MEGA LECTURE

IB DP CHEMISTRY

Structure 3: Classification of Matter

Structure 3.2 Functional Groups

Classification of Organic Compounds

Revision Notes · Standard and Higher Level

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What the syllabus requires

Structure 3.2 is the gateway to organic chemistry. It asks you to organise the enormous number of carbon compounds into **homologous series**, to recognise the **functional group** that defines each series, to name and draw structures using **IUPAC** rules, and to identify the different kinds of **isomerism** that arise when the same atoms are joined in different ways. Use the checklist below as a final revision sweep. Content common to SL and HL is unmarked; HL-only extensions are flagged **(HL)**.

Understanding	You should be able to...
Homologous series	Explain why members of a series share a functional group and a general formula, and show gradual trends in physical properties.
Functional groups	Identify the functional group in a molecule and assign the compound to the correct class (alcohol, aldehyde, ester, amine and so on).
Formulae	Interconvert empirical, molecular, structural, condensed and skeletal formulae.
IUPAC nomenclature	Name straight-chain and branched compounds up to six carbons containing a single functional group, and draw the structure from the name.
Structural isomers	Recognise and draw chain, position and functional-group isomers of a given molecular formula.
Classes	Classify alcohols and halogenoalkanes as primary, secondary or tertiary.
Property trends	Account for boiling-point and solubility trends within a series using intermolecular forces.
Stereoisomerism (HL)	Distinguish cis−trans (E/Z) and optical isomers; identify a chiral carbon; describe enantiomers and their effect on plane-polarised light.
Unsaturation (HL)	Use the index of hydrogen deficiency to deduce the number of rings plus multiple bonds in a molecule.

> **How this topic is examined:** Multiple-choice questions test naming, spotting isomers and counting chiral centres; short-answer questions ask you to draw and name structures and to justify property trends. Accurate structural drawings and correct locants earn the marks.

1. The foundations of organic chemistry

Organic chemistry is the chemistry of carbon compounds (with a few exceptions such as the oxides of carbon, carbonates and cyanides, which are treated as inorganic). A single element, carbon, gives rise to more compounds than all the other elements combined. Two special properties of the carbon atom explain this.

Why carbon?

- **Tetravalency.** Carbon has four electrons in its outer shell and therefore forms **four** covalent bonds. This lets each carbon connect to as many as four other atoms, building three-dimensional frameworks of great variety.
- **Catenation.** Carbon−carbon bonds are strong and stable, so carbon atoms bond to one another to form long straight chains, branched chains and rings. No other element catenates so extensively.

Because each carbon can also form strong bonds to hydrogen, oxygen, nitrogen and the halogens, and can form single, double or triple bonds, the number of possible structures is essentially unlimited. Classification is therefore essential.

Homologous series

A **homologous series** is a family of organic compounds with the same general formula, in which each successive member differs from the previous one by a $–CH_2–$ unit. The members share the same functional group and therefore very similar chemical properties, while their physical properties change gradually as the chain lengthens.

The defining features of a homologous series are:

- the same **general formula** (for example C_nH_{2n+2} for alkanes);
- successive members differ by **CH_2** (a relative formula mass difference of 14);
- the same **functional group**, so members undergo the same types of reaction;
- a **gradual trend** in physical properties such as boiling point and density;
- members can be prepared by similar methods.

The alkanes illustrate the pattern: methane CH_4, ethane C_2H_6, propane C_3H_8, butane C_4H_{10} – each has two more hydrogen atoms than carbon atoms times two, matching C_nH_{2n+2}.

Representing organic molecules

The same molecule can be written in several ways, each conveying a different amount of information. You must be able to move between them.

Type of formula	What it shows	Example (butan-1-ol)
Empirical	Simplest whole-number ratio of atoms of each element.	C_2H_5O
Molecular	Actual number of atoms of each element in one molecule.	$C_4H_{10}O$
Structural (full)	Every atom and every bond drawn out explicitly.	shows all C–C, C–H and O–H bonds
Condensed	Atoms grouped around each carbon; bonds implied.	$CH_3CH_2CH_2CH_2OH$
Skeletal	Carbon skeleton as lines; C and H on carbon omitted; functional groups shown.	zig-zag line ending in –OH

In a **skeletal formula** each line end and each vertex is a carbon atom, and enough hydrogen atoms are assumed present to give every carbon four bonds. Only heteroatoms (O, N, halogens) and the hydrogens attached to them are drawn. Skeletal formulae are quick to draw and are the standard way to show larger molecules.

