

An introduction to A Level organic chemistry

A2

Read online at pastopic.com/cambridge/chemistry-9701/notes/an-introduction-to-a-level-organic-chemistry

Last checked 1 October 2026

Read first: [An introduction to AS Level organic chemistry](#)

© 2026 Pastopic. Free for personal study. Please share the link, not the file.

What you need to know

This topic adds the A Level families of organic compounds to the ones you met at AS, and three new ideas: benzene's bonding, two new mechanism names, and what optical isomers mean for making medicines. By the end you should be able to:

1. The new families and their names (29.1)

- (a) Recognise the new families: arenes, halogenoarenes, phenols, acyl chlorides, secondary and tertiary amines, primary, secondary and tertiary amides, and amino acids. Know that in each one it is the functional group that sets how the compound behaves, both its physical properties and its reactions.
- (b) Read and draw any of these as a general, structural, displayed or skeletal formula. (Nobody expects you to draw every bond inside a benzene ring.)
- (c) Name non-aromatic molecules with up to six carbons, including a single ring of up to six carbons, using all the functional groups from AS and A Level. Esters and amides can have up to six carbons on each side; esters and nitriles are only asked with unbranched chains.
- (d) Name compounds built on one benzene ring carrying one or more simple groups, numbering the ring carbons.

2. Two more mechanism names (29.2): know what **electrophilic substitution** and **addition-elimination** mean and use the terms correctly.

3. The shape of benzene (29.3): describe and explain why benzene and other aromatic molecules are flat, with 120° angles, in terms of sp^2 carbons, σ bonds and a ring of delocalised π electrons.

4. Optical isomers (29.4)

- (a) Know that the two enantiomers of a compound behave identically in every physical and chemical way except two: the direction in which they turn plane-polarised light, and (possibly) how they act in the body.
- (b) Use the words **optically active** and **racemic mixture** correctly.
- (c) Say what each of the two enantiomers does to plane-polarised light.

- (d) Explain why chirality matters when a drug is made: the two enantiomers may act differently in the body, a racemic mixture then has to be separated into its two pure forms, and a chiral catalyst can be used to make just the one wanted form.
- (e) Accept that a molecule can have several chiral centres. Meso compounds and the word "diastereoisomer" are not needed.

Understand it

The A Level families

At AS you met alkanes, alkenes, halogenoalkanes, alcohols, aldehydes, ketones, carboxylic acids, esters, primary amines and nitriles. A Level adds eight families. As before, the **functional group** decides the chemistry: every phenol reacts like a phenol whatever else is attached, and a molecule with three functional groups can show the reactions of all three.

Family	Functional group	Example
arene	benzene ring	methylbenzene, $\text{C}_6\text{H}_5\text{CH}_3$
halogenoarene	halogen joined directly to a benzene ring	chlorobenzene, $\text{C}_6\text{H}_5\text{Cl}$
phenol	$-\text{OH}$ joined directly to a benzene ring	phenol, $\text{C}_6\text{H}_5\text{OH}$
acyl chloride	$-\text{COCl}$	ethanoyl chloride, CH_3COCl
secondary amine	N joined to two carbons and one H	$(\text{CH}_3)_2\text{NH}$
tertiary amine	N joined to three carbons	$(\text{CH}_3)_3\text{N}$
amide	$-\text{CONH}_2$, $-\text{CONHR}$ or $-\text{CONR}_2$	ethanamide, CH_3CONH_2
amino acid	$-\text{NH}_2$ and $-\text{COOH}$ in one molecule	alanine, $\text{CH}_3\text{CH}(\text{NH}_2)\text{COOH}$

Look carefully at what the group is joined to. An $-\text{OH}$ on a ring carbon is a phenol; an $-\text{OH}$ on a chain carbon (even one next to a ring, as in $\text{C}_6\text{H}_5\text{CH}_2\text{OH}$) is an alcohol. A $-\text{Cl}$ on a ring is a halogenoarene; on a chain it is a halogenoalkane; on a $\text{C}=\text{O}$ it is an acyl chloride.

Amines and amides are both "primary, secondary, tertiary", but counted differently. For an amine, count the carbons joined to the N: one is primary (RNH_2), two secondary (R_2NH), three tertiary (R_3N). For an amide, count the carbons on the N *as well as* the $\text{C}=\text{O}$ carbon: RCONH_2 is primary, RCONHR secondary, RCONR_2 tertiary. An amide N next to a $\text{C}=\text{O}$ is never called an amine: $\text{C}(=\text{O})-\text{N}$ is **amide**; N with only single bonds to carbon and H is **amine**. In the same way, $\text{C}(=\text{O})-\text{O}-\text{C}$ is an **ester**, not an ether plus a ketone, and $-\text{COOH}$ is **carboxylic acid** (write both words).

