Free IB Chemistry SL Organic Chemistry Notes 2026

IB SL Study Guide

Contents

IB TIP

Data booklet: You can use the IB Chemistry Data Booklet in the exam — all constants, the periodic table, and key equations are provided.

IB Chemistry SL — Reactivity 3: Mechanisms of Chemical Change

Complete Study Guide

Topics Covered

1. Acid-Base Reactions — Proton Transfer (R3.1)
2. Redox Reactions — Electron Transfer (R3.2)
3. Functional Groups & Homologous Series
4. IUPAC Naming
5. Structural Isomers
6. Combustion Reactions
7. Addition Reactions (Alkenes)
8. Oxidation of Alcohols
9. Nucleophilic Substitution (SN1 & SN2) HL
10. Free Radical Substitution
11. Polymerization
12. Properties of Organic Compounds

Videos on this page: Functional Groups & Naming · Reactions — Addition, Combustion & Derivatives · Nucleophilic Substitution SN1 & SN2

1. Acid-Base Reactions — Proton Transfer (R3.1)

Acids and bases are among the most important categories of chemical substances. At the IB level, we define them using the **Bronsted-Lowry model**: an acid is a proton (H^+) donor, and a base is a proton acceptor. Every acid-base reaction is fundamentally a **proton transfer** — a hydrogen ion moves from the acid to the base. This simple idea explains neutralization, pH, buffer solutions, and many reactions you will encounter across the syllabus.

Bronsted-Lowry Definitions

MEMORISE THIS

Term	Definition
Bronsted-Lowry acid	A proton (H^+) donor
Bronsted-Lowry base	A proton (H^+) acceptor
Conjugate acid	The species formed when a base accepts a proton
Conjugate base	The species formed when an acid donates a proton
Conjugate acid-base pair	Two species that differ by one proton (H^+)
Amphiprotic (amphoteric)	A substance that can act as both an acid and a base

Conjugate Acid-Base Pairs

In every Bronsted-Lowry reaction, there are **two conjugate pairs**. The acid donates a proton to become its conjugate base; the base accepts a proton to become its conjugate acid.

$$HCl + H_2O \rightarrow Cl^- + H_3O^+$$

- **Pair 1:** HCl (acid) / Cl^- (conjugate base)
- **Pair 2:** H_2O (base) / H_3O^+ (conjugate acid)

IB TIP

The IB frequently asks you to identify conjugate pairs from a given equation. Look for two species that differ by exactly one H^+.

Amphiprotic Substances

Water is the classic amphiprotic substance — it can donate or accept a proton:

- **Acting as a base:** $HCl + H_2O \rightarrow Cl^- + H_3O^+$ (water accepts H^+)
- **Acting as an acid:** $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$ (water donates H^+)

Water also undergoes **autoionization**:

$$H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$$

Other amphiprotic species include HCO_3^-, HSO_4^-, and amino acids.

EXAM ALERT

HSO_4^- is amphiprotic: it can donate a proton to form SO_4^{2-}, or accept a proton to form H_2SO_4. This is a common exam question.

Strong vs Weak Acids and Bases

The distinction between strong and weak is about the **degree of ionization** — not concentration.

	Strong	Weak
Ionization	Complete (100%) — single arrow ($\rightarrow$)	Partial — equilibrium arrow ($\rightleftharpoons$)
Examples (acids)	HCl, HNO_3, H_2SO_4	CH_3COOH, H_2CO_3, H_3PO_4
Examples (bases)	$NaOH$, KOH, $Ba(OH)_2$	NH_3, CH_3NH_2
Conductivity	Higher (more ions in solution)	Lower (fewer ions in solution)
pH (same conc.)	Lower (acids) / Higher (bases)	Closer to 7

EXAM ALERT

Strong vs concentrated are NOT the same thing! A strong acid fully ionizes regardless of concentration — you can have a dilute strong acid. A concentrated weak acid is still weak because it only partially ionizes. The IB tests this distinction repeatedly.

MEMORISE THIS

The 6 strong acids: HCl, HBr, HI, HNO_3, H_2SO_4, $HClO_4$

Strong bases: Group 1 hydroxides ($LiOH$, $NaOH$, KOH) and Group 2 hydroxides ($Ca(OH)_2$, $Ba(OH)_2$)

Everything else is weak unless told otherwise.

The pH Scale

pH measures the concentration of hydrogen ions in solution:

$$\text{pH} = -\log[\text{H}^+]$$

pH	Nature	$[\text{H}^+]$
< 7	Acidic	$> 10^{-7}$ mol/dm^3
$= 7$	Neutral (at 25 degrees C)	10^{-7} mol/dm^3
> 7	Basic / alkaline	$< 10^{-7}$ mol/dm^3

Key relationships:

- Each pH unit represents a **10-fold** change in $[\text{H}^+]$
- Lower pH = more acidic = higher $[\text{H}^+]$
- $[\text{H}^+] \times [\text{OH}^-] = K_w = 1.0 \times 10^{-14}$ at 25 degrees C

WORKED EXAMPLE

Worked Example: Calculating pH

What is the pH of a $0.01\ \text{mol/dm}^3$ solution of HCl?

Step 1: HCl is a strong acid, so it fully ionizes: $[\text{H}^+] = 0.01 = 10^{-2}\ \text{mol/dm}^3$

Step 2: $\text{pH} = -\log(10^{-2}) = 2$

Answer: pH = 2

WORKED EXAMPLE

Worked Example: Finding $[\text{H}^+]$ from pH

A solution has pH 4.5. What is the hydrogen ion concentration?

$[\text{H}^+] = 10^{-\text{pH}} = 10^{-4.5} = 3.16 \times 10^{-5}\ \text{mol/dm}^3$

IB TIP

The IB data booklet gives you the formula $\text{pH} = -\log[\text{H}^+]$. You also need to rearrange it: $[\text{H}^+] = 10^{-\text{pH}}$. Practise both directions on your calculator.

Neutralization Reactions

When an acid reacts with a base, they undergo **neutralization**, producing a salt and water:

$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

Reaction	Equation	Salt Produced
HCl + NaOH	$\text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}$	Sodium chloride
H_2SO_4 + 2NaOH	$\text{H}_2\text{SO}_4 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$	Sodium sulfate
HNO_3 + KOH	$\text{HNO}_3 + \text{KOH} \rightarrow \text{KNO}_3 + \text{H}_2\text{O}$	Potassium nitrate

Naming salts: The cation comes from the base; the anion comes from the acid. HCl gives chloride; HNO_3 gives nitrate; H_2SO_4 gives sulfate.

Net ionic equation for neutralization:

$$\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$$

EXAM ALERT

When writing neutralization equations, always check the formula of the acid: H_2SO_4 is diprotic (provides 2 H^+), so it reacts with 2 mol of NaOH. HCl is monoprotic (1 H^+), so the ratio is 1:1.

Titration Curves

A **titration** determines the concentration of an unknown solution by reacting it with a solution of known concentration. The **titration curve** plots pH against volume of

titrant added.

Strong acid + strong base (e.g. $HCl + NaOH$):

- Starts at low pH (~1)
- Sharp vertical jump at the **equivalence point** (pH = 7)
- Ends at high pH (~13)
- Any indicator that changes between pH 4-10 is suitable

Weak acid + strong base (e.g. $CH_3COOH + NaOH$):

- Starts at higher pH (~3)
- Gradual rise with a **buffer region** around the half-equivalence point
- **Equivalence point is above pH 7** (typically ~8-9) because the conjugate base (CH_3COO^-) is weakly basic
- Ends at high pH (~13)
- Use phenolphthalein (not methyl orange) as the indicator

Strong acid + weak base (e.g. $HCl + NH_3$):

- Equivalence point is **below pH 7** (typically ~5-6) because the conjugate acid (NH_4^+) is weakly acidic
- Use methyl orange as the indicator

> ⚠ **EXAM ALERT**
> At the equivalence point of a weak acid-strong base titration, the pH is ABOVE 7 — not exactly 7. This is because the salt formed contains the conjugate base of the weak acid, which hydrolyses slightly. The IB tests this every year.

> 💡 **IB TIP**
> You must be able to sketch and interpret titration curves. Key features to label: initial pH, buffer region (for weak acid/base), equivalence point (steepest part of the curve), and final pH.

Buffer Solutions HL

A **buffer solution** resists changes in pH when small amounts of acid or base are added. Buffers contain:

- A **weak acid** and its **conjugate base** (e.g. CH_3COOH / CH_3COO^-)
- OR a **weak base** and its **conjugate acid** (e.g. NH_3 / NH_4^+)

How buffers work:

- If acid (H^+) is added: the conjugate base reacts with it — $CH_3COO^- + H^+ \rightarrow CH_3COOH$ — removing the added H^+
- If base (OH^-) is added: the weak acid reacts with it — $CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$ — removing the added OH^-

The buffer works because the weak acid/conjugate base pair acts as a "reservoir" that can absorb or release H^+ without significantly changing the overall $[H^+]$.

MEMORISE THIS

Buffer = weak acid + conjugate base (or weak base + conjugate acid). The two components "mop up" added acid or base, keeping pH nearly constant.

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. Which of the following is a conjugate acid-base pair?

A. HCl and $NaOH$

B. H_2SO_4 and SO_4^{2-}

C. NH_3 and NH_4^+ ← CORRECT

D. HCl and HNO_3

Why: A conjugate acid-base pair consists of two species that differ by exactly one proton (H^+). NH_3 (base) accepts a proton to form NH_4^+ (conjugate acid). Option A is an acid and a base but not a conjugate pair (they don't differ by one H^+). Option B differs by 2 protons. Option D is two different acids.

WORKED EXAMPLE

Q2. What is the pH of a $0.001\ mol/dm^3$ solution of HNO_3?

A. 1

B. 2

C. 3 ← CORRECT

D. 4

Why: HNO_3 is a strong acid, so it fully ionizes: $[H^+] = 0.001 = 10^{-3}$. pH $= -\log(10^{-3}) = 3$.

WORKED EXAMPLE

Q3. At the equivalence point of a titration between ethanoic acid and sodium hydroxide, the pH is:

A. Exactly 7

B. Below 7

C. Above 7 ← CORRECT

D. Impossible to determine

Why: Ethanoic acid is a weak acid. At the equivalence point, the solution contains sodium ethanoate (CH_3COONa). The ethanoate ion (CH_3COO^-) is the conjugate base of a weak acid, so it hydrolyses slightly to produce OH^-, making the solution basic (pH > 7).

WORKED EXAMPLE

Q4. Which statement correctly distinguishes a strong acid from a weak acid?

A. A strong acid has a higher concentration than a weak acid

B. A strong acid reacts faster than a weak acid

C. A strong acid ionizes completely in water; a weak acid ionizes partially ← CORRECT

D. A strong acid always has a lower pH than a weak acid

Why: The definition of "strong" in chemistry refers to the degree of ionization, not concentration. A strong acid completely dissociates into ions (→); a weak acid establishes an equilibrium (⇌). Option D is only true at the same concentration.

Written Questions (answers at end of guide):

W1. Define the terms "strong acid" and "weak acid" with reference to the degree of ionization. Give one example of each, write equations to show their behaviour in water, and explain how you would distinguish between them experimentally at the same concentration. [4 marks]

WORKED EXAMPLE

Q5. A student adds 25.0 cm^3 of 0.100 mol/dm^3 $NaOH$ to 25.0 cm^3 of 0.100 mol/dm^3 CH_3COOH. Which best describes the pH at the equivalence point?

