CH ₃ OH (methanol)	HCOOCH ₃	Methyl methanoate
CH ₃ CH ₂ COOH (propanoic acid)	CH ₃ OH (methanol)	CH ₃ CH ₂ COOCH ₃	Methyl propanoate

MEMORISE THIS

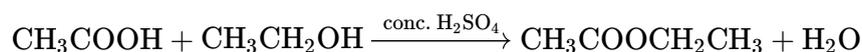
Naming rule: [alcohol part]-yl [acid part]-anoate

- The -yl comes from the **alcohol** (methanol → methyl, ethanol → ethyl)
- The -anoate comes from the **acid** (ethanoic acid → ethanoate, propanoic acid → propanoate)

Worked Examples

WORKED EXAMPLE

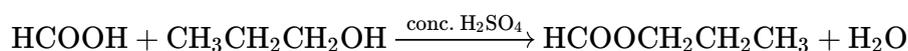
Example 1 — Ethanoic acid + Ethanol:



- Acid: ethanoic acid → provides the **ethanoate** part
- Alcohol: ethanol → provides the **ethyl** part
- Product: **ethyl ethanoate** (sweet, fruity smell — similar to nail polish remover)
- Conditions: concentrated H₂SO₄ catalyst, heat under **reflux**
- Reaction type: **condensation** (water is released)

WORKED EXAMPLE

Example 2 — Methanoic acid + Propan-1-ol:

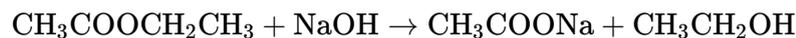


- Acid: methanoic acid → provides the **methanoate** part
- Alcohol: propan-1-ol → provides the **propyl** part
- Product: **propyl methanoate**

Hydrolysis of Esters — The Reverse Reaction

Esters can be broken back down into the original carboxylic acid and alcohol by **hydrolysis** (reaction with water). This can be done under:

Condition	Details
Acid hydrolysis	Ester + H ₂ O with dilute H ₂ SO ₄ or HCl, heat under reflux → carboxylic acid + alcohol. Reversible.
Base hydrolysis (saponification)	Ester + NaOH(aq), heat under reflux → sodium salt of carboxylic acid + alcohol. Irreversible. Used in soap-making.



Key Facts for IB

Point	Detail
Reaction type	Condensation (esterification) — small molecule (H ₂ O) released
Catalyst	Concentrated H ₂ SO ₄
Conditions	Heat under reflux
Reversibility	Reversible — reaches equilibrium
How to detect an ester	Sweet, fruity smell. Does NOT turn litmus red (unlike carboxylic acid).
Hydrolysis	Reverse of esterification — ester + water → acid + alcohol
Uses of esters	Perfumes, food flavourings, solvents, plasticisers

IB TIP

The IB often gives you an ester and asks you to identify the acid and alcohol it was made from. Split the ester at the -COO- bond: the part bonded to the C=O came from the acid, the part bonded to the single-bonded O came from the alcohol.

EXAM ALERT

Do NOT confuse esterification (condensation — water released, reversible) with addition polymerization (no by-product, irreversible). Both involve joining molecules, but the mechanisms and products are completely different.

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. Ethanoic acid reacts with methanol in the presence of concentrated H_2SO_4 . What is the name of the ester produced?

A. Ethyl methanoate

B. Methyl ethanoate ← CORRECT

C. Methyl methanoate

D. Ethyl ethanoate

Why: The ester name is built as [alcohol part]-yl [acid part]-anoate. The alcohol is methanol (gives “methyl”), and the acid is ethanoic acid (gives “ethanoate”). So the product is methyl ethanoate ($\text{CH}_3\text{COOCH}_3$). A common IB trap is reversing the two parts.

WORKED EXAMPLE

Q2. What type of reaction is esterification?

A. Addition

B. Substitution

C. Condensation ← CORRECT

D. Elimination

Why: Esterification is a condensation reaction because two molecules (carboxylic acid + alcohol) join together with the loss of a small molecule — water (H_2O). It is NOT addition (no $\text{C}=\text{C}$ involved) and NOT substitution (no atom is replaced by another).

Written Questions (answers at end of guide):

W1. The ester propyl methanoate ($\text{HCOOCH}_2\text{CH}_2\text{CH}_3$) is hydrolysed using aqueous NaOH . Write the equation for this reaction, name both organic products, and state the conditions required. Explain why base hydrolysis is described as irreversible, unlike acid hydrolysis. [4 marks]

6B. Identifying Reactions & Experimental Tests

One of the most common IB question types gives you a reaction or a structural formula and asks you to identify the **reaction type, reagents, conditions, or products**. This section gives you worked examples of every major reaction type so you can recognise them on sight. The key is to look at what changes between reactant and product — then ask: what type of change is this?

The Reaction Identification Checklist

- **Addition:** Two reactants combine into ONE product. A double bond disappears. No atoms lost.
- **Substitution:** One atom or group is REPLACED by another. Two products always formed.
- **Elimination:** Atoms are REMOVED from adjacent carbons to form a double bond. HX or H₂O lost.
- **Oxidation:** Oxygen added or hydrogen removed. Use [O]. Colour change orange → green with K₂Cr₂O₇.
- **Hydrolysis:** Bond broken by water (or OH⁻). Often seen in esters.
- **Polymerization:** Many identical monomers join into a long chain. n appears in the equation.