> **Empirical vs molecular:** The molecular formula is always a whole-number multiple of the empirical formula. For ethanoic acid CH_3COOH the molecular formula is $C_2H_4O_2$ but the empirical formula is CH_2O – halve every subscript.

Worked example (Section 1) – interconverting formulae

A compound has the condensed structural formula CH_3CH_2COOH. State its molecular and empirical formulae, and its degree of unsaturation.

Count the atoms: 3 C, 6 H, 2 O → molecular formula $C_3H_6O_2$.

The subscripts 3, 6 and 2 share no common factor, so the empirical formula is the same, $C_3H_6O_2$.

IHD = $(2\times3 + 2 - 6)/2 = 1$ → one double bond, the C=O of the carboxyl group (this compound is propanoic acid).

2. The functional groups

A **functional group** is an atom or group of atoms that gives a molecule its characteristic chemical properties. Two molecules with the same functional group react in essentially the same way, whatever the length of their carbon chain. The table below lists every functional group named in the syllabus, together with the prefix or suffix used in naming and a worked example.

Class	Functional group	Prefix / suffix	General formula	Example
Alkane	C–C (single bonds only)	-ane	C_nH_{2n+2}	ethane, CH_3CH_3
Alkene	C=C double bond	-ene	C_nH_{2n}	ethene, $CH_2{=}CH_2$
Alkyne	C≡C triple bond	-yne	C_nH_{2n-2}	ethyne, CH≡CH
Halogenoalkane	C–X (X = F, Cl, Br, I)	halo-	$C_nH_{2n+1}X$	chloroethane, CH_3CH_2Cl
Alcohol	–OH (hydroxyl)	-ol	$C_nH_{2n+1}OH$	ethanol, CH_3CH_2OH
Aldehyde	–CHO (terminal carbonyl)	-al	$C_nH_{2n}O$	ethanal, CH_3CHO
Ketone	C=O within the chain	-one	$C_nH_{2n}O$	propanone, CH_3COCH_3
Carboxylic acid	–COOH (carboxyl)	-oic acid	$C_nH_{2n+1}COOH$	ethanoic acid, CH_3COOH
Ester	–COO– (ester linkage)	-yl -oate	–	methyl ethanoate, CH_3COOCH_3
Ether	C–O–C	-oxy-	–	methoxymethane, CH_3OCH_3
Amine	$–NH_2$ (primary)	amino- / -amine	$C_nH_{2n+1}NH_2$	ethanamine, $CH_3CH_2NH_2$
Amide	$–CONH_2$	-amide	–	ethanamide, CH_3CONH_2
Nitrile	–C≡N	-nitrile	$C_nH_{2n-1}N$	ethanenitrile, CH_3CN
Arene	benzene ring	phenyl- / -benzene	–	methylbenzene, $C_6H_5CH_3$