A. pH = 7, because equal moles of acid and base have reacted

B. pH < 7, because CH_3COOH is a stronger acid than $NaOH$ is a base

C. pH > 7, because the salt CH_3COONa produces a basic solution ← CORRECT

D. pH = 7, because the solution is neutral after neutralization

Why: At the equivalence point of a weak acid–strong base titration, the solution contains sodium ethanoate ($CH_3COO^-Na^+$). The ethanoate ion is the conjugate base of a weak acid and partially hydrolyses: $CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$, producing excess OH^- and giving pH > 7. pH = 7 only at the equivalence point of strong acid + strong base.

WORKED EXAMPLE

Q6. Which of the following pairs consists of an amphiprotic species and one of its possible roles?

A. HCl — acts as a base by donating H^+

B. HCO_3^- — acts as an acid by donating H^+ to form CO_3^{2-} ← CORRECT

C. $NaOH$ — acts as an acid in some reactions

D. NH_4^+ — acts as a base by accepting H^+

Why: HCO_3^- is amphiprotic: it can donate a proton ($HCO_3^- \rightarrow CO_3^{2-} + H^+$, acting as an acid) or accept a proton ($HCO_3^- + H^+ \rightarrow H_2CO_3$, acting as a base). NH_4^+ (D) can only donate a proton — it is a weak acid, not amphiprotic.

WORKED EXAMPLE

Q7. A buffer solution is prepared by mixing ethanoic acid and sodium ethanoate. A small amount of HCl is added to this buffer. Which equation correctly represents how the buffer responds?

A. $CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$

B. $CH_3COO^- + H^+ \rightarrow CH_3COOH$ ← CORRECT

C. $CH_3COOH + H^+ \rightarrow CH_3COO^- + 2H^+$

D. $Na^+ + Cl^- \rightarrow NaCl$

Why: When a small amount of acid (H^+) is added, the conjugate base (CH_3COO^-) absorbs it, forming the weak acid CH_3COOH. This keeps $[H^+]$ nearly constant. Option A describes how the buffer responds to added base (OH^-), not added acid.

W2. A 25.0 cm^3 sample of $0.200\ mol/dm^3$ HCl is titrated with $0.200\ mol/dm^3$ $NaOH$. (a) Calculate the volume of $NaOH$ required to reach the equivalence point. (b) State the pH at the equivalence point and explain your reasoning. (c) Sketch and label the titration curve, identifying the equivalence point and suggesting a suitable indicator. [5 marks]

For more on periodic trends and functional group classification, see the Classification of Matter guide.

2. Redox Reactions — Electron Transfer (R3.2)

Redox reactions involve the **transfer of electrons** between species. Just as acid-base reactions are defined by proton transfer, redox reactions are defined by electron transfer. The term "redox" combines **red**uction (gain of electrons) and **ox**idation (loss of electrons). These reactions are everywhere — from rusting iron to electrochemical cells that power batteries. Understanding oxidation numbers, half equations, and the reactivity series gives you the tools to predict and explain these reactions.

Oxidation and Reduction — Definitions

MEMORISE THIS

OIL RIG — the essential mnemonic:

- **O**xidation **I**s **L**oss (of electrons)
- **R**eduction **I**s **G**ain (of electrons)

Term	In terms of electrons	In terms of oxidation number
Oxidation	Loss of electrons	Increase in oxidation number
Reduction	Gain of electrons	Decrease in oxidation number
Oxidizing agent	The substance that is reduced (gains electrons, causes the other to be oxidized)	Decreases in oxidation number
Reducing agent	The substance that is oxidized (loses electrons, causes the other to be reduced)	Increases in oxidation number

⚠ EXAM ALERT

A common trick: the oxidizing agent is the substance that gets REDUCED, and the reducing agent is the substance that gets OXIDIZED. The name describes what the substance does to others, not what happens to itself.

Oxidation Numbers (Oxidation States)

Oxidation numbers are a bookkeeping system that tracks where electrons "belong" in a compound. They allow you to identify which atoms are oxidized and which are reduced in a reaction.

Rules for assigning oxidation numbers (in order of priority):

MEMORISE THIS

Rule	Oxidation Number
Elements in their natural state	0 (e.g. O_2, Fe, Na, S_8)
Monatomic ions	Equal to the charge (e.g. $Na^+ = +1$, $Cl^- = -1$, $Fe^{3+} = +3$)
Fluorine in compounds	Always -1
Oxygen in compounds	Usually -2 (except: peroxides -1, e.g. H_2O_2; in OF_2: $+2$)
Hydrogen in compounds	Usually $+1$ (except: metal hydrides -1, e.g. NaH)
Sum in a neutral compound	Must equal 0
Sum in a polyatomic ion	Must equal the charge of the ion

WORKED EXAMPLE

Worked Example: Finding Oxidation Numbers

What is the oxidation number of sulfur in H_2SO_4?

Step 1: H = $+1$ each ($\times 2 = +2$); O = -2 each ($\times 4 = -8$)

Step 2: Sum must equal 0 (neutral compound): $+2 + x + (-8) = 0$

Step 3: $x = +6$

Answer: Sulfur has an oxidation number of $+6$ in H_2SO_4.

WORKED EXAMPLE

Worked Example: Oxidation Number in a Polyatomic Ion

What is the oxidation number of Cr in $Cr_2O_7^{2-}$?

Step 1: O = -2 each ($\times 7 = -14$)

Step 2: Sum must equal the ion charge (-2): $2x + (-14) = -2$

Step 3: $2x = 12$, so $x = +6$

Answer: Chromium has an oxidation number of $+6$ in $Cr_2O_7^{2-}$.

IB TIP

Always show your working when finding oxidation numbers. Write out the equation with unknowns and solve. The IB awards method marks even if the final answer is wrong.

Identifying Redox Reactions

A reaction is a **redox reaction** if the oxidation numbers of any atoms change between reactants and products. If no oxidation numbers change, it is NOT a redox reaction.

WORKED EXAMPLE

Example — Redox:

$2Mg + O_2 \rightarrow 2MgO$

- Mg: $0 \rightarrow +2$ (oxidized — lost 2 electrons per atom)
- O: $0 \rightarrow -2$ (reduced — gained 2 electrons per atom)
- This IS a redox reaction. Mg is the reducing agent; O_2 is the oxidizing agent.

WORKED EXAMPLE

Example — NOT redox:

$HCl + NaOH \rightarrow NaCl + H_2O$

- H: $+1 \rightarrow +1$; Cl: $-1 \rightarrow -1$; Na: $+1 \rightarrow +1$; O: $-2 \rightarrow -2$
- No oxidation numbers change. This is an acid-base (neutralization) reaction, NOT a redox reaction.

Half Equations

A redox reaction can be split into two **half equations** — one showing oxidation and one showing reduction. Each half equation must be balanced for both atoms and charge.

WORKED EXAMPLE

Worked Example: Writing Half Equations

For the reaction: $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$

Oxidation half equation: $Zn \rightarrow Zn^{2+} + 2e^-$

Reduction half equation: $Cu^{2+} + 2e^- \rightarrow Cu$

Check: Electrons lost (2) = electrons gained (2) ✓

Balancing half equations in acidic solution:

1. Balance atoms other than O and H
2. Balance O by adding H_2O
3. Balance H by adding H^+
4. Balance charge by adding electrons (e^-)

WORKED EXAMPLE

Worked Example: Balancing a Complex Half Equation

Write the balanced half equation for the reduction of MnO_4^- to Mn^{2+} in acidic solution.

Step 1: Mn is already balanced: $MnO_4^- \rightarrow Mn^{2+}$

Step 2: Balance O with water: $MnO_4^- \rightarrow Mn^{2+} + 4H_2O$

Step 3: Balance H with H^+: $MnO_4^- + 8H^+ \rightarrow Mn^{2+} + 4H_2O$

Step 4: Balance charge: Left = $(-1) + (+8) = +7$. Right = $+2$. Add $5e^-$ to the left:

$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

Check: Charge: $-1 + 8 - 5 = +2$ ✓ Atoms: Mn 1=1, O 4=4, H 8=8 ✓

IB TIP

The IB data booklet contains standard half equations. You need to be able to combine two half equations into a full redox equation by making sure the electrons cancel.

Activity (Reactivity) Series of Metals

The **reactivity series** ranks metals by how readily they lose electrons (are oxidized). A more reactive metal will displace a less reactive metal from its salt solution.

MEMORISE THIS

Reactivity series (most reactive to least reactive):

K > Na > Ca > Mg > Al > Zn > Fe > Ni > Sn > Pb > **H** > Cu > Ag > Au > Pt

Key principles:

- Metals **above hydrogen** react with dilute acids to produce H_2 gas
- Metals **below hydrogen** do NOT react with dilute acids
- A more reactive metal displaces a less reactive metal from solution

Displacement Reactions

A **displacement reaction** occurs when a more reactive element replaces a less reactive element from a compound. These are always redox reactions.

$$Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$$

- Zinc is more reactive than copper, so zinc displaces copper
- Zn is oxidized ($0 \rightarrow +2$); Cu is reduced ($+2 \rightarrow 0$)
- **Ionic equation:** $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$
- **Observation:** Blue solution fades; reddish-brown solid (Cu) deposits on the zinc

⚠ EXAM ALERT

If you add copper to zinc sulfate solution, NOTHING happens — copper is LESS reactive than zinc, so it cannot displace it. Always check the reactivity series before predicting whether a reaction occurs!

Electrochemical Cells (Voltaic / Galvanic Cells)

A **voltaic (galvanic) cell** converts chemical energy into electrical energy through a spontaneous redox reaction. The two half-reactions are physically separated into different half-cells, and electrons flow through an external wire.

Key components:

Component	Role
Anode (negative electrode)	Where oxidation occurs — the more reactive metal loses electrons
Cathode (positive electrode)	Where reduction occurs — the less reactive metal ions gain electrons
Salt bridge	Completes the circuit by allowing ion flow; maintains electrical neutrality in each half-cell
External wire	Carries electrons from anode to cathode

MEMORISE THIS

AN OX RED CAT:

- **AN**ode = **OX**idation
- **RED**uction = **CAT**hode

Electrons flow from **anode to cathode** through the external wire.

Example — Zn/Cu voltaic cell:

- **Anode:** $\text{Zn(s)} \rightarrow \text{Zn}^{2+}\text{(aq)} + 2e^-$ (oxidation)
- **Cathode:** $\text{Cu}^{2+}\text{(aq)} + 2e^- \rightarrow \text{Cu(s)}$ (reduction)
- Electrons flow from Zn to Cu through the wire
- The zinc electrode slowly dissolves; copper is deposited on the copper electrode
- The salt bridge allows ions to migrate to keep the solutions electrically neutral

Standard Electrode Potentials HL

The **standard electrode potential** (E°) measures the tendency of a half-cell to be reduced, relative to the **standard hydrogen electrode (SHE)**, which is assigned $E^\circ = 0.00\ \text{V}$.

Key principles:

- More positive E° = greater tendency to be reduced = stronger oxidizing agent
- More negative E° = greater tendency to be oxidized = stronger reducing agent
- **Cell EMF:** $E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$
- A **positive** E°_{cell} indicates a spontaneous reaction

WORKED EXAMPLE

Worked Example: Calculating Cell EMF HL

Given: $E^\circ(\text{Cu}^{2+}/\text{Cu}) = +0.34\ \text{V}$ and $E^\circ(\text{Zn}^{2+}/\text{Zn}) = -0.76\ \text{V}$

Which metal is the anode? Calculate the cell EMF.