Example Set 1 – Identify the Reaction Type

Reaction Equation	Reaction Type & Key Clues
$\text{CH}_2=\text{CH}_2 + \text{H}_2 \rightarrow \text{CH}_3\text{CH}_3$	ADDITION (hydrogenation). The C=C double bond opens and H ₂ adds across it. One product formed. Catalyst: Ni, heat.
$\text{CH}_2=\text{CH}_2 + \text{Br}_2 \rightarrow \text{CH}_2\text{BrCH}_2\text{Br}$	ADDITION (halogenation). Bromine adds across the double bond. Bromine water decolourises (orange → colourless). One product.
$\text{CH}_2=\text{CH}_2 + \text{HBr} \rightarrow \text{CH}_3\text{CH}_2\text{Br}$	ADDITION (hydrohalogenation). H and Br both add across the C=C.
$\text{CH}_2=\text{CH}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{OH}$	ADDITION (hydration). Water adds across the double bond to form an alcohol. Catalyst: H ₃ PO ₄ , high temperature and pressure.
$\text{CH}_4 + \text{Cl}_2 \xrightarrow{\text{UV}} \text{CH}_3\text{Cl} + \text{HCl}$	FREE RADICAL SUBSTITUTION. Cl replaces H. UV light required. Two products. Alkane + halogen.
$\text{CH}_3\text{CH}_2\text{OH} + [\text{O}] \rightarrow \text{CH}_3\text{CHO} + \text{H}_2\text{O}$	OXIDATION. Primary alcohol → aldehyde. K ₂ Cr ₂ O ₇ /H ₂ SO ₄ , orange → green. Distil off product.
$\text{CH}_3\text{CHO} + [\text{O}] \rightarrow \text{CH}_3\text{COOH}$	OXIDATION. Aldehyde → carboxylic acid. K ₂ Cr ₂ O ₇ /H ₂ SO ₄ , orange → green. Reflux conditions.
$\text{CH}_3\text{CH}(\text{OH})\text{CH}_3 + [\text{O}] \rightarrow \text{CH}_3\text{COCH}_3 + \text{H}_2\text{O}$	OXIDATION. Secondary alcohol (propan-2-ol) → ketone (propanone). Orange → green. Cannot oxidise further.
$n \text{CH}_2=\text{CH}_2 \rightarrow [-\text{CH}_2-\text{CH}_2-]_n$	ADDITION POLYMERIZATION. Many ethene monomers join. Double bond opens. No by-product.

Example Set 2 — Identify the Product

Starting Materials	Product & Reaction Type
Propene + Br ₂ → ?	CH ₃ CHBrCH ₂ Br (1,2-dibromopropane). Type: addition. Both Br atoms add across the C=C of propene.
But-2-ene + HBr → ?	CH ₃ CH ₂ CHBrCH ₃ (2-bromobutane). Type: addition. H adds to one end of C=C, Br to the other.
Butan-1-ol + excess K ₂ Cr ₂ O ₇ /H ₂ SO ₄ → ?	CH ₃ CH ₂ CH ₂ COOH (butanoic acid). Type: oxidation (full). Primary alcohol + excess oxidant under reflux → carboxylic acid.
Butan-2-ol + K ₂ Cr ₂ O ₇ / H ₂ SO ₄ → ?	CH ₃ COCH ₂ CH ₃ (butanone). Type: oxidation. Secondary alcohol → ketone. Cannot go further.
2-methylpropan-2-ol + K ₂ Cr ₂ O ₇ /H ₂ SO ₄ → ?	NO REACTION. Tertiary alcohol. Solution stays orange.
2-methylpropane + Cl ₂ $\xrightarrow{\text{UV}}$?	2-chloro-2-methylpropane (major) + HCl. Type: free radical substitution. Multiple products possible.
Ethene + H ₂ O → ?	CH ₃ CH ₂ OH (ethanol). Type: addition (hydration). Catalyst: H ₃ PO ₄ , 300°C, high pressure.

Example Set 3 — Identify the Reagent or Condition

Transformation	Reagent, Condition & Type
CH ₂ =CH ₂ → CH ₃ CH ₃ (What reagent and condition?)	Reagent: H ₂ (hydrogen gas). Condition: Ni catalyst, heat (about 150°C). Type: hydrogenation (addition)
CH ₃ CH ₂ OH → CH ₃ CHO (What reagent and condition?)	Reagent: acidified K ₂ Cr ₂ O ₇ (K ₂ Cr ₂ O ₇ + H ₂ SO ₄). Condition: gentle heat, DISTIL product off immediately. Type: oxidation (limited)
CH ₃ CH ₂ OH → CH ₃ COOH (What reagent and condition?)	Reagent: excess acidified K ₂ Cr ₂ O ₇ . Condition: heat under REFLUX. Type: oxidation (full)
CH ₄ → CH ₃ Cl (What reagent and condition?)	Reagent: Cl ₂ (chlorine gas). Condition: UV light (sunlight). Type: free radical substitution
CH ₂ =CH ₂ → [−CH ₂ CH ₂ −] _n (What reagent and condition?)	Reagent: none (self-reaction of monomers). Condition: high pressure, catalyst (Ziegler-Natta). Type: addition polymerization

Example Set 4 — Given a Colour Change, What Does It Tell You?

These are 'interpret the observation' questions — very common in IB Paper 2.

Observation	What It Tells You
$\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$ turns orange → green	Oxidation has occurred. The substance is either a primary or secondary alcohol, OR an aldehyde. Something has been oxidised.
$\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$ stays orange (no change)	No oxidation has occurred. The substance is either a tertiary alcohol, a ketone, or an alkane — none of these can be oxidised under these conditions.
Bromine water (orange/brown) → colourless	An addition reaction has occurred. A C=C double bond was present (alkene). The compound is UNSATURATED.
Bromine water stays orange/brown	No addition reaction. No C=C present. The compound is saturated (e.g. alkane, alcohol, ketone).
Tollens' reagent → silver mirror	An aldehyde is present. The aldehyde reduced Ag^+ to Ag metal.
Fehling's solution (blue) → brick-red precipitate	An aldehyde is present. Cu^{2+} was reduced to Cu_2O . NOT a ketone.
Both solutions stay unchanged (Tollens' + Fehling's)	A KETONE is present (or a carboxylic acid, or an alcohol). NOT an aldehyde.
Na_2CO_3 solution produces CO_2 bubbles	A CARBOXYLIC ACID is present. Acid + carbonate → salt + water + CO_2 .
pH paper shows strongly acidic (pH 1-3)	A carboxylic acid is likely present. Confirms acid functional group.