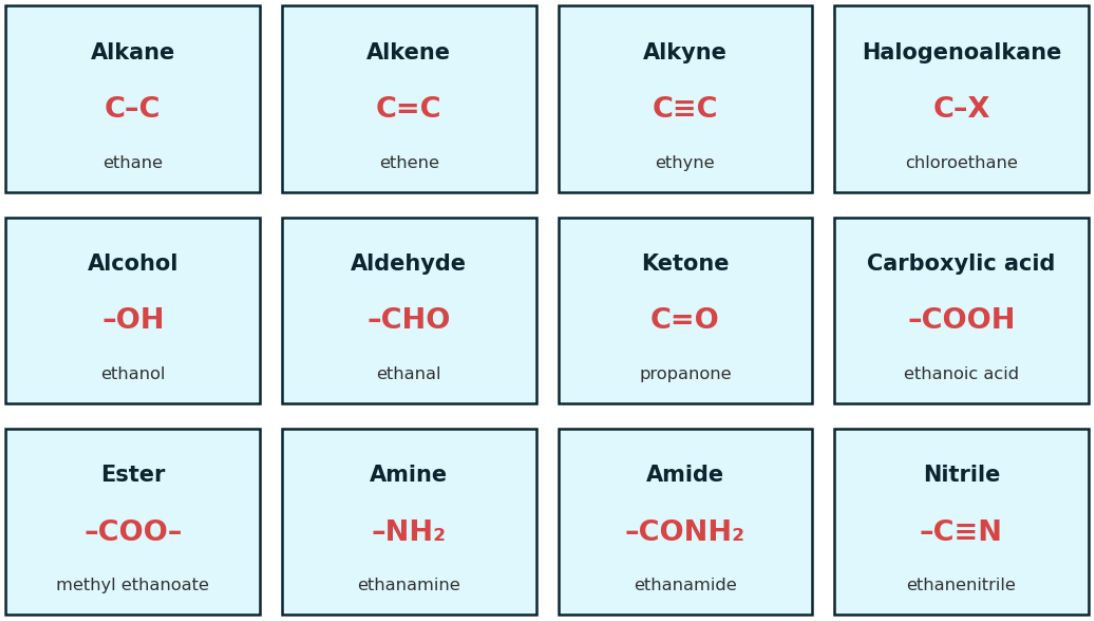

Figure 1. The functional groups that define the main homologous series named in the syllabus, each shown with a worked example.

> **Aldehyde vs ketone:** Both contain the carbonyl group C=O. In an **aldehyde** the carbonyl carbon is at the end of the chain and carries an H (–CHO); in a **ketone** it is inside the chain, bonded to two other carbon atoms. This is why methanal and propanone can never be isomers of different classes at the same carbon number without the position changing.

3. IUPAC nomenclature

The International Union of Pure and Applied Chemistry (IUPAC) system gives every compound one unambiguous name from which the structure can be rebuilt. A name has three parts: a **stem** that states the number of carbons in the main chain, a **suffix** that states the principal functional group, and **prefixes** that list substituents.

Carbons	1	2	3	4	5	6
Stem	meth	eth	prop	but	pent	hex

Branches that come off the main chain are named as **alkyl groups** – an alkane that has lost one hydrogen. The common substituent prefixes are listed below.

Substituent	Formula	Prefix
Methyl	$–CH_3$	methyl-
Ethyl	$–C_2H_5$	ethyl-
Propyl	$–C_3H_7$	propyl-
Fluorine / chlorine / bromine / iodine	–F, –Cl, –Br, –I	fluoro- / chloro- / bromo- / iodo-

The rules, applied in order

- **1. Find the longest continuous carbon chain** that contains the principal functional group. Its length gives the stem. The chain is not always drawn in a straight line – follow it around corners.
- **2. Number the chain** from the end that gives the **lowest locant** (lowest number) to the principal functional group, then to substituents.
- **3. Identify substituents** branching off the chain: alkyl groups (methyl –CH_3, ethyl –C_2H_5) and halogens (fluoro, chloro, bromo, iodo). Give each its locant.
- **4. Assemble the name**: substituent prefixes in **alphabetical order**, then stem, then suffix. Use di-, tri-, tetra- for repeated substituents (these multipliers are ignored when alphabetising).
- **5. Show positions of double/triple bonds** with a locant before the -ene or -yne suffix, and the position of the functional group with a locant before its suffix (for example butan-2-ol).

> **Lowest set of locants:** When numbering could start from either end, compare the full set of locants and choose the set that is lower at the first point of difference. The principal functional group always takes priority for the lowest number, ahead of substituents.

Worked example A – naming a branched alkane

Name the compound $CH_3CH(CH_3)CH_2CH_2CH_3$.

Longest chain: five carbons → pentane. A methyl branch sits on the second carbon. Numbering from the left gives the methyl a locant of 2; from the right it would be 4, so we number from the left.

Name: **2-methylpentane**.

Worked example B – two substituents

Name $CH_3CHClCH(CH_3)CH_3$.

Longest chain containing the chlorine: four carbons → butane. Substituents: a chloro group and a methyl group. Numbering from the left: Cl on C2, methyl on C3 (locant set 2,3). From the right: methyl on C2, Cl on C3 (set 2,3 as well). The sets tie, so we give the lower number to the substituent first in the alphabet – chloro before methyl – so chloro takes C2.

Name: **2-chloro-3-methylbutane**.

Worked example C – a functional group with a locant

Name $CH_3CH(OH)CH_2CH_3$.

Four carbons → butan-. The principal group is –OH → -ol. Numbering to give –OH the lowest locant: from the left the OH is on C2, from the right it is on C3, so number from the left.

Name: **butan-2-ol**.