Step 1: Zn has the more negative E°, so Zn is more easily oxidized. Zn is the anode. Cu is the cathode.

Step 2: $E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = (+0.34) - (-0.76) = +1.10\ \text{V}$

Answer: Zn is the anode. Cell EMF = $+1.10$ V. The positive value confirms this reaction is spontaneous.

EXAM ALERT

The IB data booklet lists standard electrode potentials as REDUCTION potentials. The species with the more positive E° is reduced (cathode). The species with the more negative E° is oxidized (anode). Do NOT flip the sign — just use $E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$.

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. In the reaction $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$, which substance is the reducing agent?

A. Fe_2O_3

B. CO ← CORRECT

C. Fe

D. CO_2

Why: Carbon in CO has oxidation number $+2$; in CO_2 it is $+4$ — carbon has been oxidized (lost electrons). The substance that is oxidized is the reducing agent. Iron in Fe_2O_3 goes from $+3$ to 0 — it is reduced, making Fe_2O_3 the oxidizing agent.

WORKED EXAMPLE

Q2. What is the oxidation number of nitrogen in NO_3^-?

A. -3

B. $+3$

C. $+5$ ← CORRECT

D. -5

Why: Oxygen is -2 each ($-2 \times 3 = -6$). The sum must equal the ion charge (-1): $x + (-6) = -1$, so $x = +5$.

WORKED EXAMPLE

Q3. A strip of zinc is placed into a solution of $AgNO_3$. What is observed?

A. No reaction occurs

B. Silver dissolves into solution

C. The solution turns blue

D. A grey deposit forms on the zinc ← CORRECT

Why: Zinc is more reactive than silver. Zn displaces Ag: $Zn + 2Ag^+ \rightarrow Zn^{2+} + 2Ag$. Silver metal (grey) deposits on the zinc strip. The colourless Zn^{2+} ions replace Ag^+ in solution.

WORKED EXAMPLE

Q4. In a voltaic cell, oxidation occurs at the:

A. Cathode

B. Anode ← CORRECT

C. Salt bridge

D. External wire

Why: AN OX RED CAT — oxidation occurs at the anode. Reduction occurs at the cathode. The salt bridge allows ion flow; the wire carries electrons.

Written Questions (answers at end of guide):

W1. Define oxidation and reduction in terms of electron transfer. In the reaction $2Mg + O_2 \rightarrow 2MgO$, identify the oxidizing agent and the reducing agent, and write half equations for each process. [4 marks]

WORKED EXAMPLE

Q5. What is the oxidation number of sulfur in H_2SO_4?

A. $+2$

B. $+4$

C. $+6$ ← CORRECT

D. -2

Why: In H_2SO_4: each H is $+1$ (total $+2$), each O is -2 (total -8). Sum must equal 0 (neutral compound): $+2 + x + (-8) = 0$, so $x = +6$. This is the maximum oxidation state of sulfur and is why H_2SO_4 is a strong oxidizing agent in concentrated form.

WORKED EXAMPLE

Q6. In a voltaic (galvanic) cell using zinc and copper electrodes in their respective sulfate solutions, which statement is correct?

A. Copper is oxidized at the anode; zinc is reduced at the cathode

B. Zinc is oxidized at the anode; copper ions are reduced at the cathode ← CORRECT

C. The salt bridge transfers electrons between the two half-cells

D. The cell produces a positive cell voltage only if copper is the more reactive metal

Why: Zinc is more reactive (higher up in the activity series) and is oxidized: $\text{Zn} \rightarrow \text{Zn}^{2+} + 2e^-$ (anode). Copper ions are reduced: $\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}$ (cathode). The salt bridge transfers **ions** (not electrons) to maintain electrical neutrality. The cell produces a positive EMF because zinc is the stronger reducing agent.

WORKED EXAMPLE

Q7. Iron rusts according to the overall equation $4\text{Fe} + 3\text{O}_2 + 6\text{H}_2\text{O} \rightarrow 4\text{Fe(OH)}_3$. What is the change in oxidation number of iron and the change in oxidation number of oxygen in this reaction?

A. Fe: 0 to +3 (oxidized); O: 0 to -2 (reduced) ← CORRECT

B. Fe: +3 to 0 (reduced); O: -2 to 0 (oxidized)

C. Fe: 0 to +2 (oxidized); O: 0 to +2 (oxidized)

D. Fe: 0 to +3 (reduced); O: 0 to -2 (oxidized)

Why: In Fe(OH)_3, iron is $+3$ (increased from 0 — oxidized). In O_2, oxygen is 0; in Fe(OH)_3 and H_2O, oxygen is -2 (decreased — reduced). This is a redox reaction: Fe is the reducing agent, O_2 is the oxidizing agent.

W2. A displacement reaction occurs when a piece of magnesium ribbon is added to a solution of CuSO_4. (a) Write the balanced ionic equation for this reaction. (b) Identify the species oxidized and the species reduced, stating the change in oxidation number for each. (c) Write separate half equations for the oxidation and reduction processes. (d) Explain why magnesium displaces copper but copper cannot displace magnesium. [5 marks]

3. 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: C_nH_{2n+2}. e.g. CH_3CH_3 (ethane)
Alkene	Contains a C=C double bond. General formula: C_nH_{2n}. e.g. $CH_2{=}CH_2$ (ethene)
Alcohol (-OH)	Contains an -OH group. e.g. CH_3CH_2OH (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. CH_3CH_2Br (bromoethane)
Ester (-COO-)	Contains a -COO- group. Formed from carboxylic acid + alcohol. e.g. $CH_3COOCH_2CH_3$ (ethyl ethanoate). Sweet/fruity smell. Suffix: -yl -anoate
Amine (-NH_2)	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_2H_6 (ethane)
Alkenes	C_nH_{2n}	C=C double bond	-ene	C_2H_4 (ethene), C_3H_6 (propene)
Alcohols	$C_nH_{2n+1}OH$	-OH (hydroxyl)	-ol	CH_3OH (methanol), C_2H_5OH (ethanol)
Aldehydes	$C_nH_{2n}O$	-CHO (at chain end)	-al	$HCHO$ (methanal), CH_3CHO (ethanal)
Ketones	$C_nH_{2n}O$	C=O (in chain middle)	-one	CH_3COCH_3 (propanone)
Carboxylic acids	$C_nH_{2n}O_2$	-COOH	-oic acid	$HCOOH$ (methanoic acid), CH_3COOH (ethanoic acid)
Esters	$C_nH_{2n}O_2$	-COO-	-yl -anoate	CH_3COOCH_3 (methyl ethanoate)
Halogenoalkanes	$C_nH_{2n+1}X$	C-X (X = F, Cl, Br, I)	prefix: fluoro/chloro/bromo/iodo	CH_3Cl (chloromethane)
Amines	$C_nH_{2n+1}NH_2$	-NH_2	-amine	CH_3NH_2 (methylamine)

MEMORISE THIS

Key properties of homologous series:

- Members differ by CH_2 (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 $CH_3CH_2CH_2OH$?

A. CH_3OCH_3

B. CH_3CHO

C. CH_3OH ← CORRECT

D. CH_3COOH

Why: $CH_3CH_2CH_2OH$ 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 $C_nH_{2n}O$. 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: C_2H_4O vs C_3H_6O) 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]

▸**Watch: Organic Chemistry — Functional Groups and Naming** VIDEO

4. 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 $CH_3CH(CH_3)CH_2CH_3$?

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 $CH_3CH_2CH(OH)CH_3$. 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]

5. 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; tertiary halogenoalkanes react by SN1 not SN2 HL).

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)

MEMORISE THIS

The 3 structural isomers of C_5H_{12}:

Isomer	Structural Formula	Name
Straight chain	$CH_3CH_2CH_2CH_2CH_3$	Pentane
One branch	$CH_3CH(CH_3)CH_2CH_3$	2-methylbutane
Two branches	$C(CH_3)_4$	2,2-dimethylpropane (neopentane)

WORKED EXAMPLE

Worked Example: Drawing isomers of C_5H_{12} systematically

Step 1: Start with the longest possible chain — 5 carbons in a row: $CH_3CH_2CH_2CH_2CH_3$ (pentane).

Step 2: Shorten the chain to 4 carbons, place the remaining carbon as a branch. Only one valid position (carbon 2): $CH_3CH(CH_3)CH_2CH_3$ (2-methylbutane). Putting the branch on carbon 1 just extends the chain back to pentane.

Step 3: Shorten the chain to 3 carbons, place 2 remaining carbons as branches. Both must go on the middle carbon: $C(CH_3)_4$ (2,2-dimethylpropane). That is all — 3 isomers total.

IB TIP

C_4H_8 isomers at SL: The main structural isomers you need to know are **but-1-ene** ($CH_2{=}CHCH_2CH_3$) and **but-2-ene** ($CH_3CH{=}CHCH_3$) — position isomers with the double bond in different places. Cyclobutane is also C_4H_8 but is not required at SL.

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 → ketone. Primary → aldehyde → 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]

6. 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 CO_2 and H_2O.

Complete Combustion General Equation:

$$C_xH_y + O_2 \rightarrow CO_2 + H_2O$$

Example: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ *(propane)*

Incomplete Combustion

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

Incomplete Combustion (limited O_2):

$$C_xH_y + O_2 \rightarrow CO + C + H_2O$$

The IB may ask: 'which products are formed?' — answer includes CO and/or C (soot), but NOT CO_2 *if very limited* O_2

Concept	Details
Products of complete combustion	CO_2 and H_2O only
Products of incomplete combustion	CO (carbon monoxide), C (carbon/soot), H_2O — 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. CO_2 and H_2O only

B. CO_2, CO, and H_2

C. CO, C, and H_2O ← CORRECT

D. CO and H_2 only

Why: Incomplete combustion occurs with limited oxygen. Carbon forms CO (carbon monoxide) and/or C (soot/carbon) instead of CO_2. Water is still produced. Hydrogen gas (H_2) is NOT a product of combustion.

WORKED EXAMPLE

Q2. What is the balanced equation for the complete combustion of butane (C_4H_{10})?

A. $C_4H_{10} + 4O_2 \rightarrow 4CO_2 + 5H_2O$

B. $C_4H_{10} + 5O_2 \rightarrow 4CO_2 + 5H_2O$

C. $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$ ← CORRECT

D. $C_4H_{10} + 6O_2 \rightarrow 4CO_2 + 4H_2O$

Why: Balancing $C_4H_{10} + O_2$: 4 carbons need 4 CO_2; 10 hydrogens need 5 H_2O (requiring 8 + 5 = 13 oxygen atoms, so 6.5 O_2). Multiply through by 2 to get whole numbers: $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$.