EXAM ALERT

In a 'describe a test' question, you MUST give: (1) the name of the reagent, (2) the positive result (what you observe if the compound IS what you think), and (3) ideally the negative result for comparison. Just saying 'it goes green' without naming the reagent gets 0 marks.

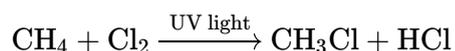
IB TIP

A really useful IB strategy: if you are given an unknown compound and told only the molecular formula, use the degree of unsaturation to predict whether it has a C=C (test with bromine water). If it does, it's an alkene. If bromine water stays orange but $\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$ turns green, it's an alcohol or aldehyde.

8. Free Radical Substitution

Alkanes are actually quite unreactive under normal conditions — they have no polar bonds, no double bonds, and no lone pairs, so they don't attract nucleophiles or electrophiles. However, they **will react with halogens in the presence of UV light** via a mechanism involving **free radicals** — highly reactive species with an unpaired electron. UV light provides the energy to break the Cl-Cl (or Br-Br) bond **homolytically**, meaning each atom takes one electron. This produces two Cl radicals that kick off a self-sustaining chain reaction. The reaction proceeds through three distinct stages — initiation, propagation, and termination — and the IB expects you to write equations for all three and explain what happens in each. A key limitation of this reaction is that it can produce a mixture of products (e.g. CH_3Cl , CH_2Cl_2 , CHCl_3 , CCl_4), making it non-selective.

Overall Reaction (e.g. methane + chlorine):



Reaction type: free radical substitution

The Three Steps

Step	What Happens
1. Initiation	UV light breaks the Cl-Cl bond by HOMOLYTIC FISSION . $\text{Cl}_2 \rightarrow 2 \text{Cl}\cdot$ (Each Cl atom gets one electron — shown as $\text{Cl}\cdot$, a free radical)
2. Propagation	Two steps that repeat in a chain reaction: (a) $\text{Cl}\cdot + \text{CH}_4 \rightarrow \text{HCl} + \text{CH}_3\cdot$ (b) $\text{CH}_3\cdot + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{Cl}\cdot$. The $\text{Cl}\cdot$ produced in (b) re-enters step (a)
3. Termination	Two radicals combine — the chain ends: $\text{Cl}\cdot + \text{Cl}\cdot \rightarrow \text{Cl}_2$ / $\text{CH}_3\cdot + \text{Cl}\cdot \rightarrow \text{CH}_3\text{Cl}$ / $\text{CH}_3\cdot + \text{CH}_3\cdot \rightarrow \text{C}_2\text{H}_6$

What is a Free Radical?

Property	Detail
Definition	A species with an UNPAIRED electron
Charge	NEUTRAL (no charge)
Formation	By HOMOLYTIC fission (bond splits equally, each atom gets one electron)
Notation	Written with a dot: $\text{Cl}\cdot$, $\text{CH}_3\cdot$
Reactivity	Very reactive because the unpaired electron makes it unstable

IB TIP
Homolytic fission = each atom gets **ONE** electron (forms radicals). Heterolytic fission = one atom gets **BOTH** electrons (forms ions). Free radical substitution uses homolytic fission.

EXAM ALERT
The IB often asks you to identify which step is initiation, propagation, or termination. Termination always involves two radicals combining. Propagation always regenerates a radical.

Homolytic vs Heterolytic Bond Fission

When a covalent bond breaks, the two bonding electrons must go somewhere. Free radical substitution uses **homolytic fission**; ionic mechanisms (e.g. electrophilic addition) use **heterolytic fission**. The IB mark scheme requires you to use these exact words.

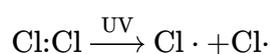
Type	Definition, Result & Example
Homolytic fission ('homo' = equal)	Bond breaks EQUALLY — each atom gets ONE electron. Result: two FREE RADICALS (neutral, one unpaired electron each). Shown as: $\text{Cl}-\text{Cl} \xrightarrow{\text{UV}} \text{Cl}\cdot + \text{Cl}\cdot$. When: FREE RADICAL reactions (alkane + halogen, UV light). Memory: HOME run = EQUAL split
Heterolytic fission ('hetero' = unequal)	Bond breaks UNEQUALLY — one atom takes BOTH electrons. Result: two IONS (one cation +, one anion -). Shown as: $\text{H}-\text{Br} \rightarrow \text{H}^+ + \text{Br}^-$. When: IONIC mechanisms (e.g. electrophilic addition). Memory: HETERO = DIFFERENT = unequal split

Analogy: Two people sharing 2 sweets and then splitting up:

- **Homolytic:** Each person takes 1 sweet — both leave with something (radicals, neutral, reactive)
- **Heterolytic:** One person takes both sweets — one leaves with 2 (anion), one with 0 (cation)

Reaction Type	Fission Type
Free radical substitution (this section)	Homolytic — UV light splits Cl-Cl equally \rightarrow Cl \cdot + Cl \cdot
Electrophilic addition (Section 5)	Heterolytic — H-Br breaks: H $^+$ adds to alkene carbon, Br $^-$ released

Homolytic fission — free radical substitution:



(1 electron each — both neutral radicals)

Required IB wording: 'UV light causes homolytic fission of the Cl-Cl bond to form two Cl radicals.'

Heterolytic fission — electrophilic addition:



(both electrons go to Br — forms ions)

The H $^+$ is the electrophile that attacks the C=C double bond in electrophilic addition.