Formulas with rings

In a skeletal formula every corner and line end is a carbon carrying enough hydrogens to make four bonds. A benzene ring is drawn as a hexagon with either a circle inside or three alternating double lines; either way it is C_6H_5- is a benzene ring with one group on it, C_6H_4 has two groups, and so on.

To get a molecular formula from a big skeletal formula, count in a fixed order: carbons first (corners, ends, ring carbons, and the carbons inside written groups such as CH_3 or $COOH$), then hydrogens carbon by carbon, then every other atom. A quick check: a compound of C, H and O with no rings or double bonds has $2n + 2$ hydrogens for n carbons, and **each ring or double bond removes 2** (a benzene ring removes 8: one ring plus three double bonds). Each N adds 1 hydrogen to this count and each halogen atom takes the place of one H.

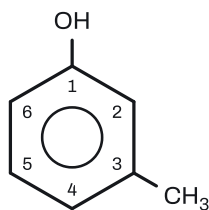
Naming

Non-aromatic compounds follow the AS rules (longest chain holding the main group, lowest numbers, prefixes in alphabetical order), with these additions:

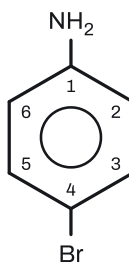
- **Rings:** add cyclo- to the stem and number from the carbon with the main group: cyclohexanol, 2-methylcyclohexan-1-ol.
- **Acyl chlorides:** stem + -oyl chloride, counting the $C=O$ carbon: CH_3CH_2COCl has three carbons.
- **Amides:** stem + -amide, counting the $C=O$ carbon. Groups on the nitrogen are shown with N-: $CH_3CH_2CONHCH_3$ is **N-methylpropanamide** (secondary) and $CH_3CH_2CON(CH_3)_2$ is **N,N-dimethylpropanamide** (tertiary).
- **Amino acids:** amino- as a prefix on the acid, as in 2-aminopropanoic acid. You will not be asked to name secondary or tertiary amines.

Benzene compounds. A single group gives names such as chlorobenzene, nitrobenzene, methylbenzene, phenol, phenylamine ($C_6H_5NH_2$) and benzoic acid (C_6H_5COOH). With more than one group, number the ring carbons 1 to 6:

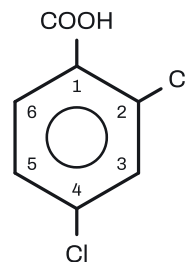
1. The group that gives the parent name (the $-OH$ of a phenol, the $-NH_2$ of phenylamine, the $-COOH$ of benzoic acid) is on carbon 1.
2. Go round the ring in the direction that gives the other groups the lowest numbers.
3. Put the prefixes in alphabetical order, with di- or tri- for repeats.



3-methylphenol



4-bromophenylamine



2,4-dichlorobenzoic acid

If a ring has only substituents such as CH_3 , Cl or NO_2 (no parent group), give them the lowest set of numbers: 1,3-dimethylbenzene.

Two mechanism names

Both describe what the attacking species is and what happens overall.

- **Electrophilic substitution** is the typical reaction of a benzene ring. An electrophile (an electron-pair acceptor, such as NO_2^+ , Cl^+ or CH_3^+ , usually made with the help of a catalyst such as AlCl_3) is attracted to the ring's π electrons. It joins the ring and an H^+ leaves, so one H on the ring is **substituted**. For example, benzene + Br_2 with an FeBr_3 catalyst gives bromobenzene + HBr . The ring does not keep the electrophile by addition, because that would destroy the stable delocalised π system; losing H^+ restores it.
- **Addition-elimination** is the typical reaction of an acyl chloride with a nucleophile such as water, an alcohol, ammonia or an amine. The nucleophile first **adds** to the δ^+ carbon of the $\text{C}=\text{O}$, then HCl is **eliminated** and the $\text{C}=\text{O}$ re-forms. For example, ethanoyl chloride + ethanol gives ethyl ethanoate + HCl . Because a small molecule (HCl) is lost when two molecules join, mark schemes also accept **condensation** for this.

The details of each mechanism (curly arrows, intermediates) belong to the topics on arenes and acyl chlorides. Here you need the names, and to pick the right one for a given step.