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]

7. 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. $CH_2{=}CH_2 + H_2 \rightarrow CH_3CH_3$
Halogenation (+ Br_2)	Alkene + Br_2 → dibromoalkane. No catalyst needed. $CH_2{=}CH_2 + Br_2 \rightarrow CH_2BrCH_2Br$. Test: bromine water turns from orange/brown to colourless
Hydrohalogenation (+ HBr)	Alkene + HBr → bromoalkane. $CH_2{=}CH_2 + HBr \rightarrow CH_3CH_2Br$
Hydration (+ H_2O)	Alkene + H_2O → Alcohol. Catalyst: H_3PO_4, high temp & pressure. $CH_2{=}CH_2 + H_2O \rightarrow CH_3CH_2OH$ (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: $CH_2{=}CH\text{-}CH_2\text{-}CH_3$. 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: $CH_3\text{-}CH{=}CH\text{-}CH_3$. 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_4H_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: $CH_2{=}CHCH_2CH_3$ (double bond at C1, terminal)

but-2-ene: $CH_3CH{=}CHCH_3$ (double bond at C2, internal, symmetrical)

Adding HBr to but-2-ene:

$$CH_3CH{=}CHCH_3 + HBr \rightarrow CH_3CH_2CHBrCH_3 \text{ (one product, symmetrical)}$$

Adding HBr to but-1-ene:

$$CH_2{=}CHCH_2CH_3 + HBr \rightarrow$$
$$\text{1-bromobutane OR 2-bromobutane (two possible products)}$$

Both are C_4H_8 — same molecular formula, different position of the C=C. They are structural isomers.

IB TIP
When a question says 'alkene A' and 'alkene B', draw them out fully. The position of the C=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 C=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 C=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 C=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 $\delta+$. 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 electrophilic addition (alkenes + electrophile, C=C opens, 1 product) with nucleophilic substitution (halogenoalkanes + nucleophile, C-X replaced, 2 products). HL

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 ($CH_3CH{=}CHCH_3$) is a symmetrical internal alkene. Adding HBr across the double bond gives only one product: 2-bromobutane ($CH_3CHBrCH_2CH_3$). 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]

Watch: Reactions of Organic Compounds — Addition, Combustion, and Derivatives VIDEO

8. 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 $K_2Cr_2O_7$ / H_2SO_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):

$$CH_3CH_2OH + [O] \rightarrow CH_3CHO + H_2O$$

ethanol → ethanal

$$CH_3CH_2CH_2OH + [O] \rightarrow CH_3CH_2CHO + H_2O$$

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):

$$CH_3CH_2OH + 2[O] \rightarrow CH_3COOH + H_2O$$

ethanol → ethanoic acid

$$CH_3CH_2CH_2OH + 2[O] \rightarrow CH_3CH_2COOH + H_2O$$

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:

$$CH_3CH(OH)CH_3 + [O] \rightarrow CH_3COCH_3 + H_2O$$

propan-2-ol → propanone

$$CH_3CH(OH)CH_2CH_3 + [O] \rightarrow CH_3COCH_2CH_3 + H_2O$$

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:

$$(CH_3)_3COH + K_2Cr_2O_7/H_2SO_4 \rightarrow \text{NO REACTION}$$

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 $K_2Cr_2O_7$ → 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.
Step 4: Prove it is a carboxylic acid	Test with litmus/pH paper: acidic pH (turns red) confirms a carboxylic acid is present. 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 → green (oxidation occurred) + no silver mirror (not aldehyde) + acidic pH + CO_2 with Na_2CO_3 → 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 → brick-red precipitate (Cu_2O). Ketone: stays blue. Proves: aldehyde present vs ketone
Acidified $K_2Cr_2O_7$ (orange)	Aldehyde: orange → 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 [H] to represent the reducing agent. Reduction converts C=O to C-OH.

Transformation	Product, Reagent & Example
Aldehyde + [H] → Primary alcohol	C=O at the END of the chain is reduced to C-OH. Reagent: $NaBH_4$ (or [H]) in water. Example: $CH_3CHO + 2[H] \rightarrow CH_3CH_2OH$ (ethanal → ethanol)
Ketone + [H] → Secondary alcohol	C=O in the MIDDLE of the chain is reduced to C-OH. Reagent: $NaBH_4$ (or [H]) in water. Example: $CH_3COCH_3 + 2[H] \rightarrow CH_3CH(OH)CH_3$ (propanone → propan-2-ol)
Carboxylic acid + [H] → Primary alcohol	Requires stronger reducing agent ($LiAlH_4$, more common at HL). Example: $CH_3COOH + 4[H] \rightarrow CH_3CH_2OH + H_2O$

Reduction Worked Examples

1. Aldehyde → primary alcohol:

$CH_3CHO + 2[H] \rightarrow CH_3CH_2OH$

ethanal → ethanol

$CH_3CH_2CH_2CHO + 2[H] \rightarrow CH_3CH_2CH_2CH_2OH$

butanal → butan-1-ol

2. Ketone → secondary alcohol:

$CH_3COCH_3 + 2[H] \rightarrow CH_3CH(OH)CH_3$

propanone → propan-2-ol

$CH_3COCH_2CH_3 + 2[H] \rightarrow CH_3CH(OH)CH_2CH_3$

butanone → butan-2-ol

Reduction = add [H]. Oxidation = add [O] or remove [H]. They are exact reverse operations.

Complete Oxidation-Reduction Pathway for a Primary Alcohol

Primary alcohol $\xrightarrow{K_2Cr_2O_7/H_2SO_4,\ \text{distil}}$ Aldehyde $\xrightarrow{K_2Cr_2O_7/H_2SO_4,\ \text{reflux}}$ Carboxylic acid

Carboxylic acid $\xleftarrow{LiAlH_4}$ Aldehyde $\xleftarrow{NaBH_4}$ 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: $K_2Cr_2O_7$ stays orange. Tollens' gives no mirror.
After reduction: test for alcohol	$K_2Cr_2O_7/H_2SO_4$: 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 C=C, not C=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 $K_2Cr_2O_7$. 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 $K_2Cr_2O_7$, 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 $K_2Cr_2O_7/H_2SO_4$, distillation

B. $NaBH_4$ in water, reflux

C. Excess $K_2Cr_2O_7/H_2SO_4$, reflux ← CORRECT

D. Excess $K_2Cr_2O_7/H_2SO_4$, 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 $K_2Cr_2O_7/H_2SO_4$. 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]

8A. 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 $NaBH_4$ **(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 $LiAlH_4$ **(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. $CH_3CHO + 2[H] \rightarrow CH_3CH_2OH$ (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. $CH_3COCH_3 + 2[H] \rightarrow CH_3CH(OH)CH_3$ (propanone → propan-2-ol)
Carboxylic acid → Primary alcohol	Requires a stronger reducing agent ($LiAlH_4$). Not common at SL but worth knowing. e.g. $CH_3COOH + 4[H] \rightarrow CH_3CH_2OH + H_2O$ (ethanoic acid → ethanol)
Ester → Two alcohols	Full reduction of an ester gives two alcohols (HL topic mostly). e.g. $CH_3COOCH_2CH_3 + 4[H] \rightarrow CH_3CH_2OH + CH_3CH_2OH$

Full Worked Examples — Reduction Equations

WORKED EXAMPLE

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

$$CH_3CHO + 2[H] \rightarrow CH_3CH_2OH$$

ethanal → ethanol

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

Notice: this is the exact REVERSE of oxidising ethanol to ethanal with $K_2Cr_2O_7$.

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

$$CH_3COCH_3 + 2[H] \rightarrow CH_3CH(OH)CH_3$$

propanone → propan-2-ol

Reagent: $NaBH_4$ in water. What happened: C=O in middle of chain became C-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:

$$CH_3CH_2CH_2CHO + 2[H] \rightarrow CH_3CH_2CH_2CH_2OH$$

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:

$$CH_3COCH_2CH_3 + 2[H] \rightarrow CH_3CH(OH)CH_2CH_3$$

butanone → butan-2-ol

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

The C=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 $\xrightarrow{\text{oxidation, } K_2Cr_2O_7/H_2SO_4, \text{ distil}}$ Aldehyde

Aldehyde $\xrightarrow{\text{oxidation, } K_2Cr_2O_7/H_2SO_4, \text{ reflux}}$ 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: $K_2Cr_2O_7$ stays orange. Tollens' gives no mirror.
After reduction: test for alcohol	Test with $K_2Cr_2O_7/H_2SO_4$: if the product is a PRIMARY or SECONDARY alcohol, solution turns orange → 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 C=O stretch at ~1700 cm^{-1} disappears and broad O-H stretch appears at ~3300 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 C=O gives C-OH, and you need 2[H] per carbonyl group. Do not confuse with hydrogenation of alkenes (also adds H_2 but across C=C, not C=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 ($CH_3COCH_2CH_3$) is reduced with $NaBH_4$?

A. Butan-1-ol

B. Butan-2-ol ← CORRECT

C. Butanal

D. Butanoic acid

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

WORKED EXAMPLE

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

A. $K_2Cr_2O_7/H_2SO_4$ is added and the solution turns green

B. [O] is added to convert C=O to C-OH

C. [H] is added to convert C=O to C-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 [H]). The C=O double bond in the aldehyde gains hydrogen to become C-OH. The reagent is $NaBH_4$ (sodium tetrahydridoborate). Options A and D describe oxidation, not reduction. Option B incorrectly uses [O].

Written Questions (answers at end of guide):

W1. Propanal (CH_3CH_2CHO) can be reduced to an alcohol. Write the equation for this reaction using [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]

8C. 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

$$\text{Carboxylic acid} + \text{Alcohol} \xrightarrow{\text{conc. } H_2SO_4,\ \text{reflux}} \text{Ester} + H_2O$$

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_3COOH (ethanoic acid)	CH_3OH (methanol)	CH_3COOCH_3	Methyl ethanoate
CH_3COOH (ethanoic acid)	CH_3CH_2OH (ethanol)	$CH_3COOCH_2CH_3$	Ethyl ethanoate
$HCOOH$ (methanoic acid)	CH_3OH (methanol)	$HCOOCH_3$	Methyl methanoate
CH_3CH_2COOH (propanoic acid)	CH_3OH (methanol)	$CH_3CH_2COOCH_3$	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:

$$CH_3COOH + CH_3CH_2OH \xrightarrow{\text{conc. } H_2SO_4} CH_3COOCH_2CH_3 + H_2O$$

- 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 H_2SO_4 catalyst, heat under **reflux**
- Reaction type: **condensation** (water is released)

WORKED EXAMPLE

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

$$HCOOH + CH_3CH_2CH_2OH \xrightarrow{\text{conc. } H_2SO_4} HCOOCH_2CH_2CH_3 + H_2O$$

- 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_2O with dilute H_2SO_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.

$$CH_3COOCH_2CH_3 + NaOH \rightarrow CH_3COONa + CH_3CH_2OH$$

Key Facts for IB

Point	Detail
Reaction type	Condensation (esterification) — small molecule (H_2O) released
Catalyst	Concentrated H_2SO_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 (CH_3COOCH_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 C=C involved) and NOT substitution (no atom is replaced by another).