EXAM ALERT

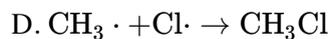
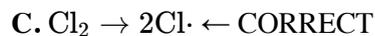
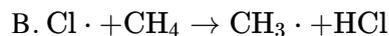
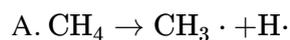
The IB mark scheme requires the word 'homolytic fission' for the initiation step. Just writing 'the bond breaks' loses the mark. Always say: 'UV light causes homolytic fission of the Cl-Cl bond, forming two Cl radicals.'

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

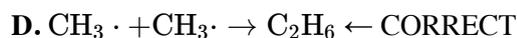
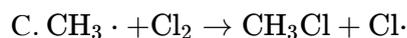
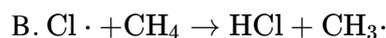
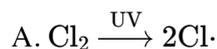
Q1. In the free radical substitution of methane with chlorine, what is the initiation step?



Why: Initiation is the first step where UV light causes homolytic fission of the Cl-Cl bond, producing two chlorine free radicals. Option B is a propagation step. Option D is a termination step. The C-H bond in methane is too strong to break by UV light alone.

WORKED EXAMPLE

Q2. Which of the following is a termination step in the free radical substitution of methane with chlorine?



Why: Termination occurs when two free radicals combine, removing radicals from the system and ending the chain reaction. $\text{CH}_3 \cdot + \text{CH}_3 \cdot \rightarrow \text{C}_2\text{H}_6$ combines two radicals. This also explains why ethane (C_2H_6) can be detected as a minor by-product.

Written Questions (answers at end of guide):

W1. Write equations for the initiation, two propagation steps, and one termination step for the free radical substitution of ethane (C_2H_6) with bromine (Br_2) in the presence of UV light. State the overall equation and explain why a mixture of products is obtained. [5 marks]

9. Polymerization

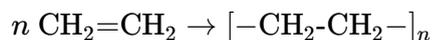
Polymers are giant molecules made by linking thousands of small repeating units called **monomers** together. They are the basis of all plastics, synthetic fibres, and many natural materials (DNA, proteins, and cellulose are all biological polymers). In IB SL, you need to understand two types of polymerization. **Addition polymerization** occurs when alkene monomers (containing $\text{C}=\text{C}$) simply join end-to-end as the double bond opens up — nothing is lost or produced as a by-product. **Condensation polymerization** involves monomers with two functional groups reacting to form a polymer chain while releasing a small molecule (usually water) each time a bond forms. The real-world scale of polymers explains why they

behave so differently from their monomers: ethene is a gas, but polyethene is a tough solid plastic used in everything from food packaging to bulletproof vests.

Addition Polymerization

Small molecules (monomers) containing C=C double bonds join together. The double bond opens up and monomers link in a chain. No other products are formed.

Addition polymerization of ethene → polyethene:



The monomer must contain a C=C double bond. The polymer has no double bonds.

Monomer	Polymer & Uses
Chloroethene ($\text{CH}_2=\text{CHCl}$)	→ poly(chloroethene), PVC. Used in pipes, window frames
Ethene ($\text{CH}_2=\text{CH}_2$)	→ poly(ethene)/polyethene. Plastic bags, bottles
Propene ($\text{CH}_2=\text{CHCH}_3$)	→ poly(propene). Ropes, carpets
Tetrafluoroethene ($\text{CF}_2=\text{CF}_2$)	→ PTFE (Teflon). Non-stick coatings

How to Draw the Repeating Unit

- Remove the double bond from the monomer
- Draw the single bond chain, connecting to the next unit with bonds extending outside the brackets
- Add a subscript 'n' outside the brackets

Example for chloroethene: monomer is $\text{CH}_2=\text{CHCl}$ → repeating unit is $[-\text{CH}_2-\text{CHCl}-]_n$

Condensation Polymerization

Monomers with TWO functional groups react together, releasing a small molecule (usually water or HCl) with each bond formed.

Type	Details
Polyester	Diol + dicarboxylic acid → polyester + water. e.g. PET (drinks bottles, clothing)
Polyamide (nylon)	Diamine + dicarboxylic acid → polyamide + water. e.g. Nylon-6,6, Kevlar
Small molecule produced	H_2O (in polyester and polyamide from carboxylic acid groups)

IB TIP

Addition polymers come from alkenes (have C=C). Condensation polymers come from bifunctional monomers and always release a small molecule. The IB can ask you to name both types.

EXAM ALERT

When drawing a repeating unit, make sure you show the bonds extending OUTSIDE the brackets on both sides. This shows the unit continues in both directions.

Why Are Monomers Gases/Liquids but Polymers Are Solids?

Monomers have small molecular masses → low intermolecular forces → low boiling points → gases or volatile liquids.

Polymers have very large molecular masses (thousands of monomer units) → very strong intermolecular forces → high melting points → solids at room temperature.

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. What is the repeating unit of the polymer formed from chloroethene ($\text{CH}_2=\text{CHCl}$)?

- A. $[-\text{CH}_2=\text{CHCl}-]_n$
- B. $[-\text{CH}_2-\text{CH}_2-\text{CHCl}-]_n$
- C. $[-\text{CH}_2-\text{CHCl}-]_n$ ← CORRECT
- D. $[-\text{CHCl}-\text{CHCl}-]_n$

Why: In addition polymerization, the $\text{C}=\text{C}$ double bond opens up. The repeating unit is drawn by converting $\text{C}=\text{C}$ to $\text{C}-\text{C}$ and showing the bonds extending outside the brackets. The substituent (Cl) stays on the same carbon. This polymer is PVC (poly(chloroethene)).

WORKED EXAMPLE

Q2. Which statement correctly distinguishes addition polymerization from condensation polymerization?