Worked example D0 – an alkene with a branch

Name $CH_2{=}CHCH(CH_3)CH_3$.

Longest chain containing the C=C: four carbons → but-. The double bond and a methyl branch are present. Number so the double bond gets the lowest locant: from the left the C=C starts at C1 and the methyl is on C3.

Name: **3-methylbut-1-ene**. (The double-bond locant 1 beats the alternative numbering, which would place it at C3.)

4. Structural isomerism

Isomers are compounds with the same molecular formula but different arrangements of atoms. **Structural (constitutional) isomers** have their atoms connected in a different order, i.e. they differ in their structural formula. There are three kinds you must recognise.

Type	What differs	Example (both C_4H_{10} or C_3H_6O)
Chain isomerism	The arrangement of the carbon skeleton (straight vs branched).	butane $CH_3CH_2CH_2CH_3$ and methylpropane $(CH_3)_3CH$
Position isomerism	The position of the functional group on the same skeleton.	propan-1-ol and propan-2-ol (both C_3H_8O)
Functional-group isomerism	The functional group itself differs, so the compounds belong to different classes.	propanal (aldehyde) and propanone (ketone), both C_3H_6O

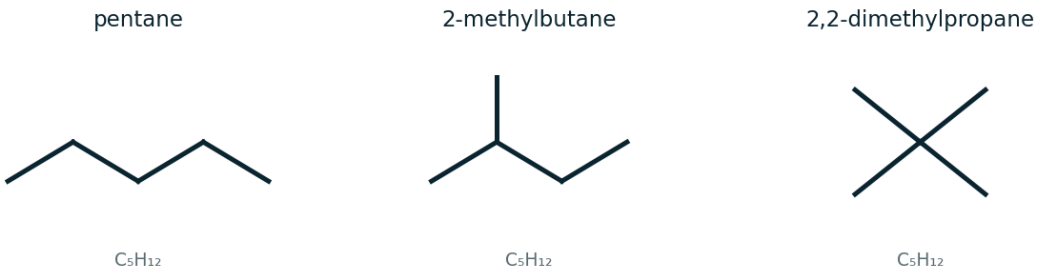

Figure 3. The three structural (chain) isomers of C_5H_{12}: pentane, 2-methylbutane and 2,2-dimethylpropane. All share the molecular formula C_5H_{12} and have IHD = 0.

Isomers can have markedly different physical and chemical properties. Functional-group isomers, belonging to different classes, differ the most; chain isomers usually differ only in physical properties such as boiling point.

Drawing all isomers of a formula

Work systematically so that none is missed and none is counted twice:

- Start with the longest straight chain, then shorten it by one carbon and add that carbon as a branch, and so on.
- For each skeleton, move the functional group to every distinct position.
- Finally consider functional-group isomers of a different class with the same formula.

- Check for duplicates: two drawings that are the same molecule seen from a different angle are **not** separate isomers.

> **Counting trap:** Rotating a molecule or flipping it left-to-right does not make a new isomer. 1-chlorobutane drawn with the Cl on the left is the same compound as 1-chlorobutane drawn with the Cl on the right. Always name each structure you draw – if two drawings give the same name, they are one isomer.

Worked example (Section 4) – counting isomers of C_5H_{12}

How many structural isomers does the alkane C_5H_{12} have? Work down from the longest chain.

Five-carbon chain: pentane, $CH_3CH_2CH_2CH_2CH_3$.

Four-carbon chain + one methyl branch: the branch can only go on C2 (a branch on C3 gives the same molecule numbered from the other end) → 2-methylbutane.

Three-carbon chain + two methyl branches: both on C2 → 2,2-dimethylpropane.

There are exactly **three** isomers. Placing a branch anywhere else simply reproduces one of these three when you re-number – a reminder always to name each structure and reject duplicates.

5. Primary, secondary and tertiary classification

Alcohols and halogenoalkanes are further divided according to how many carbon atoms are attached to the carbon bearing the functional group. This classification matters because it controls how the compound reacts (studied in Reactivity 3).