Written Questions (answers at end of guide):

W1. The ester propyl methanoate ($HCOOCH_2CH_2CH_3$) 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]

8B. 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 H_2O lost.
- **Oxidation:** Oxygen added or hydrogen removed. Use [O]. Colour change orange $\rightarrow$ green with $K_2Cr_2O_7$.
- **Hydrolysis:** Bond broken by water (or OH^-). Often seen in esters and halogenoalkanes.
- **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
$CH_2{=}CH_2 + H_2 \rightarrow CH_3CH_3$	ADDITION (hydrogenation). The C=C double bond opens and H_2 adds across it. One product formed. Catalyst: Ni, heat.
$CH_2{=}CH_2 + Br_2 \rightarrow CH_2BrCH_2Br$	ADDITION (halogenation). Bromine adds across the double bond. Bromine water decolourises (orange → colourless). One product.
$CH_2{=}CH_2 + HBr \rightarrow CH_3CH_2Br$	ADDITION (hydrohalogenation). H and Br both add across the C=C.
$CH_2{=}CH_2 + H_2O \rightarrow CH_3CH_2OH$	ADDITION (hydration). Water adds across the double bond to form an alcohol. Catalyst: H_3PO_4, high temperature and pressure.
$CH_4 + Cl_2 \xrightarrow{UV} CH_3Cl + HCl$	FREE RADICAL SUBSTITUTION. Cl replaces H. UV light required. Two products. Alkane + halogen.
$CH_3CH_2Br + NaOH(aq) \rightarrow CH_3CH_2OH + NaBr$	NUCLEOPHILIC SUBSTITUTION (SN2) HL. -OH replaces -Br. Primary halogenoalkane. Two products.
$(CH_3)_3CBr + NaOH(aq) \rightarrow (CH_3)_3COH + NaBr$	NUCLEOPHILIC SUBSTITUTION (SN1) HL. Tertiary halogenoalkane. Via carbocation intermediate.
$CH_3CH_2OH + [O] \rightarrow CH_3CHO + H_2O$	OXIDATION. Primary alcohol → aldehyde. $K_2Cr_2O_7/H_2SO_4$, orange → green. Distil off product.
$CH_3CHO + [O] \rightarrow CH_3COOH$	OXIDATION. Aldehyde → carboxylic acid. $K_2Cr_2O_7/H_2SO_4$, orange → green. Reflux conditions.
$CH_3CH(OH)CH_3 + [O] \rightarrow CH_3COCH_3 + H_2O$	OXIDATION. Secondary alcohol (propan-2-ol) → ketone (propanone). Orange → green. Cannot oxidise further.
$n\ CH_2{=}CH_2 \rightarrow [-CH_2\text{-}CH_2-]_n$	ADDITION POLYMERIZATION. Many ethene monomers join. Double bond opens. No by-product.

Example Set 2 — Identify the Product

Starting Materials	Product & Reaction Type
Propene + $Br_2 \rightarrow$ **?**	$CH_3CHBrCH_2Br$ (1,2-dibromopropane). Type: addition. Both Br atoms add across the C=C of propene.
But-2-ene + HBr $\rightarrow$ **?**	$CH_3CH_2CHBrCH_3$ (2-bromobutane). Type: addition. H adds to one end of C=C, Br to the other.
Butan-1-ol + excess $K_2Cr_2O_7/H_2SO_4 \rightarrow$ **?**	$CH_3CH_2CH_2COOH$ (butanoic acid). Type: oxidation (full). Primary alcohol + excess oxidant under reflux $\rightarrow$ carboxylic acid.
Butan-2-ol + $K_2Cr_2O_7/H_2SO_4 \rightarrow$ **?**	$CH_3COCH_2CH_3$ (butanone). Type: oxidation. Secondary alcohol $\rightarrow$ ketone. Cannot go further.
2-methylpropan-2-ol + $K_2Cr_2O_7/H_2SO_4 \rightarrow$ **?**	NO REACTION. Tertiary alcohol. Solution stays orange.
1-bromopropane + NaOH(aq) $\rightarrow$ **?**	$CH_3CH_2CH_2OH$ + NaBr (propan-1-ol). Type: SN2 nucleophilic substitution HL. -OH replaces -Br.
2-methylpropane + $Cl_2 \xrightarrow{UV}$ **?**	2-chloro-2-methylpropane (major) + HCl. Type: free radical substitution. Multiple products possible.
Ethene + $H_2O \rightarrow$ **?**	CH_3CH_2OH (ethanol). Type: addition (hydration). Catalyst: H_3PO_4, 300°C, high pressure.

Example Set 3 — Identify the Reagent or Condition

Transformation	Reagent, Condition & Type
$CH_2{=}CH_2 \rightarrow CH_3CH_3$ (What reagent and condition?)	Reagent: H_2 (hydrogen gas). Condition: Ni catalyst, heat (about 150°C). Type: hydrogenation (addition)
$CH_3CH_2Br \rightarrow CH_3CH_2OH$ (What reagent and condition?)	Reagent: NaOH(aq) or KOH(aq) — aqueous sodium/potassium hydroxide. Condition: warm. Type: nucleophilic substitution (SN2) HL
$CH_3CH_2OH \rightarrow CH_3CHO$ (What reagent and condition?)	Reagent: acidified $K_2Cr_2O_7$ ($K_2Cr_2O_7 + H_2SO_4$). Condition: gentle heat, DISTIL product off immediately. Type: oxidation (limited)
$CH_3CH_2OH \rightarrow CH_3COOH$ (What reagent and condition?)	Reagent: excess acidified $K_2Cr_2O_7$. Condition: heat under REFLUX. Type: oxidation (full)
$CH_4 \rightarrow CH_3Cl$ (What reagent and condition?)	Reagent: Cl_2 (chlorine gas). Condition: UV light (sunlight). Type: free radical substitution
$CH_2{=}CH_2 \rightarrow [-CH_2CH_2-]_n$ (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
$K_2Cr_2O_7/H_2SO_4$ **turns orange → green**	Oxidation has occurred. The substance is either a primary or secondary alcohol, OR an aldehyde. Something has been oxidised.
$K_2Cr_2O_7/H_2SO_4$ **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 $K_2Cr_2O_7$ turns green, it's an alcohol or aldehyde.

9. Nucleophilic Substitution (SN1 & SN2) HL

Halogenoalkanes contain a polar C-X bond (where X is a halogen). Because halogens are highly electronegative, they pull electron density away from the carbon they are bonded to, leaving that carbon slightly electron-deficient ($\delta+$). This makes it a target for **nucleophiles** — electron-rich species such as OH^- that are attracted to positive (or partially positive) centres. In a nucleophilic substitution reaction, the nucleophile attacks the $\delta+$ carbon and the halogen leaves as a halide ion (X^-). The key question for the IB is: does this happen in one step or two? The answer depends on whether the halogenoalkane is primary, secondary, or tertiary. **Primary halogenoalkanes react by SN2** (one concerted step, back-side attack). **Tertiary halogenoalkanes react by SN1** (two steps, via a stable carbocation intermediate). Understanding these two

mechanisms — and being able to draw them with curly arrows — is a major IB assessment skill.

SN2 — Primary Halogenoalkanes

Feature	Detail
Substrate	Primary halogenoalkane (1 carbon attached to the C-X carbon)
Mechanism	One step — OH^- attacks the carbon from the BACK while X^- leaves from the front simultaneously
Transition state	Carbon is bonded to 5 atoms momentarily — pentavalent carbon (draw with dashes)
Stereochemistry	Inversion of configuration (Walden inversion) — not required at SL
Rate	Depends on both [RX] and $[OH^-]$ — bimolecular
Example	$CH_3CH_2CH_2Br + NaOH(aq) \rightarrow CH_3CH_2CH_2OH + NaBr$

SN1 — Tertiary Halogenoalkanes

Feature	Detail
Substrate	Tertiary halogenoalkane (3 carbons attached to the C-X carbon)
Mechanism	Two steps: Step 1: halogen leaves → carbocation intermediate. Step 2: OH^- attacks carbocation
Intermediate	Carbocation (positively charged carbon, planar). Draw this in the mechanism.
Rate	Depends only on [RX] — unimolecular. Rate-determining step is step 1.
Why tertiary?	Tertiary carbocations are more stable (3 alkyl groups donate electron density)
Example	$(CH_3)_3CBr + NaOH(aq) \rightarrow (CH_3)_3COH + NaBr$

Curly Arrow Rules (Very Important for Marks)

- Curly arrows show movement of ELECTRON PAIRS (not atoms)
- Arrow starts from lone pair or bond, ends at atom or between atoms
- For SN2: one arrow from OH^- lone pair to C, one arrow from C-X bond to X
- For SN1 Step 1: one arrow from C-X bond to X (heterolytic fission)
- For SN1 Step 2: one arrow from OH^- lone pair to carbocation

⚠ **EXAM ALERT**
Draw the carbocation intermediate for SN1. If you skip it, you lose marks. Label it as a carbocation and show it is positively charged.

IB TIP
Primary = SN2 (back-attack). Tertiary = SN1 (carbocation). Secondary can go both ways but the IB mainly tests primary and tertiary at SL.

Animated Mechanism: SN2 Back-Side Attack

This animation shows what happens at the molecular level. In reality, molecules are 3D and in constant motion — this is a simplified 2D representation of bond-breaking and bond-forming.

Interactive **Step-by-step SN2 mechanism animation**

Worked Examples — Nucleophilic Substitution Equations

Conditions: aqueous NaOH (or KOH), warm. OH^- *replaces the halogen. Always two products: the alcohol + sodium halide salt.*

WORKED EXAMPLE

Example 1 — 1-Bromopropane + NaOH (SN2 — primary):

$$CH_3CH_2CH_2Br + NaOH(aq) \rightarrow CH_3CH_2CH_2OH + NaBr$$

1-bromopropane → propan-1-ol + sodium bromide

Mechanism: SN2 — one-step, OH^- attacks from the back simultaneously as Br^- leaves. Evidence: primary halogenoalkane = SN2. Rate depends on BOTH [RX] and [OH^-].

Example 2 — 2-Bromo-2-methylpropane + NaOH (SN1 — tertiary):

$$(CH_3)_3CBr + NaOH(aq) \rightarrow (CH_3)_3COH + NaBr$$

2-bromo-2-methylpropane → 2-methylpropan-2-ol

Mechanism: SN1 — two steps:

Step 1 (slow, rate-determining): $(CH_3)_3CBr \rightarrow (CH_3)_3C^+ + Br^-$

Step 2 (fast): $(CH_3)_3C^+ + OH^- \rightarrow (CH_3)_3COH$

Example 3 — Chloroethane + NaOH (SN2 — primary):

$$CH_3CH_2Cl + NaOH(aq) \rightarrow CH_3CH_2OH + NaCl$$

chloroethane → ethanol + sodium chloride

Note: C-Cl reacts more slowly than C-Br or C-I. Reactivity order: C-I > C-Br > C-Cl > C-F.

Example 4 — Bromoethane + KCN (different nucleophile — extends carbon chain):

$$CH_3CH_2Br + KCN \rightarrow CH_3CH_2CN + KBr$$

bromoethane → propanenitrile

Nucleophile: CN^- (cyanide ion). Replaces Br^-. Important: this EXTENDS the carbon chain by 1 carbon (C2 → C3 chain).

WORKED EXAMPLE

Worked Example: Determining SN1 vs SN2 Mechanism

Problem: 2-chloro-2-methylbutane reacts with aqueous sodium hydroxide. (a) Classify the halogenoalkane. (b) Predict the mechanism. (c) Draw the mechanism with curly arrows. (d) Name the organic product.

Step 1: Classify the halogenoalkane

Draw the structure. The carbon bonded to Cl is bonded to THREE other carbons: CH_3, CH_3, and CH_2CH_3. This is a **TERTIARY** halogenoalkane.

Step 2: Predict the mechanism

Tertiary halogenoalkanes favor the **SN1 mechanism** (two-step, via carbocation intermediate). Tertiary carbocations are stabilized by three electron-donating alkyl groups, making them sufficiently stable to exist as intermediates.