- A. Addition polymers produce water as a by-product
- B. Condensation polymers require monomers with $\text{C}=\text{C}$ double bonds
- C. **Condensation polymerization releases a small molecule (e.g. H_2O) whereas addition polymerization does not** ← CORRECT
- D. Addition polymerization uses bifunctional monomers

Why: The key difference is that condensation polymerization releases a small molecule (usually water) with each bond formed, while addition polymerization produces no by-product. Addition polymers come from alkene monomers (with $\text{C}=\text{C}$). Condensation polymers come from bifunctional monomers (e.g. diols + dicarboxylic acids).

Written Questions (answers at end of guide):

W1. Propene ($\text{CH}_2=\text{CHCH}_3$) undergoes addition polymerization. Draw the repeating unit of the polymer formed, name the polymer, and explain why the monomer is a gas at room temperature but the polymer is a solid. [3 marks]

10. Properties of Organic Compounds

The physical properties of organic compounds — particularly **boiling point and solubility** — are largely determined by the **intermolecular forces** between molecules. The stronger the intermolecular forces, the more energy is needed to separate molecules from each other, and the higher the boiling point. All organic molecules have London dispersion forces (van der Waals), which increase with molecular size and surface area. Branching reduces surface area and weakens these forces, lowering the boiling point. Compounds with -OH groups (alcohols, carboxylic acids) can form hydrogen bonds — the strongest intermolecular force at SL — dramatically raising their boiling points compared to similarly sized alkanes. Organic chemistry also has enormous industrial importance: crude oil is the world's primary source of fuels, solvents, and feedstocks for making plastics, medicines, and fertilisers. Understanding where these products come from — and the environmental consequences of their use — is part of the IB curriculum.

Boiling Points

Factor	Effect on Boiling Point
Molecular mass increases	Boiling point increases (stronger London/van der Waals forces)
Branching increases	Boiling point decreases (less surface area, weaker dispersion forces). e.g. pentane > 2-methylbutane > 2,2-dimethylpropane
Hydrogen bonding	Alcohols and carboxylic acids have H-bonding → much higher boiling points than similar alkanes
Polar functional groups	Aldehydes/ketones have dipole-dipole forces → higher bp than similar alkanes

Crude Oil & Petroleum

Product	Source & Notes
Fractional distillation	Separates crude oil by boiling point into fractions. Shorter chains = lower bp = collected at top
Plastics	From alkenes via polymerization (e.g. ethene → polyethene)
Margarine	From vegetable oils + H ₂ (hydrogenation of C=C double bonds)
Motor fuel	Mainly alkanes (petrol = C ₅ -C ₁₀ chain lengths)

Crude Oil Concerns

- Non-renewable resource — will run out
- Burning releases CO₂ → greenhouse effect / climate change
- Incomplete combustion releases CO → toxic
- Combustion of S impurities → SO₂ → acid rain

Quick Reaction Summary Table

Reaction	Type & Product
Alkane + halogen (UV)	Free radical substitution → halogenoalkane + HX
Alkene + Br ₂	Addition → dibromoalkane (decolourises bromine water)
Alkene + H ₂ (Ni, heat)	Addition (hydrogenation) → alkane
Alkene + HBr	Addition (hydrohalogenation) → bromoalkane
Alkene + H ₂ O (H ₃ PO ₄)	Addition (hydration) → alcohol
Primary alcohol + K ₂ Cr ₂ O ₇	Oxidation → aldehyde → carboxylic acid
Secondary alcohol + K ₂ Cr ₂ O ₇	Oxidation → ketone
Tertiary alcohol + K ₂ Cr ₂ O ₇	No reaction (stays orange)
Alkene + n (polymerize)	Addition polymerization → polymer
Carboxylic acid + Alcohol (conc. H ₂ SO ₄)	Esterification (condensation) → ester + H ₂ O
Ester + NaOH(aq)	Base hydrolysis (saponification) → sodium salt + alcohol

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. Ethanol (CH₃CH₂OH) has a significantly higher boiling point than ethane (C₂H₆), despite having a similar molecular mass. What is the best explanation?

- A. Ethanol has stronger covalent bonds
- B. Ethanol has a higher molecular mass
- C. Ethanol can form hydrogen bonds between molecules, whereas ethane can only form London dispersion forces ← CORRECT**
- D. Ethanol is an ionic compound

Why: The -OH group in ethanol allows hydrogen bonding between molecules (O-H ··· O). Hydrogen bonds are much stronger than London dispersion forces (the only intermolecular force in ethane). More energy is needed to separate ethanol molecules, so the boiling point is higher. Covalent bond strength is irrelevant to boiling point — it is intermolecular forces that matter.

Written Questions (answers at end of guide):

W1. Arrange the following compounds in order of increasing boiling point: pentane, pentan-1-ol, 2,2-dimethylpropane. Justify your answer by identifying the types of intermolecular forces present in each compound and explaining how molecular structure affects boiling point. [4 marks]

11. What You MUST Memorise – IB Exam Checklist

This section is your final revision checklist. These are the facts, colour changes, reagents, conditions, and definitions that the IB repeatedly tests. If you can answer every item below from memory, you are well prepared for the organic chemistry section of your exam.