Class	Carbon bearing the group is bonded to...	Alcohol example	Halogenoalkane example
Primary (1°)	one carbon atom (or none, e.g. methanol)	propan-1-ol, $CH_3CH_2CH_2OH$	1-chloropropane, $CH_3CH_2CH_2Cl$
Secondary (2°)	two carbon atoms	propan-2-ol, $(CH_3)_2CHOH$	2-chloropropane, $(CH_3)_2CHCl$
Tertiary (3°)	three carbon atoms	2-methylpropan-2-ol, $(CH_3)_3COH$	2-chloro-2-methylpropane, $(CH_3)_3CCl$

To classify, locate the carbon that carries the –OH or the halogen and count the other carbon atoms directly bonded to it. Do not count hydrogen atoms, and do not count carbons further down the chain – only the immediate neighbours of the functional carbon.

> **Watch methanol:** In methanol CH_3OH the carbon bearing –OH has no other carbon attached, yet it is still classified as a **primary** alcohol by convention.

Amines are classified by the same idea, but here you count the carbon atoms bonded directly to the **nitrogen**: a primary amine has nitrogen bonded to one carbon ($–NH_2$), a secondary amine to two, and a tertiary amine to three. Note the subtle difference from alcohols, where it is the carbon – not the heteroatom – whose neighbours are counted.

6. Physical-property trends in a series

As you climb a homologous series the chemistry stays the same but the physical properties change smoothly. These trends are explained entirely by **intermolecular forces** (IMF), not by the strength of covalent bonds.

Boiling point and chain length

Within a series, boiling point **rises** as the molecules get larger. A longer carbon chain has more electrons and a greater surface area of contact between molecules, so the **London (dispersion) forces** between molecules are stronger and more energy is needed to separate them. For example, among the alkanes methane, ethane and propane are gases at room temperature, pentane is a liquid, and long-chain alkanes are waxy solids.

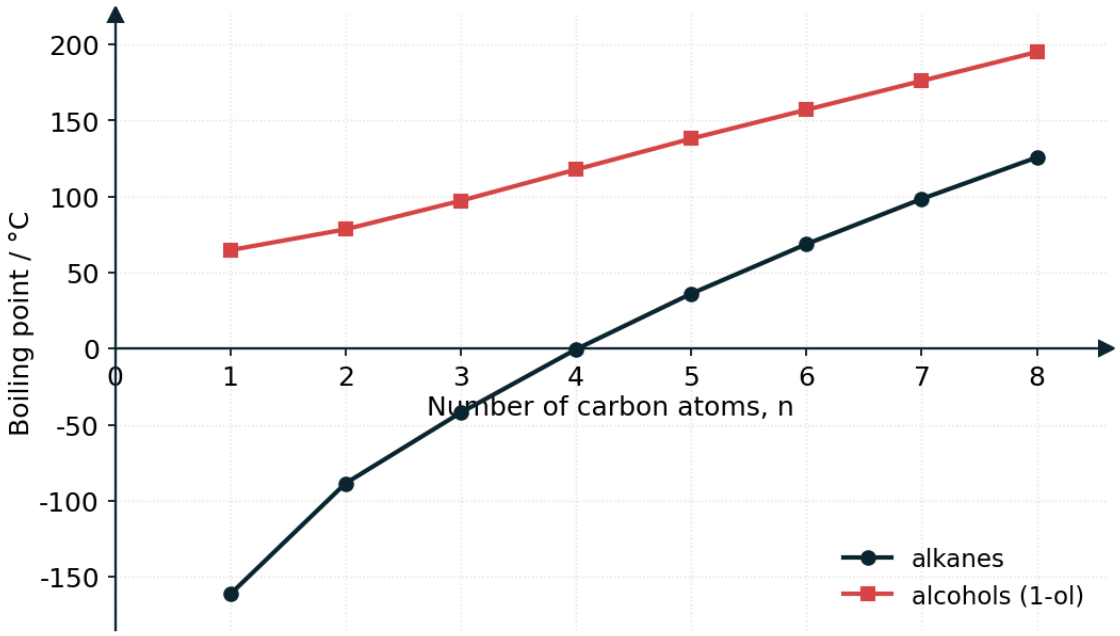

Figure 2. Boiling point rises steadily with chain length; at every n the alcohol boils far above the alkane of the same n because of hydrogen bonding. (bp in °C.)

Boiling point and branching

Comparing **isomers** of the same molecular formula, the more **branched** isomer has the **lower** boiling point. Branching makes the molecule more compact and spherical, reducing the surface area over which neighbouring molecules can touch, so the London forces are weaker. Pentane (straight, b.p. 36 °C) boils higher than 2,2-dimethylpropane (highly branched, b.p. 10 °C).