Step 3: Draw the mechanism with curly arrows

Step 1 (slow, rate-determining):

$$(CH_3)_2(C_2H_5)CCl \rightarrow (CH_3)_2(C_2H_5)C^+ + Cl^-$$

Curly arrow: from the C–Cl bond to Cl (heterolytic fission — both electrons go to Cl, forming Cl^- and leaving behind a carbocation).

Step 2 (fast):

$$(CH_3)_2(C_2H_5)C^+ + OH^- \rightarrow (CH_3)_2(C_2H_5)COH$$

Curly arrow: from an OH^- lone pair to the carbocation (nucleophile donates electron pair to form C–O bond).

Step 4: Name the organic product

Product: **2-methylbutan-2-ol** (a tertiary alcohol).

Key takeaway: Always count the carbons attached to the C–X carbon. 1 carbon attached = primary = SN2. 3 carbons attached = tertiary = SN1. Tertiary carbocations are stabilized by hyperconjugation from three alkyl groups donating electron density.

IB mark scheme note: [3 marks] — 1 mark for correct classification (tertiary), 1 mark for mechanism choice with reasoning (SN1 because tertiary carbocation is stable), 1 mark for correct curly arrows or product structure.

WORKED EXAMPLE

Worked Example: SN1 vs SN2 — Side-by-Side Mechanism Comparison

Problem: Compare the reactions of (A) 1-bromobutane with aqueous NaOH and (B) 2-bromo-2-methylpropane (tert-butyl bromide) with aqueous NaOH. For each, classify the substrate, predict the mechanism, draw the full mechanism with curly arrows, and explain why that mechanism is favored.

Reaction A: 1-bromobutane + NaOH(aq) → SN2 mechanism

Step 1: Classify the substrate

Structure: $CH_3CH_2CH_2CH_2Br$

The carbon bonded to Br is bonded to ONE other carbon ($CH_2CH_2CH_3$) and two hydrogens. This is a **PRIMARY** halogenoalkane.

Step 2: Predict the mechanism

Primary halogenoalkanes favor the **SN2 mechanism** (one-step, concerted). Reasons:

- Primary carbocations are extremely unstable (only one alkyl group for stabilization), so SN1 is not viable.
- The carbon bearing Br has minimal steric hindrance — the nucleophile can easily approach from the backside.

Step 3: Draw the mechanism with curly arrows

One-step mechanism (concerted):

$$OH^- + CH_3CH_2CH_2CH_2Br \rightarrow CH_3CH_2CH_2CH_2OH + Br^-$$

Curly arrows:

1. From a lone pair on OH^- to the carbon bearing Br (nucleophile attacks from backside).
2. From the C–Br bond to Br (C–Br bond breaks, both electrons go to Br, forming Br^-).

Transition state: The nucleophile approaches from the opposite side of the leaving group. At the transition state, the C–OH bond is partially formed and the C–Br bond is partially broken. The carbon center undergoes inversion of configuration (Walden inversion).

Step 4: Name the product

Product: **butan-1-ol** (a primary alcohol).

Why SN2? Primary substrate + minimal steric hindrance + strong nucleophile (OH^-) = SN2 pathway.

Reaction B: 2-bromo-2-methylpropane + NaOH(aq) → SN1 mechanism

Step 1: Classify the substrate

Structure: $(CH_3)_3CBr$ (tert-butyl bromide)

The carbon bonded to Br is bonded to THREE other carbons (three CH_3 groups). This is a **TERTIARY** halogenoalkane.

Step 2: Predict the mechanism

Tertiary halogenoalkanes favor the **SN1 mechanism** (two-step, via carbocation intermediate). Reasons:

- Tertiary carbocations are stabilized by three electron-donating alkyl groups (hyperconjugation and inductive effect).
- The carbon bearing Br is heavily sterically hindered — the nucleophile cannot easily approach for an SN2 backside attack.

Step 3: Draw the mechanism with curly arrows

Step 1 (slow, rate-determining):

Heterolytic fission of the C–Br bond:

$$(CH_3)_3CBr \rightarrow (CH_3)_3C^+ + Br^-$$

Curly arrow: from the C–Br bond to Br (both electrons go to Br, forming Br^- and leaving behind a tertiary carbocation $(CH_3)_3C^+$).

Carbocation intermediate: The tertiary carbocation $(CH_3)_3C^+$ is planar (sp^2 hybridized). It is stabilized by hyperconjugation from the three adjacent CH_3 groups.

Step 2 (fast):

Nucleophilic attack on the carbocation:

$$(CH_3)_3C^+ + OH^- \rightarrow (CH_3)_3COH$$

Curly arrow: from a lone pair on OH^- to the positively charged carbon (nucleophile donates electron pair to form the C–O bond).

Step 4: Name the product

Product: **2-methylpropan-2-ol** (a tertiary alcohol, also called tert-butanol).

Why SN1? Tertiary substrate + stable carbocation intermediate + significant steric hindrance = SN1 pathway.

Side-by-side summary:

Feature	Reaction A (SN2)	Reaction B (SN1)
Substrate classification	Primary (1-bromobutane)	Tertiary (2-bromo-2-methylpropane)
Number of steps	One (concerted)	Two (stepwise)
Intermediate	Transition state (no stable intermediate)	Carbocation intermediate $(CH_3)_3C^+$
Rate-determining step	Single step (bimolecular)	Step 1: C–Br bond breaking (unimolecular)
Stereochemistry	Inversion of configuration (Walden inversion)	Racemization (nucleophile can attack from either face of planar carbocation)
Why this mechanism?	Primary carbocation too unstable; minimal steric hindrance allows backside attack	Tertiary carbocation stable; steric hindrance prevents SN2

Key IB exam point: The classification (primary vs secondary vs tertiary) determines the mechanism. Always count the carbons attached to the C–X carbon FIRST. This tells you which mechanism is favored before you even draw anything.

IB mark scheme note: [4-5 marks total for a two-part comparison] — 1 mark for correct classification of each substrate, 1 mark for correct mechanism choice with reasoning (SN2 for primary, SN1 for tertiary), 2-3 marks for correct curly arrows and intermediate/transition state description.

Addition vs Substitution — How to Tell Apart

Feature	Addition vs Substitution
Number of products	Addition: ONE product. Substitution: TWO products (organic + small molecule like HCl, NaBr).
Starting material	Addition: always an ALKENE (has C=C). Substitution: an ALKANE (+ UV light) or a HALOGENOALKANE (+ NaOH).
What happens to double bond	Addition: C=C disappears — becomes C-C. Substitution: no double bond involved — C-X single bond is replaced.
Bromine water test	Addition: bromine water decolourises (C=C reacted). Substitution: bromine water stays orange (no C=C).
Example comparison	Addition: $CH_2{=}CH_2 + HBr \rightarrow CH_3CH_2Br$ (1 product). Substitution: $CH_3CH_2Br + NaOH \rightarrow CH_3CH_2OH + NaBr$ (2 products)

⚠ EXAM ALERT
A very common mistake: calling halogenoalkane + NaOH an ‘addition’ reaction. It is NOT — it is substitution. The Br is replaced, not added. There are always TWO products in substitution.

IB TIP
Quick check: count the products. One product = addition. Two products = substitution (or elimination).

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. 2-Bromo-2-methylpropane reacts with aqueous $NaOH$. Which mechanism does this reaction follow?

A. SN2 — one-step, back-side attack

B. SN1 — two steps, via a carbocation intermediate ← CORRECT

C. Free radical substitution

D. Electrophilic addition

Why: 2-Bromo-2-methylpropane is a tertiary halogenoalkane (the carbon bearing Br is bonded to three other carbons). Tertiary halogenoalkanes react by SN1: the halogen leaves first to form a stable tertiary carbocation, then the nucleophile (OH^-) attacks. Primary halogenoalkanes react by SN2.

WORKED EXAMPLE

Q2. In an SN2 reaction, the rate depends on the concentration of:

A. Only the halogenoalkane

B. Only the nucleophile

C. Both the halogenoalkane and the nucleophile ← CORRECT

D. Neither — it depends only on temperature

Why: SN2 is bimolecular — the rate-determining step involves both the substrate (halogenoalkane) and the nucleophile (OH^-) in a single concerted step. In contrast, SN1 is unimolecular — its rate depends only on the concentration of the halogenoalkane, because the slow step is the loss of the halide ion.

⚠ EXAM ALERT

Common Mistakes — SN1 vs SN2

- **Confusing rate law with mechanism steps**: Students often think "SN2 is second order because it's a 2-step mechanism" — WRONG. **Correct:** SN2 is a ONE-step mechanism that is second order overall because the rate depends on both [RX] and [nucleophile]. SN1 is a TWO-step mechanism but first order (depends only on [RX]).
- **Forgetting stereochemistry**: SN2 causes inversion of configuration (Walden inversion) because the nucleophile attacks from the back side. SN1 gives a racemic mixture because the planar carbocation can be attacked from either face. **Correct:** Always specify stereochemical outcome when asked about mechanism.
- **Substrate confusion**: Thinking primary substrates favor SN1 because "the carbocation forms easily" — WRONG. **Correct:** Tertiary substrates favor SN1 because tertiary carbocations are stabilized by three electron-donating alkyl groups. Primary substrates favor SN2 because primary carbocations are too unstable to form.

Written Questions (answers at end of guide):

W1. 1-Bromobutane ($CH_3CH_2CH_2CH_2Br$) reacts with aqueous $NaOH$. Write the equation for the reaction, name the organic product, state the mechanism (SN1 or SN2), and explain why this mechanism is favoured for this substrate. [4 marks]

W2. Compare the mechanisms of SN1 and SN2 nucleophilic substitution. In your answer, state the number of steps for each, explain the role of the carbocation in SN1, and describe how the type of halogenoalkane (primary vs tertiary) determines the mechanism. [4 marks]

▸**Watch: Nucleophilic Substitution — SN1 and SN2 Mechanisms** VIDEO

10. 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):

$$CH_4 + Cl_2 \xrightarrow{\text{UV light}} CH_3Cl + HCl$$

Reaction type: free radical substitution

The Three Steps

Step	What Happens
1. Initiation	UV light breaks the Cl-Cl bond by HOMOLYTIC FISSION. $Cl_2 \rightarrow 2\ Cl\cdot$ (Each Cl atom gets one electron — shown as $Cl\cdot$, a free radical)
2. Propagation	Two steps that repeat in a chain reaction: (a) $Cl\cdot + CH_4 \rightarrow HCl + CH_3\cdot$ (b) $CH_3\cdot + Cl_2 \rightarrow CH_3Cl + Cl\cdot$ The $Cl\cdot$ produced in (b) re-enters step (a)
3. Termination	Two radicals combine — the chain ends: $Cl\cdot + Cl\cdot \rightarrow Cl_2$ / $CH_3\cdot + Cl\cdot \rightarrow CH_3Cl$ / $CH_3\cdot + CH_3\cdot \rightarrow C_2H_6$

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: $Cl\cdot$, $CH_3\cdot$
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 (SN1, SN2 HL, 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: Cl-Cl $\xrightarrow{UV}$ Cl· + Cl·. 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: C-Br → $C^+ + Br^-$. When: IONIC mechanisms (SN1, SN2 HL, 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 → Cl· + Cl·
SN1 mechanism (Section 9) HL	Heterolytic — C-X breaks: C^+ (carbocation) + X^- (halide ion)
SN2 mechanism (Section 9) HL	Heterolytic — C-X breaks as OH^- attacks; Br^- leaves as ion
Electrophilic addition (Section 7)	Heterolytic — H-Br breaks: H^+ adds to alkene carbon, Br^- released

Homolytic fission — free radical substitution:

$$Cl{:}Cl \xrightarrow{UV} Cl\cdot + Cl\cdot$$

(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 — SN1 tertiary halogenoalkane: HL

$$C\text{-}Br \rightarrow C^+ + Br^-$$

(both electrons go to Br — forms ions)

The C^+ is the carbocation intermediate in the SN1 mechanism.