1. Colour Changes – Know These Cold

MEMORISE THIS	
Reagent	Result & What It Means
$K_2Cr_2O_7 / H_2SO_4$ (acidified dichromate)	ORANGE → GREEN = oxidation occurred. ORANGE stays = no oxidation (tertiary alcohol, ketone, or alkane)
Bromine water ($Br_2(aq)$)	ORANGE/BROWN → COLOURLESS = addition reaction, C=C present (alkene). Stays orange = no C=C (saturated compound)
Tollens' reagent	COLOURLESS → SILVER MIRROR = aldehyde present. No change = ketone, alcohol, or carboxylic acid
Fehling's / Benedict's solution	BLUE → BRICK-RED PRECIPITATE = aldehyde present. Stays blue = ketone (or no reducing sugar)
Litmus / universal indicator	Turns RED / low pH = carboxylic acid present. Neutral = alcohol, aldehyde, ketone, or alkane
Na_2CO_3 added	BUBBLES (CO_2) = carboxylic acid present. No bubbles = not an acid

2. Reagents & Conditions – Exact Answers Required

MEMORISE THIS	
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Reaction	Reagent(s) & Conditions
Oxidation of primary alcohol → aldehyde	Acidified $K_2Cr_2O_7$ ($K_2Cr_2O_7 + H_2SO_4$), limited amount, gentle heat, DISTIL
Oxidation of primary alcohol → carboxylic acid	Acidified $K_2Cr_2O_7$ ($K_2Cr_2O_7 + H_2SO_4$), excess, heat under REFLUX
Oxidation of secondary alcohol → ketone	Acidified $K_2Cr_2O_7$ ($K_2Cr_2O_7 + H_2SO_4$), heat
Reduction of aldehyde → primary alcohol	$NaBH_4$ (sodium tetrahydridoborate) in water, OR write [H]
Reduction of ketone → secondary alcohol	$NaBH_4$ in water, OR write [H]
Addition of H_2 to alkene	H_2 gas, Ni catalyst, heat ($\sim 150^\circ C$) — hydrogenation
Addition of Br_2 to alkene	$Br_2(aq)$ (bromine water) — no catalyst needed
Addition of HBr to alkene	HBr gas or solution — no catalyst
Hydration of alkene → alcohol	Steam (H_2O), H_3PO_4 catalyst, high temperature ($\sim 300^\circ C$) and pressure
Free radical substitution (alkane → halogenoalkane)	Halogen (Cl_2 or Br_2), UV light (sunlight)
Addition polymerization (alkene → polymer)	High pressure, Ziegler-Natta catalyst (or just: high pressure, catalyst)
Esterification (acid + alcohol → ester)	Concentrated H_2SO_4 catalyst, heat under reflux
Hydrolysis of ester (base)	$NaOH(aq)$, heat under reflux (saponification)

3. Definitions — Write These Out Word for Word

MEMORISE THIS

Term	Definition
Homologous series	A series of compounds with the same functional group and general formula, differing by CH_2 between successive members, with gradually changing physical properties.
Functional group	An atom or group of atoms in a molecule that is responsible for the characteristic chemical reactions of that molecule.
Structural isomers	Compounds with the same molecular formula but different structural arrangements of atoms.
Free radical	A species with one unpaired electron. It is neutral and highly reactive.
Homolytic fission	The breaking of a covalent bond in which each atom receives one electron from the shared pair, producing two free radicals.
Heterolytic fission	The breaking of a covalent bond in which one atom receives both electrons from the shared pair, producing a cation and an anion.
Electrophile	An electron-deficient species that accepts a pair of electrons. Examples: H^+ , Br_2 , HBr , carbocations.
Addition reaction	A reaction in which two molecules combine to form a single product. No atoms are lost. Requires a $\text{C}=\text{C}$ double bond.
Substitution reaction	A reaction in which one atom or group is replaced by another atom or group. Two products are always formed.
Oxidation (organic)	The addition of oxygen or removal of hydrogen from an organic molecule.
Reduction (organic)	The removal of oxygen or addition of hydrogen to an organic molecule.
Unsaturated hydrocarbon	A hydrocarbon that contains at least one $\text{C}=\text{C}$ or $\text{C}\equiv\text{C}$ bond. Can undergo addition reactions.
Saturated hydrocarbon	A hydrocarbon that contains only $\text{C}-\text{C}$ single bonds. Cannot undergo addition reactions.
Ester	An organic compound formed by the reaction of a carboxylic acid with an alcohol, with the elimination of water. Contains the $-\text{COO}-$ functional group.
Esterification	A condensation reaction between a carboxylic acid and an alcohol to form an ester and water. Requires an acid catalyst.
Hydrolysis	The breaking of a chemical bond by the addition of water. In organic chemistry, used to break down esters into carboxylic acids and alcohols.
Condensation reaction	A reaction in which two molecules join together with the loss of a small molecule (usually water).

4. General Formulas – Must Know

MEMORISE THIS

Compound Type General Formula & Examples

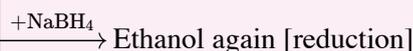
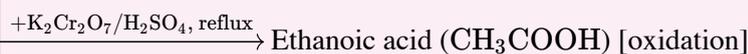
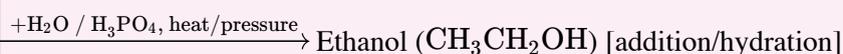
Alkanes	C_nH_{2n+2} — e.g. methane CH_4 , ethane C_2H_6 , propane C_3H_8
Alkenes	C_nH_{2n} — e.g. ethene C_2H_4 , propene C_3H_6
Cycloalkanes	C_nH_{2n} — same as alkene (but no double bond, no addition reactions)
Alcohols	$C_nH_{2n+1}OH$ — e.g. methanol CH_3OH , ethanol C_2H_5OH
Aldehydes	$C_nH_{2n}O$ — e.g. methanal $HCHO$, ethanal CH_3CHO
Carboxylic acids	$C_nH_{2n}O_2$ — e.g. methanoic acid $HCOOH$, ethanoic acid CH_3COOH

5. Key Reaction Sequences — The Big Picture

MEMORISE THIS

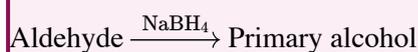
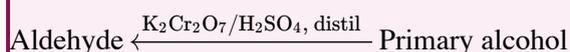
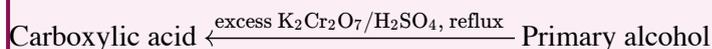
The Central Ethene/Ethanol Pathway (common exam multi-step question):

Ethene ($CH_2=CH_2$)



This pathway comes up almost every year. Know every step, reagent and condition.