Effect of the functional group

The functional group determines which additional forces act. Alcohols, carboxylic acids and amines can form **hydrogen bonds**, so they boil far higher than alkanes of similar size. Aldehydes and ketones are polar (C=O) and have permanent dipole−dipole forces, so they boil higher than alkanes but lower than the corresponding alcohols, which hydrogen bond.

The table compares four two-carbon compounds of similar molar mass. The ordering follows directly from the strength of the intermolecular forces present.

Compound	Formula	Strongest IMF	Boiling point / °C
Ethane	CH_3CH_3	London (dispersion)	−89
Ethanal	CH_3CHO	dipole−dipole	20
Ethanol	CH_3CH_2OH	hydrogen bonding	78
Ethanoic acid	CH_3COOH	hydrogen bonding (two sites)	118

Solubility in water

A compound dissolves readily in water when it can hydrogen bond with water molecules. The short-chain alcohols, carboxylic acids and amines are very soluble because their –OH or $–NH_2$ group hydrogen bonds to water. As the **hydrocarbon chain lengthens**, the non-polar part dominates and solubility **falls** – the long chain cannot interact favourably with water. Alkanes, having no polar group, are essentially insoluble.

> **The rule of thumb:** ‘Like dissolves like’. A small polar head on a short chain is soluble; a small head on a long chain is not. Compare ethanol (fully miscible) with hexan-1-ol (only slightly soluble).

7. Stereoisomerism (HL)

Stereoisomers have the same molecular formula and the same order of bonding (the same structural formula) but a different arrangement of their atoms **in space**. There are two types on the HL syllabus: cis−trans isomerism and optical isomerism.

cis−trans (E/Z) isomerism

This arises when rotation within the molecule is **restricted** and two different groups are attached on each side of the rigid part. Two conditions must both be met:

- **Restricted rotation** – a C=C double bond (or a ring) that cannot rotate. The π bond of a double bond locks the two carbons in place.
- **Two different groups on each carbon** of the double bond. If either carbon carries two identical groups, no cis−trans isomers exist.

In the **cis (Z)** isomer the two higher-priority groups lie on the same side of the double bond; in the **trans (E)** isomer they lie on opposite sides. But-2-ene, $CH_3CH{=}CHCH_3$, exists as cis-but-2-ene and trans-but-2-ene, which have different melting and boiling points. But-1-ene shows no such isomerism because its terminal carbon carries two hydrogen atoms.

> **Quick test for cis−trans:** Look at each carbon of the C=C. If **both** carbons have two **different** groups attached, cis−trans isomers exist. If either carbon has two the same, they do not.

Optical isomerism

Optical isomerism arises when a molecule contains a **chiral carbon** (a stereocentre): a carbon atom bonded to **four different** atoms or groups. Such a molecule is not superimposable on its mirror image. The two non-superimposable mirror-image forms are called **enantiomers**.

A useful analogy is a pair of hands: your left and right hands are mirror images but cannot be placed exactly on top of one another. A molecule with this property is described as **chiral**.

- Enantiomers have **identical** physical properties (same melting point, boiling point, density) and identical ordinary chemical reactions.
- They differ in one respect: their effect on **plane-polarised light**. One enantiomer rotates the plane of polarisation clockwise, the other rotates it by the same angle anticlockwise. They are said to be **optically active**.
- A 50:50 mixture of the two enantiomers (a **racemic mixture**) shows no net rotation, because the two effects cancel.
- Enantiomers can also behave differently in biological systems, which is why the chirality of drug molecules matters.

Identifying a chiral centre

Scan the molecule for any carbon bonded to four different groups. In butan-2-ol, $CH_3CH(OH)CH_2CH_3$, carbon 2 is bonded to –H, –OH, $–CH_3$ and $–CH_2CH_3$ – four different groups – so it is a chiral centre and the molecule is optically active. Carbon 2 of propan-2-ol, by contrast, carries two identical methyl groups, so it is not chiral.

> **The chirality requirement:** A carbon is chiral only when all four attached groups are different. If two are identical (for example two H atoms, or two $–CH_3$ groups), the carbon is **not** a stereocentre and the molecule is not optically active on that account.