⚠ 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?

A. $CH_4 \rightarrow CH_3\cdot + H\cdot$

B. $Cl\cdot + CH_4 \rightarrow CH_3\cdot + HCl$

C. $Cl_2 \rightarrow 2Cl\cdot$ ← CORRECT

D. $CH_3\cdot + Cl\cdot \rightarrow CH_3Cl$

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?

A. $Cl_2 \xrightarrow{UV} 2Cl\cdot$

B. $Cl\cdot + CH_4 \rightarrow HCl + CH_3\cdot$

C. $CH_3\cdot + Cl_2 \rightarrow CH_3Cl + Cl\cdot$

D. $CH_3\cdot + CH_3\cdot \rightarrow C_2H_6$ ← CORRECT

Why: Termination occurs when two free radicals combine, removing radicals from the system and ending the chain reaction. $CH_3\cdot + CH_3\cdot \rightarrow C_2H_6$ 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]

11. 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 C=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:

$n\ CH_2{=}CH_2 \rightarrow [-CH_2\text{-}CH_2-]_n$

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

Monomer	Polymer & Uses
Chloroethene ($CH_2{=}CHCl$)	→ poly(chloroethene), PVC. Used in pipes, window frames
Ethene ($CH_2{=}CH_2$)	→ poly(ethene)/polyethene. Plastic bags, bottles
Propene ($CH_2{=}CHCH_3$)	→ poly(propene). Ropes, carpets
Tetrafluoroethene ($CF_2{=}CF_2$)	→ 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 $CH_2{=}CHCl$ → repeating unit is $[-CH_2\text{-}CHCl-]_n$

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 ($CH_2{=}CHCl$)?

A. $[-CH_2{=}CHCl-]_n$

B. $[-CH_2\text{-}CH_2\text{-}CHCl-]_n$

C. $[-CH_2\text{-}CHCl-]_n$ ← CORRECT

D. $[-CHCl\text{-}CHCl-]_n$

Why: In addition polymerization, the C=C double bond opens up. The repeating unit is drawn by converting C=C to C-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 C=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 C=C). Condensation polymers come from bifunctional monomers (e.g. diols + dicarboxylic acids).

Written Questions (answers at end of guide):

W1. Propene ($CH_2{=}CHCH_3$) 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]

12. 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 = C5-C10 chain lengths)

Crude Oil Concerns

- Non-renewable resource — will run out
- Burning releases CO_2 → greenhouse effect / climate change
- Incomplete combustion releases CO → toxic
- Combustion of S impurities → SO_2 → 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_2O (H_3PO_4)	Addition (hydration) → alcohol
Primary alcohol + $K_2Cr_2O_7$	Oxidation → aldehyde → carboxylic acid
Secondary alcohol + $K_2Cr_2O_7$	Oxidation → ketone
Tertiary alcohol + $K_2Cr_2O_7$	No reaction (stays orange)
Halogenoalkane (1°) + NaOH HL	SN2 nucleophilic substitution → alcohol
Halogenoalkane (3°) + NaOH HL	SN1 nucleophilic substitution → alcohol (via carbocation)
Alkene + n (polymerize)	Addition polymerization → polymer
Carboxylic acid + Alcohol (conc. H_2SO_4**)**	Esterification (condensation) → ester + H_2O
Ester + NaOH(aq)	Base hydrolysis (saponification) → sodium salt + alcohol

Practice Questions

MCQ (inline answers — students see answer immediately):

WORKED EXAMPLE

Q1. Ethanol (CH_3CH_2OH) has a significantly higher boiling point than ethane (C_2H_6), 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 $\cdots$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]

13. 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

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 (~150°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 (~300°C) and pressure
Nucleophilic substitution (halogenoalkane → alcohol) HL	NaOH(aq) or KOH(aq), warm, aqueous solution
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.
Nucleophile HL	An electron-rich species that donates a pair of electrons to an electron-deficient atom. Examples: OH^-, CN^-, NH_3.
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 C=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 C=C or C≡C bond. Can undergo addition reactions.
Saturated hydrocarbon	A hydrocarbon that contains only C-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 -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 ($CH_2{=}CH_2$)

$\xrightarrow{+H_2O\ /\ H_3PO_4,\ \text{heat/pressure}}$ Ethanol (CH_3CH_2OH) [addition/hydration]

$\xrightarrow{+K_2Cr_2O_7/H_2SO_4,\ \text{distil}}$ Ethanal (CH_3CHO) [oxidation]

$\xrightarrow{+K_2Cr_2O_7/H_2SO_4,\ \text{reflux}}$ Ethanoic acid (CH_3COOH) [oxidation]

$\xrightarrow{+NaBH_4}$ Ethanol again [reduction]

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

Alkane → Halogenoalkane → Alcohol pathway: HL

Alkane $\xrightarrow{X_2,\ UV}$ Halogenoalkane $\xrightarrow{NaOH(aq),\ warm}$ Alcohol

Example:

$CH_4 \xrightarrow{Cl_2,\ UV} CH_3Cl \xrightarrow{NaOH(aq)} CH_3OH$

methane → chloromethane → methanol

Type 1: free radical substitution. Type 2: nucleophilic substitution.

Alcohol oxidation and reduction summary:

Carboxylic acid $\xleftarrow{\text{excess } K_2Cr_2O_7/H_2SO_4,\ \text{reflux}}$ Primary alcohol

Aldehyde $\xleftarrow{K_2Cr_2O_7/H_2SO_4,\ \text{distil}}$ Primary alcohol

Aldehyde $\xrightarrow{NaBH_4}$ Primary alcohol

Ketone $\xleftarrow{K_2Cr_2O_7/H_2SO_4}$ Secondary alcohol

Ketone $\xrightarrow{NaBH_4}$ Secondary alcohol

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

Orange → 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. Say 'nucleophilic substitution' not just 'substitution' for halogenoalkane + NaOH. HL 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. $CH_3Br + NaOH \rightarrow CH_3OH$ is INCOMPLETE — must add + NaBr.
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.

14. Written Question Answers

Section 1, W1:

A **strong acid** is an acid that ionizes completely (100%) when dissolved in water; the reaction goes to completion, shown with a single arrow. Example: $\mathrm{HCl(aq)} \rightarrow \mathrm{H^+(aq)} + \mathrm{Cl^-(aq)}$ [1 mark]. A **weak acid** is an acid that only partially ionizes in water; an equilibrium is established, shown with a double arrow. Example: $\mathrm{CH_3COOH(aq)} \rightleftharpoons \mathrm{CH_3COO^-(aq)} + \mathrm{H^+(aq)}$ [1 mark]. To distinguish experimentally at the same concentration: measure pH — the strong acid has a lower pH (higher $[\mathrm{H^+}]$) because it fully ionizes [1 mark]. Alternatively, measure electrical conductivity — the strong acid has higher conductivity because it produces more ions in solution [1 mark].

Section 1, W2:

(a) At the equivalence point, moles of HCl = moles of NaOH. Moles of $\mathrm{HCl} = 0.0250 \times 0.200 = 0.00500\ \mathrm{mol}$. Volume of NaOH required $= 0.00500 / 0.200 = 0.0250\ \mathrm{dm^3} = 25.0\ \mathrm{cm^3}$ [1 mark]. (b) pH = 7 at the equivalence point [1 mark], because both acid and base are strong — the resulting salt (NaCl) does not hydrolyse, and neither the $\mathrm{Na^+}$ nor the $\mathrm{Cl^-}$ ion reacts with water to produce $\mathrm{H^+}$ or $\mathrm{OH^-}$ [1 mark]. (c) Curve starts at low pH (approximately 1 for 0.200 mol/dm^3 HCl); rises gradually; shows a sharp vertical inflection at the equivalence point (25.0 cm^3) at pH 7; then levels off near pH 13 [1 mark]. Any indicator that changes colour between pH 4 and 10 is suitable, e.g. phenolphthalein (changes pH 8.2–10) or methyl orange (changes pH 3.1–4.4) [1 mark].

Section 2, W1:

Oxidation is the loss of electrons; **reduction** is the gain of electrons (OIL RIG) [1 mark]. In $\mathrm{2Mg + O_2 \rightarrow 2MgO}$: Mg is oxidized ($0 \rightarrow +2$, loses 2 electrons per atom) and $\mathrm{O_2}$ is reduced ($0 \rightarrow -2$, gains 2 electrons per atom) [1 mark]. The **oxidizing agent** is $\mathrm{O_2}$ because it gains electrons (is reduced), causing Mg to be oxidized. The **reducing agent** is Mg because it loses electrons (is oxidized), causing $\mathrm{O_2}$ to be reduced [1 mark]. Half equations — Oxidation: $\mathrm{Mg \rightarrow Mg^{2+} + 2}e^-$. Reduction: $\mathrm{O_2} + 4e^- \rightarrow \mathrm{2O^{2-}}$ [1 mark].

Section 2, W2:

(a) Ionic equation: $\mathrm{Mg(s) + Cu^{2+}(aq) \rightarrow Mg^{2+}(aq) + Cu(s)}$ [1 mark]. (b) Magnesium is oxidized ($0 \rightarrow +2$, loses 2 electrons); copper ion is reduced ($+2 \rightarrow 0$, gains 2 electrons) [1 mark]. (c) Oxidation half equation: $\mathrm{Mg \rightarrow Mg^{2+} + 2}e^-$. Reduction half equation: $\mathrm{Cu^{2+} + 2}e^- \rightarrow \mathrm{Cu}$ [1 mark]. (d) Magnesium is higher in the reactivity series (activity series) than copper, meaning magnesium has a stronger tendency to lose electrons (is a stronger reducing agent) [1 mark]. Copper cannot

displace magnesium because copper is lower in the reactivity series — it has a weaker tendency to lose electrons and therefore cannot reduce Mg^{2+} ions to magnesium metal [1 mark].

Section 3, 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 4, 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: $CH_3CH(CH_3)CH(OH)CH_2CH_3$ [1 mark].

Section 5, W1:

There are two structural isomers of C_3H_7Br:

- 1-Bromopropane ($CH_3CH_2CH_2Br$) — this is a primary halogenoalkane (the carbon bonded to Br is attached to only 1 other carbon) [1 mark].
- 2-Bromopropane ($CH_3CHBrCH_3$) — 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 6, 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 7, W1:

Add bromine water ($Br_2(aq)$, 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 C=C double

bond, forming 1,2-dibromoethane [1 mark]. With ethane: the bromine water remains orange/brown because ethane is saturated (no C=C) and cannot undergo addition reactions under these conditions [1 mark].

Section 7, W2:

But-1-ene: $CH_2{=}CHCH_2CH_3$ (terminal alkene, C=C at carbon 1) [1 mark]. But-2-ene: $CH_3CH{=}CHCH_3$ (internal alkene, C=C at carbon 2) [1 mark].