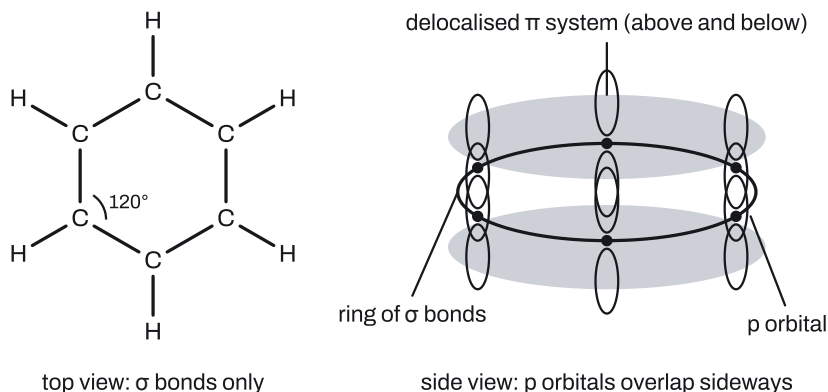
Other types you already know still turn up in these questions: **hydrolysis** (a bond split by water, as in esters and amides heated with acid or alkali), **acid-base** (for example $-\text{COOH}$ or a phenol reacting with OH^- , or an amine with H^+), **reduction**, **oxidation**, **nucleophilic substitution**.

The shape of benzene

Benzene, C_6H_6 , is a flat regular hexagon. Every carbon is joined to three atoms (two carbons and one hydrogen), so it uses **sp^2 hybridisation**: three sp^2 orbitals in one plane at 120° to each other, and one p orbital left over, at right angles to that plane.

- The sp^2 orbitals overlap **head-on (end-on)** with those of the two neighbouring carbons and with the 1s orbital of the hydrogen, forming **σ bonds**. That makes a flat ring of 12 σ bonds (6 C–C and 6 C–H), all angles 120° .

- The six leftover p orbitals, one on each carbon, stand up and down from the ring. Each overlaps **sideways** with the p orbitals on **both** of its neighbours, so the overlap runs all the way round. The six electrons in them form a **delocalised π system**: two rings of electron density, one above and one below the plane of the carbon atoms.

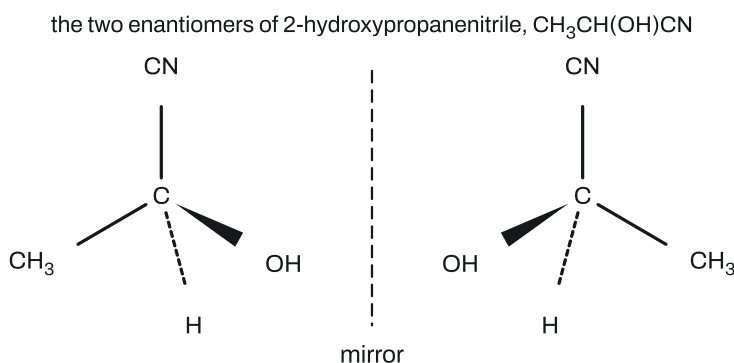


Because the π electrons are shared by all six carbons, the six C–C bonds are **all the same length**, between a single and a double bond. The p orbitals can only overlap if they are parallel, which forces all six carbons (and the atoms joined directly to them) into one plane.

Other aromatic molecules have the same flat ring: in phenol, methylbenzene or chlorobenzene the ring carbons are still sp^2 , the ring is still planar with 120° angles, and the first atom of each group sits in the plane of the ring. A carbon in a side chain with four single bonds is sp^3 as usual (109.5°).

Optical isomers and plane-polarised light

From AS: a **chiral centre** is a carbon joined to four different atoms or groups, and a molecule with one chiral centre exists as two **enantiomers**, non-superimposable mirror images of each other.

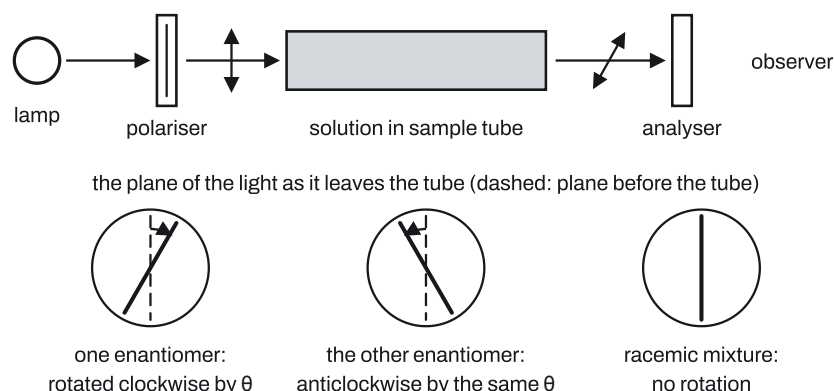


Drawing them in 3D. Put the chiral carbon in the middle, two bonds as plain lines (in the page), one as a solid wedge (towards you) and one as a dashed line (away from you), with the four groups spread out like a tetrahedron. Then draw its reflection: same groups, mirrored left to right. Swapping any two groups on one drawing also gives the other enantiomer.