8. Degree of unsaturation (HL)

The **index of hydrogen deficiency** (IHD), also called the degree of unsaturation, counts how many hydrogen molecules a compound is ‘missing’ compared with the fully saturated open-chain formula. Each unit of IHD corresponds to **one ring or one degree of multiple bonding**: a C=C or C=O counts as one, a triple bond counts as two, and each ring counts as one.

For a compound containing C, H, O, N and halogen (X), the IHD is found from:

$$\mathbf{IHD = [\,2C + 2 + N - H - X\,] / 2}$$

Oxygen atoms are ignored because inserting an –O– does not change the hydrogen count. A saturated open-chain molecule has IHD = 0; every ring or double bond raises it by one.

Worked example D – using the IHD

Deduce the degree of unsaturation of (i) hexane C_6H_{14}, (ii) benzene C_6H_6, (iii) propanone C_3H_6O.

(i) IHD = $(2\times6 + 2 - 14)/2 = 0$ → saturated, no rings or multiple bonds.

(ii) IHD = $(2\times6 + 2 - 6)/2 = 4$ → one ring plus three C=C, consistent with the benzene ring.

(iii) O is ignored: IHD = $(2\times3 + 2 - 6)/2 = 1$ → one double bond, the C=O of the ketone.

Why it helps: Given only a molecular formula, the IHD tells you at a glance whether the molecule can contain a ring, a double bond, a triple bond or an aromatic ring – a powerful first step when deducing a structure from spectroscopic data.

9. Worked examples and exam skills

The following examples pull together the naming, drawing and classification skills of this topic.

Worked example E – draw all isomers of $C_4H_{10}O$

$C_4H_{10}O$ (IHD = 0) has no rings or double bonds. It can be an alcohol or an ether. The seven structural isomers are:

Alcohols (four): butan-1-ol $CH_3CH_2CH_2CH_2OH$; butan-2-ol $CH_3CH(OH)CH_2CH_3$; 2-methylpropan-1-ol $(CH_3)_2CHCH_2OH$; 2-methylpropan-2-ol $(CH_3)_3COH$.

Ethers (three): methoxypropane $CH_3OCH_2CH_2CH_3$; 2-methoxypropane $CH_3OCH(CH_3)_2$; ethoxyethane $CH_3CH_2OCH_2CH_3$.

The four alcohols are position/chain isomers of one another; each ether is a functional-group isomer of the alcohols.

Worked example F – draw the isomers of C_4H_8

C_4H_8 has IHD = 1, so one double bond or one ring. The alkene and cycloalkane isomers are:

but-1-ene $CH_2{=}CHCH_2CH_3$; but-2-ene $CH_3CH{=}CHCH_3$; methylpropene $(CH_3)_2C{=}CH_2$; cyclobutane (a four-membered ring); methylcyclopropane.

But-2-ene additionally exists as **cis** and **trans** stereoisomers (HL), because each double-bond carbon carries an H and a CH_3 – two different groups.

Worked example G – classify and find the chiral centre

For 3-methylbutan-2-ol, $(CH_3)_2CHCH(OH)CH_3$: classify the alcohol and state whether it is chiral.

The –OH is on C2, which is bonded to two carbons (C1 and C3), so it is a **secondary** alcohol.

C2 is bonded to –H, –OH, $–CH_3$ and $–CH(CH_3)_2$ – four different groups – so C2 is a **chiral centre** and the molecule is optically active.

Worked example H – name from a skeletal-style description

A compound has a five-carbon chain with a –COOH group at one end and a methyl branch on the carbon next to the acid carbon. Name it.

The –COOH carbon is always C1. The chain is pentanoic acid; the methyl branch is on C2.

Name: **2-methylpentanoic acid**.

Common pitfalls

- **Lowest locants.** Always number from the end that gives the principal functional group the smallest number, not simply from the left.
- **Miscounting isomers.** Two drawings that give the same IUPAC name are one isomer; rotation and reflection do not create new isomers.
- **Chirality requirement.** A carbon needs four *different* groups to be chiral; a –CH_2– can never be a stereocentre.
- **cis−trans requirement.** Both carbons of the double bond must carry two different groups; check before claiming the isomers exist.
- **Primary/secondary/tertiary.** Count only the carbons directly bonded to the functional carbon, not hydrogens or distant carbons.
- **Alphabetical order.** List substituent prefixes alphabetically (chloro before methyl), ignoring di-/tri- multipliers.