Alcohol oxidation and reduction summary:



Tertiary alcohol: no oxidation, no reduction of a carbonyl to tertiary

Orange \rightarrow green = oxidation. $NaBH_4$ = reduction.

6. Things Students Always Get Wrong — Final Warnings

Common Mistake	Correct Understanding
Aldehyde vs Ketone position	Aldehyde: C=O is at the END of the chain (always on C1). Has a C-H next to C=O. Ketone: C=O is in the MIDDLE of the chain. No C-H on the carbonyl carbon.
Tertiary alcohol oxidation	Tertiary alcohols DO NOT react with $K_2Cr_2O_7$. Solution stays orange. This is NOT a failure of the test — it is the expected result. Say: ‘no oxidation occurs because the carbon bearing -OH has no hydrogen.’
Distillation vs reflux	Distil = remove product early = only get aldehyde. Reflux = keep product in = get carboxylic acid. Never swap these — it loses marks every time.
Naming the mechanism	Say ‘free radical substitution’ not just ‘substitution’ for alkane + halogen/UV. The IB mark scheme requires the full name.
Two products in substitution	Substitution ALWAYS gives two products. If you write only one, you will lose a mark. e.g. $CH_4 + Cl_2 \rightarrow CH_3Cl$ is INCOMPLETE — must add + HCl.
Homolytic fission in initiation	Do not say ‘the bond breaks’. Say: ‘UV light causes homolytic fission of the Cl-Cl bond to form two Cl radicals.’ The word homolytic is required.
Addition adds across C=C, not C-C	Addition only works if there is a C=C double bond. Alkanes have no double bonds, so they cannot undergo addition — only free radical substitution with UV.
Reduction uses [H], not H^+	[H] represents a hydride ion from $NaBH_4$. Do not write H^+ (that is an acid, not a reductant). The IB accepts [H] or $NaBH_4$ in equations.

EXAM ALERT

Read every exam question twice and underline key words: 'excess', 'reflux', 'distil', 'aqueous', 'UV light'. These words change the product or the mechanism — and ignoring them is the most common source of lost marks in organic chemistry.

IB TIP

The best revision strategy for organic chemistry is to practise writing full reaction equations from memory — starting material, reagent, conditions, product(s). Do this for every reaction in the summary table until you can do it without looking.

IB Chemistry SL — Organic Chemistry Study Guide | Good luck on your exam!

12. Written Question Answers

Section 1, W1:

A homologous series is a family of compounds that share the same functional group and the same general formula, with each successive member differing by CH_2 [1 mark]. Members have similar chemical properties because they all contain the same functional group, which determines how the molecule reacts [1 mark]. Physical properties (such as boiling point) change gradually because as the carbon chain lengthens, the molecular mass increases, leading to stronger London dispersion forces between molecules, which require more energy to overcome [1 mark].

Section 2, W1:

The compound is 2-methylpentan-3-ol [1 mark]. It has a 5-carbon longest chain (pentane) with a hydroxyl group on carbon 3 and a methyl branch on carbon 2 [1 mark]. Structural formula: $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}(\text{OH})\text{CH}_2\text{CH}_3$ [1 mark].

Section 3, W1:

There are two structural isomers of $\text{C}_3\text{H}_7\text{Br}$:

- 1-Bromopropane ($\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$) — this is a primary halogenoalkane (the carbon bonded to Br is attached to only 1 other carbon) [1 mark].
- 2-Bromopropane ($\text{CH}_3\text{CHBrCH}_3$) — this is a secondary halogenoalkane (the carbon bonded to Br is attached to 2 other carbons) [1 mark].

2-Bromopropane would react faster with aqueous NaOH [1 mark] because the C-Br bond is more accessible in the secondary isomer. At SL level, the key point is that the type of halogenoalkane affects the rate of substitution [1 mark].

Section 4, W1:

Incomplete combustion produces carbon monoxide (CO) [1 mark]. Carbon monoxide is a colourless and odourless gas, making it undetectable without specialised equipment [1 mark]. It is toxic because it binds irreversibly to haemoglobin in red blood cells (forming carboxyhaemoglobin), preventing oxygen from being transported around the body, which can lead to oxygen deprivation and death [1 mark].

Section 5, W1:

Add bromine water ($\text{Br}_2(\text{aq})$, which is orange/brown) to separate samples of each compound [1 mark]. With ethene: the bromine water decolourises (turns from orange to colourless) because Br_2 undergoes an addition reaction across the $\text{C}=\text{C}$ double bond, forming 1,2-dibromoethane [1 mark]. With ethane: the bromine water remains orange/brown because ethane is saturated (no $\text{C}=\text{C}$) and cannot undergo addition reactions under these conditions [1 mark].

Section 5, W2:

But-1-ene: $\text{CH}_2=\text{CHCH}_2\text{CH}_3$ (terminal alkene, $\text{C}=\text{C}$ at carbon 1) [1 mark]. But-2-ene: $\text{CH}_3\text{CH}=\text{CHCH}_3$ (internal alkene, $\text{C}=\text{C}$ at carbon 2) [1 mark].

When but-1-ene reacts with HBr, two products are possible: 1-bromobutane ($\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$) and 2-bromobutane ($\text{CH}_3\text{CHBrCH}_2\text{CH}_3$), because the $\text{C}=\text{C}$ is asymmetric — H and Br can add in two different orientations [1 mark].

When but-2-ene reacts with HBr, only one product is formed: 2-bromobutane ($\text{CH}_3\text{CHBrCH}_2\text{CH}_3$), because the $\text{C}=\text{C}$ is symmetric — adding H to either carbon of the

double bond gives the same product [1 mark].