What is the same and what is different? The two enantiomers have the same bonds and the same bond strengths, so they have **identical physical properties** (melting point, boiling point, density, solubility) and **identical chemical reactions** with ordinary reagents. They differ in only two ways:

1. **their effect on plane-polarised light**, and
2. **their biological activity**, because receptors and enzymes in the body are themselves chiral and fit one enantiomer better than the other, much as a right hand fits a right glove.

Ordinary light vibrates in every plane. A polariser lets through only light vibrating in **one plane**: **plane-polarised light**. A substance is **optically active** if it **rotates the plane** of plane-polarised light as the light passes through it.



- Each enantiomer on its own is optically active.
- The two enantiomers (at the same concentration, in the same tube) rotate the plane **by the same angle** but **in opposite directions**: if one turns it 12° clockwise, the other turns it 12° anticlockwise.
- A **racemic mixture** contains **equal amounts** of the two enantiomers. Their rotations cancel, so it is **not** optically active. A chiral compound made in the laboratory from reagents that are not chiral is formed as a racemic mixture, because the new chiral centre is equally likely to form either way round.

Several chiral centres. Each chiral centre can be arranged two ways, so a molecule with n chiral centres has up to 2^n stereoisomers: two centres give $2 \times 2 = 4$, three give $2 \times 2 \times 2 = 8$. Multiply; don't add. Rings count too: in 2-methylcyclohexan-1-ol both carbon 1 (with the OH) and carbon 2 (with the methyl) are chiral, because going round the ring from each one in the two directions gives different paths; in cyclohexanol no carbon is chiral, because the two paths round the ring are identical.

Chirality and medicines

Many drugs are chiral, and often only one enantiomer has the wanted effect. The other may do nothing, do something different, or cause harmful side effects. This affects how drugs are made:

- **The other enantiomer's activity.** Selling a racemic mixture means half of each dose is at best useless and at worst harmful. A single enantiomer gives a **smaller dose** for the same effect (the drug is more potent) and **fewer side effects**.

- **Separating a racemic mixture.** A normal synthesis gives a racemic mixture. Splitting it into the two pure enantiomers is difficult and costly, and at least half the product (the wrong enantiomer) is wasted, so the **yield** of the useful drug is lower.
- **Chiral catalysts.** A catalyst that is itself chiral (a single enantiomer) can make the reaction form mostly or only one enantiomer. **Enzymes** are natural chiral catalysts and can be used the same way. This avoids the separation step and the waste, so more of the starting material ends up as the active drug. Chiral catalysts can themselves be expensive to make.

Key facts and formulas

"Given" means it is printed on the Periodic Table in the exam paper. "Learn it" means you must remember it; the Data Booklet has no organic names, shapes or definitions.

Formula	Status
Relative atomic masses: H 1.0, C 12.0, N 14.0, O 16.0, Cl 35.5, Br 79.9	Given
Benzene C_6H_6 : planar hexagon, C–C–C and C–C–H angles 120° , every carbon sp^2	Learn it
σ bond: head-on overlap of orbitals; π bond: sideways overlap of p orbitals; benzene's π electrons are delocalised above and below the ring	Learn it
Electrophilic substitution: electrophile replaces an H on a benzene ring; addition–elimination: nucleophile adds to C=O of an acyl chloride, then HCl is lost	Learn it
Amine: 1° , 2° , 3° = 1, 2, 3 carbons on N; amide: $RCONH_2$ 1° , $RCONHR'$ 2° , $RCONR'_2$ 3°	Learn it
Stereoisomers from n chiral centres = 2^n	Learn it
H count: $2n + 2$ for n carbons, minus 2 for each ring or double bond (benzene ring: minus 8), plus 1 for each N, minus 1 for each halogen	Learn it
Optically active: rotates the plane of plane-polarised light. Enantiomers: same angle, opposite directions. Racemic mixture: equal amounts of both, no rotation	Learn it

How to do it

In the Paper 4 questions we have tagged for this topic (26 questions, 2021–2025; 20 different questions, 6 of them repeated in another variant), the types came up this often. 16 of the 26 questions mix more than one type, so the counts add up to more than 26. Most are parts of a longer question about a drug or natural product.