Quick-reference functional-group card

Class	Group	Suffix / prefix	Example
Alkane	C–C	-ane	propane
Alkene	C=C	-ene	propene
Alkyne	C≡C	-yne	propyne
Halogenoalkane	C–X	halo-	2-bromopropane
Alcohol	–OH	-ol	propan-1-ol
Aldehyde	–CHO	-al	propanal
Ketone	C=O (internal)	-one	propanone
Carboxylic acid	–COOH	-oic acid	propanoic acid
Ester	–COO–	-yl -oate	methyl propanoate
Ether	C–O–C	-oxy-	methoxyethane
Amine	$–NH_2$	-amine	propan-1-amine
Amide	$–CONH_2$	-amide	propanamide
Nitrile	–C≡N	-nitrile	propanenitrile

Class	Group	Suffix / prefix	Example
Arene	benzene ring	-benzene / phenyl-	methylbenzene

10. Test yourself

Attempt each question before reading the worked answer beneath it.

Q1. State four features shared by members of the same homologous series.

Q2. Give the empirical, molecular and condensed structural formula of propan-1-ol.

Q3. Name $CH_3CH_2CHClCH_3$.

Q4. Draw and name the two chain isomers of C_4H_{10}.

Q5. Classify each as primary, secondary or tertiary: (a) butan-2-ol, (b) 2-methylpropan-2-ol, (c) 1-bromobutane.

Q6. Explain why the boiling point of pentane is higher than that of 2,2-dimethylpropane, even though they have the same molecular formula.

Q7. Explain why ethanol is fully miscible with water but ethane is insoluble.

Q8. (HL) State the two conditions necessary for cis−trans isomerism, and say whether but-1-ene shows it.

Q9. (HL) Identify the chiral carbon in 2-chlorobutane and explain why the molecule is optically active.

Q10. (HL) Calculate the index of hydrogen deficiency of C_5H_8 and state what structural features are possible.

Worked answers

A1. Same general formula; successive members differ by CH_2; same functional group so similar chemical reactions; a gradual trend in physical properties (e.g. boiling point). (Any four.)

A2. Molecular C_3H_8O; condensed $CH_3CH_2CH_2OH$; empirical C_3H_8O (already simplest, since 3, 8 and 1 share no common factor).

A3. Four-carbon chain → butane; Cl on C2 (numbering from the right gives 2, from the left gives 3, so choose 2). Name: **2-chlorobutane**.

A4. Butane, $CH_3CH_2CH_2CH_3$ (straight chain); and methylpropane, $(CH_3)_3CH$ (branched). Same molecular formula C_4H_{10}, different skeleton → chain isomers.

A5. (a) secondary – the C–OH carbon has two carbon neighbours; (b) tertiary – three carbon neighbours; (c) primary – the C–Br carbon has one carbon neighbour.

A6. Both are held together only by London (dispersion) forces. Pentane is a straight chain with a larger surface area of contact, so its London forces are stronger and more energy is needed to separate the molecules; the branched, compact 2,2-dimethylpropane has weaker forces and a lower boiling point.

A7. Ethanol has an –OH group that forms hydrogen bonds with water, so it mixes in all proportions. Ethane is non-polar, has no group able to hydrogen bond to water, and cannot disrupt water's hydrogen-bonded network, so it is insoluble.

A8. (i) restricted rotation, provided by a C=C double bond (or a ring); (ii) each carbon of the double bond must carry two different groups. But-1-ene, $CH_2{=}CHCH_2CH_3$, has a terminal $=CH_2$ whose carbon bears two identical H atoms, so it shows **no** cis−trans isomerism.

A9. In 2-chlorobutane, $CH_3CHClCH_2CH_3$, C2 is bonded to –H, –Cl, $–CH_3$ and $–CH_2CH_3$ – four different groups. It is therefore a chiral centre; the molecule and its mirror image are non-superimposable enantiomers that rotate plane-polarised light in opposite directions.

A10. IHD = (2×5 + 2 − 8)/2 = 2. Two degrees of unsaturation → possibilities include one triple bond (e.g. pent-1-yne), two double bonds (a diene), or one ring plus one double bond.

End of Structure 3.2 – Functional Groups: Classification of Organic Compounds. Prepared by Fahad H. Ahmad for Megalecture. Continue with Reactivity 3.2 (nucleophilic substitution and elimination) to see how each functional group reacts.