When but-1-ene reacts with HBr, two products are possible: 1-bromobutane ($CH_3CH_2CH_2CH_2Br$) and 2-bromobutane ($CH_3CHBrCH_2CH_3$), because the C=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 ($CH_3CHBrCH_2CH_3$), because the C=C is symmetric — adding H to either carbon of the double bond gives the same product [1 mark].

Section 8, 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 $K_2Cr_2O_7$ solution remains orange [1 mark].

Section 8, W2:

Test 1 — Tollens' reagent (silver mirror test): Add ammoniacal silver nitrate solution ($Ag(NH_3)_2^+$) 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 8A, W1:

Equation: $CH_3CH_2CHO + 2[H] \rightarrow CH_3CH_2CH_2OH$ [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 $K_2Cr_2O_7$ — 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 8C, W1:

Equation: $\mathrm{HCOOCH_2CH_2CH_3 + NaOH \rightarrow HCOONa + CH_3CH_2CH_2OH}$ [1 mark]. Products: sodium methanoate (HCOONa, the sodium salt of methanoic acid) and propan-1-ol ($\mathrm{CH_3CH_2CH_2OH}$) [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 9, W1: HL

Equation: $\mathrm{CH_3CH_2CH_2CH_2Br + NaOH(aq) \rightarrow CH_3CH_2CH_2CH_2OH + NaBr}$ [1 mark]. The organic product is butan-1-ol [1 mark]. The mechanism is SN2 (bimolecular nucleophilic substitution) [1 mark]. SN2 is favoured because 1-bromobutane is a primary halogenoalkane — the carbon bonded to Br has only one other carbon attached, leaving relatively little steric hindrance. This allows the nucleophile ($\mathrm{OH^-}$) to attack the δ+ carbon directly from the back in a single concerted step, simultaneously displacing $\mathrm{Br^-}$ [1 mark].

Section 9, W2: HL

SN2 mechanism: Occurs in one step. The nucleophile ($\mathrm{OH^-}$) attacks the δ+ carbon from the opposite side to the halogen, forming a new C-OH bond while the C-X bond breaks simultaneously. There is no intermediate — a single transition state is formed [1 mark]. SN2 is favoured for primary halogenoalkanes because the carbon bonded to the halogen is relatively unhindered (only one other carbon attached), allowing direct back-side attack by the nucleophile [1 mark].

SN1 mechanism: Occurs in two steps. Step 1 (slow, rate-determining): the C-X bond breaks by heterolytic fission, and the halogen leaves as $\mathrm{X^-}$, forming a carbocation intermediate ($\mathrm{C^+}$). Step 2 (fast): the nucleophile ($\mathrm{OH^-}$) attacks the positively charged carbocation [1 mark]. SN1 is favoured for tertiary halogenoalkanes because tertiary carbocations are stabilised by the electron-donating effect (inductive effect) of three alkyl groups, making the formation of the carbocation energetically favourable. The steric crowding around the carbon also prevents direct SN2 attack [1 mark].

Section 10, W1:

Initiation: $\mathrm{Br_2 \xrightarrow{UV} 2Br\cdot}$ (UV light causes homolytic fission of the Br-Br bond to form two bromine radicals) [1 mark].

Propagation step 1: $\mathrm{Br}\cdot + \mathrm{C_2H_6} \rightarrow \mathrm{HBr} + \mathrm{C_2H_5}\cdot$ (a bromine radical abstracts a hydrogen atom from ethane, forming HBr and an ethyl radical) [1 mark].

Propagation step 2: $\mathrm{C_2H_5}\cdot + \mathrm{Br_2} \rightarrow \mathrm{C_2H_5Br} + \mathrm{Br}\cdot$ (the ethyl radical reacts with a bromine molecule, forming bromoethane and regenerating a bromine radical) [1 mark].

Termination (one example): $\mathrm{C_2H_5}\cdot + \mathrm{Br}\cdot \rightarrow \mathrm{C_2H_5Br}$ (two radicals combine, ending the chain) [1 mark].

Overall equation: $\mathrm{C_2H_6} + \mathrm{Br_2} \xrightarrow{\mathrm{UV}} \mathrm{C_2H_5Br} + \mathrm{HBr}$. 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 11, W1:

Repeating unit of poly(propene): $[-\mathrm{CH_2\text{-}CH(CH_3)}-]_n$ — the C=C double bond opens, the methyl group ($\mathrm{CH_3}$) 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 12, 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 $\mathrm{C_5H_{12}}$ (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 ($\mathrm{CH_3CH_2CH_2CH_2CH_2OH}$) 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].

Mixed Practice — Exam Style

> **IB TIP**
>
> **How to use this section:** Unlike topic-specific practice, these questions are interleaved — they mix all topics from this guide in random order. Before answering, identify *which concept or topic area* the question is testing. This is exactly the skill you need on Paper 1 and Paper 2, where you don't know in advance which topic each question covers.

1. **[Functional Group Identification]** A compound has the molecular formula C_3H_6O and gives a silver mirror in Tollens' reagent. The compound is most likely:

   A. Propan-1-ol

   B. Propanone (a ketone)

   C. Propanal (an aldehyde)

   D. Propanoic acid

2. **[IUPAC Naming]** What is the correct IUPAC name for $CH_3CH(CH_3)CH_2CH_3$?

   A. 2-methylbutane

   B. 3-methylbutane

   C. isopentane

   D. 2-methylpropane

3. **[Reaction Types — Addition]** Ethene reacts with bromine water ($Br_2(aq)$). The correct product and reaction type are:

   A. Ethane; substitution reaction

   B. 1,2-dibromoethane; electrophilic addition reaction; bromine water decolourises

   C. Bromoethene; elimination reaction

   D. Ethanol; nucleophilic addition reaction

4. **[Oxidation of Alcohols — Distractor]** A student oxidises propan-2-ol using acidified potassium dichromate ($K_2Cr_2O_7/H^+$). They expect to produce propanoic acid. Evaluate this:

   A. Correct — all alcohols are oxidised to carboxylic acids under these conditions

B. Incorrect — propan-2-ol is a secondary alcohol; it is oxidised to a ketone (propanone), not a carboxylic acid. Tertiary alcohols are not oxidised at all.

C. Incorrect — propan-2-ol cannot be oxidised because it contains no -OH group

D. Correct — secondary alcohols always produce aldehydes, not ketones

5. **[Free Radical Substitution — Mechanism]** In the free radical bromination of methane, which step produces new halogenoalkane product while simultaneously regenerating the radical needed to continue the chain?

   A. Initiation — $\mathrm{Br_2} \xrightarrow{\mathrm{UV}} 2\mathrm{Br}\cdot$

   B. First propagation step — $\mathrm{Br}\cdot + \mathrm{CH_4} \rightarrow \mathrm{HBr} + \mathrm{CH_3}\cdot$

   C. Second propagation step — $\mathrm{CH_3}\cdot + \mathrm{Br_2} \rightarrow \mathrm{CH_3Br} + \mathrm{Br}\cdot$

   D. Termination — $\mathrm{CH_3}\cdot + \mathrm{Br}\cdot \rightarrow \mathrm{CH_3Br}$

6. **[Polymers]** Poly(ethene) is produced from ethene monomers. The type of polymerisation and the structural feature of the monomer that makes this possible are:

   A. Condensation polymerisation; ethene has two -OH groups that react to eliminate water

   B. Addition polymerisation; ethene has a C=C double bond that opens to form new single bonds linking monomers together

   C. Addition polymerisation; ethene has a C≡C triple bond

   D. Condensation polymerisation; ethene has a C=C that reacts with an amine group

7. **[IUPAC Naming — Functional Groups]** A compound named “ethyl propanoate” belongs to which functional group class, and what are its two parent reactants?

   A. Ether; ethanol and propan-1-ol

   B. Ester; propanoic acid and ethanol

   C. Ester; ethanoic acid and propan-1-ol

   D. Ketone; ethane and propanoic acid

8. **[Reaction Types — Distractor]** A student adds concentrated $\mathrm{H_2SO_4}$ to ethanol and heats to 170°C. They state this is an addition reaction. Are they correct?

   A. Yes — concentrated $\mathrm{H_2SO_4}$ adds across the C-O bond

B. No — this is an elimination (dehydration) reaction. Water is removed from ethanol to form ethene. Addition reactions add atoms across double bonds; elimination reactions remove atoms to form a double bond.

C. Yes — the product is diethyl ether, formed by addition of two ethanol molecules

D. No — this is a substitution reaction; the -OH is replaced by HSO_4^-

9. **[Structural Isomers]** How many structural isomers are there with molecular formula C_4H_{10}?

   A. 1

   B. 2

   C. 3

   D. 4

10. **[Nucleophilic Substitution]** HL A primary halogenoalkane reacts with $NaOH(aq)$ via an S_N2 mechanism. Which statement about this mechanism is correct?

    A. The reaction proceeds through a planar carbocation intermediate

    B. The hydroxide ion attacks the carbon bearing the halogen from the same side as the leaving group (retention of configuration)

    C. The hydroxide ion attacks the back of the carbon bearing the halogen (backside attack), displacing the halide ion in a single concerted step with inversion of configuration

    D. S_N2 is favoured by tertiary halogenoalkanes because of steric stabilisation of the carbocation

▶ Show Answers

November 2026 Prediction Questions

⚠ EXAM ALERT

These are NOT official IB questions. These are trend-based practice questions written to reflect the topic areas and question styles most likely to appear on the November 2026 IB Chemistry SL Paper 2. Based on recent exam patterns (2022-2025), expect heavy weighting on: functional group identification and naming, nucleophilic substitution mechanisms (S_N1 vs S_N2), and reaction types of organic homologous series.

WORKED EXAMPLE

Question 1 [Functional Groups and Naming] [~6 marks]

Consider the following organic compound: $CH_3CH_2CH(OH)CH_2COOH$

(a) Identify the two functional groups present in this molecule.

(b) Name this compound using IUPAC nomenclature.

(c) State and explain one chemical test that could distinguish this compound from $CH_3CH_2CH_2CH_2CH_3$.

▶ Show Solution

WORKED EXAMPLE

Question 2 [Nucleophilic Substitution] [~7 marks]

Halogenoalkanes undergo nucleophilic substitution reactions. Consider 1-bromobutane ($CH_3CH_2CH_2CH_2Br$) and 2-bromo-2-methylpropane ($(CH_3)_3CBr$).

(a) Define the term "nucleophile" and give two examples of nucleophiles.

(b) Explain why 1-bromobutane undergoes an S_N2 mechanism while 2-bromo-2-methylpropane undergoes an S_N1 mechanism.

(c) Outline the steps of the S_N1 mechanism for the hydrolysis of 2-bromo-2-methylpropane with aqueous $NaOH$.

▶ Show Solution

WORKED EXAMPLE

Question 3 [Reactions of Organic Compounds] [~6 marks]

Ethanol (CH_3CH_2OH) can undergo several different types of reactions depending on conditions.

(a) Write a balanced equation for the complete combustion of ethanol.

(b) Ethanol can be oxidised to ethanal and then to ethanoic acid. State the reagent and conditions for each oxidation, and identify the type of organic compound formed at each stage.

(c) Ethanol reacts with ethanoic acid in the presence of a catalyst. Name the type of reaction, write the structural formula of the organic product, and name it.

▶ Show Solution