Section 6, W1:

In a tertiary alcohol, the carbon atom bonded to the -OH group is also bonded to three other carbon atoms [1 mark]. This means there is no hydrogen atom on the carbon bearing the -OH group [1 mark]. Oxidation of alcohols requires the removal of a hydrogen from the C-OH carbon to form a C=O bond. Since there is no hydrogen available on this carbon in a tertiary alcohol, oxidation cannot occur, and the acidified $\text{K}_2\text{Cr}_2\text{O}_7$ solution remains orange [1 mark].

Section 6, W2:

Test 1 — Tollens' reagent (silver mirror test): Add ammoniacal silver nitrate solution ($\text{Ag}(\text{NH}_3)_2^+$) to each sample and warm gently. With ethanal (aldehyde): a silver mirror forms on the inside of the test tube (Ag^+ is reduced to Ag metal). With propanone (ketone): no change — solution remains colourless [2 marks].

Test 2 — Fehling's (or Benedict's) solution: Add blue Fehling's solution (Cu^{2+}) to each sample and warm. With ethanal (aldehyde): the blue solution changes to a brick-red precipitate (Cu_2O formed as Cu^{2+} is reduced to Cu^+). With propanone (ketone): the solution remains blue — no reaction occurs [2 marks].

Section 6A, W1:

Equation: $\text{CH}_3\text{CH}_2\text{CHO} + 2[\text{H}] \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ [1 mark]. The product is propan-1-ol, a primary alcohol (the -OH is on a carbon bonded to only one other carbon) [1 mark].
Reagent: NaBH_4 (sodium tetrahydridoborate / sodium borohydride) in water [1 mark]. To confirm reduction has occurred: test the product with acidified $\text{K}_2\text{Cr}_2\text{O}_7$ — if propan-1-ol is present, the solution will change from orange to green (the alcohol can be oxidised back). Additionally, test the product with Tollens' reagent — if no silver mirror forms, the aldehyde has been fully consumed [1 mark].

Section 6C, W1:

Equation: $\text{HCOOCH}_2\text{CH}_2\text{CH}_3 + \text{NaOH} \rightarrow \text{HCOONa} + \text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ [1 mark].
Products: sodium methanoate (HCOONa , the sodium salt of methanoic acid) and propan-1-ol ($\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$) [1 mark]. Conditions: heat under reflux with aqueous NaOH [1 mark]. Base hydrolysis is irreversible because the carboxylic acid product reacts with NaOH to form the sodium salt (carboxylate ion), which cannot react back with the alcohol to reform the ester. In acid hydrolysis, the free carboxylic acid can recombine with the alcohol, making it reversible [1 mark].

Section 8, W1:

Initiation: $\text{Br}_2 \xrightarrow{\text{UV}} 2\text{Br}\cdot$ (UV light causes homolytic fission of the Br-Br bond to form two bromine radicals) [1 mark].

Propagation step 1: $\text{Br}\cdot + \text{C}_2\text{H}_6 \rightarrow \text{HBr} + \text{C}_2\text{H}_5\cdot$ (a bromine radical abstracts a hydrogen atom from ethane, forming HBr and an ethyl radical) [1 mark].

Propagation step 2: $\text{C}_2\text{H}_5\cdot + \text{Br}_2 \rightarrow \text{C}_2\text{H}_5\text{Br} + \text{Br}\cdot$ (the ethyl radical reacts with a bromine molecule, forming bromoethane and regenerating a bromine radical) [1 mark].

Termination (one example): $\text{C}_2\text{H}_5\cdot + \text{Br}\cdot \rightarrow \text{C}_2\text{H}_5\text{Br}$ (two radicals combine, ending the chain) [1 mark].

Overall equation: $\text{C}_2\text{H}_6 + \text{Br}_2 \xrightarrow{\text{UV}} \text{C}_2\text{H}_5\text{Br} + \text{HBr}$. A mixture of products is obtained because the organic product (bromoethane) can undergo further substitution — a bromine radical can abstract another hydrogen, leading to dibromoethane and other poly-substituted products. The chain reaction is non-selective [1 mark].

Section 9, W1:

Repeating unit of poly(propene): $[-\text{CH}_2-\text{CH}(\text{CH}_3)-]_n$ — the C=C double bond opens, the methyl group (CH_3) remains as a substituent, and bonds extend outside the brackets [1 mark]. The polymer is called poly(propene) [1 mark]. The monomer (propene) is a gas at room temperature because it has a small molecular mass and only weak London dispersion forces between molecules, requiring little energy to separate them. The polymer is a solid because it consists of thousands of monomer units joined into a very long chain with a very high molecular mass. The extensive surface contact between polymer chains creates much stronger London dispersion forces overall, requiring far more energy to separate the chains [1 mark].

Section 10, W1:

Order of increasing boiling point: 2,2-dimethylpropane < pentane < pentan-1-ol [1 mark].

2,2-dimethylpropane and pentane are both alkanes with the molecular formula C_5H_{12} (structural isomers). They have only London dispersion forces between molecules. However, 2,2-dimethylpropane is highly branched (spherical shape), giving it a smaller surface area and weaker London dispersion forces than the straight-chain pentane. Therefore 2,2-dimethylpropane has the lowest boiling point [1 mark].

Pentane has a longer, more extended chain shape, giving it a greater surface area for intermolecular contact and thus stronger London dispersion forces than 2,2-dimethylpropane [1 mark].

Pentan-1-ol ($\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$) has the highest boiling point because, in addition to London dispersion forces, the -OH group enables hydrogen bonding between molecules. Hydrogen bonds are significantly stronger than London dispersion forces alone, requiring considerably more energy to break [1 mark].