Question type	Questions
Identify and count chiral centres	10

Question type	Questions
Define and describe optical activity, enantiomers and racemic mixtures	10
Name the functional groups in a complex molecule	8
Draw 3D diagrams of stereoisomers	7
Classify a reaction or mechanism type	7
Explain why and how a drug is made as a single optical isomer	6
Describe the shape and bonding of benzene	3
Deduce a molecular formula from a skeletal formula	3
Name an aromatic compound	2

1. Identify and count chiral centres (10 questions)

Usually a large skeletal formula, often with rings; you mark each chiral carbon with an asterisk (or circle it), or state how many there are. The mark needs every one and no extras.

1. **Cross out every carbon that cannot be chiral:** CH_3 and CH_2 carbons, every benzene ring carbon, and any carbon in a $\text{C}=\text{C}$, $\text{C}=\text{O}$ or $\text{C}\equiv\text{N}$.
2. **For each carbon left** (a CH , or a carbon with four non-H groups), write its four groups, remembering the H that the skeletal formula hides.
3. **Compare the groups by following each one outwards** until they differ. In a ring, go round both ways from the carbon; if the two paths are identical all the way, the carbon is not chiral.
4. Mark or count. If asked for the number of optical isomers (stereoisomers), use 2^n .

Variations you will meet:

- **Number of optical isomers from the number of centres:** three chiral centres give $2^3 = 8$, not $2 \times 3 = 6$.
- **Two molecules to compare:** count separately and give both numbers (zero is a possible answer).
- **Carbons next to rings or heteroatoms:** a CH joined to a ring, an N and a chain is often chiral. Check carbons carrying OH , NH_2 , NH or a ring branch first; these are where drug chiral centres usually are.

2. Define and describe optical activity, enantiomers and racemic mixtures (10 questions)

Short answers, one to three marks, where the exact idea matters.

- **Optically active:** able to rotate the plane of plane-polarised light. (Mention "plane" and "polarised".)
- **Enantiomers:** a pair of molecules that are non-superimposable mirror images; or, what they do: rotate the plane of plane-polarised light by the same angle in opposite directions.
- **Racemic mixture:** a mixture of **equal amounts** of the two enantiomers.

- **"Describe similarities and a difference" for the two enantiomers in polarised light:** similarities: both rotate the plane of the light, and by the same angle; difference: in opposite directions. If one is given as, say, x° clockwise, the other is x° anticlockwise at the same concentration.
- **"Which property, other than the effect on light, differs?":** biological activity (how they act in the body).
- **"Give another term for this pair":** enantiomers (they are also optical isomers, stereoisomers and non-superimposable mirror images).

3. Name the functional groups in a complex molecule (8 questions)

Usually "any two for one mark, all four for two marks".

1. **Go round the molecule atom by atom**, looking at every O, N and halogen and at every C=C and ring.
2. **Name each group by what it is joined to:** C(=O)–O–C ester; C(=O)–OH carboxylic acid; C(=O)–N amide; N with only single bonds to C or H amine; C=O between two carbons ketone; C=O with an H aldehyde; C≡N nitrile; –OH on a chain carbon alcohol; –OH on a ring carbon phenol; C=C alkene; halogen on a ring halogenoarene.
3. **Leave out** any group the question says it has already given (often "arene").

Variations you will meet:

- **Which groups react with a reagent, and what they become.** Use the reactions from the other A Level topics; for example LiAlH_4 reduces a carboxylic acid to a primary alcohol and an amide to an amine, but leaves a benzene ring alone.
- **A simple molecule** such as $\text{CH}_2=\text{CHCH}(\text{NH}_2)\text{COOH}$: alkene, amine, carboxylic acid.

4. Draw 3D diagrams of stereoisomers (7 questions)

1. **Find the chiral carbon** first. If you are given a list of isomers and told only one has stereoisomers, test each for a carbon with four different groups; the one with a chiral centre is the answer.
2. **Draw one enantiomer:** the chiral C in the middle, two plain bonds, one wedge, one dashed bond, the four groups written out in full (no skeletal shorthand at the chiral carbon).
3. **Draw its mirror image** next to it, reflecting left to right. Check that the two drawings really differ; examiners see two identical drawings every year.
4. If asked, name the type: **optical** isomerism.

Variations you will meet:

- **"Complete the diagrams of the other stereoisomers"** of a molecule with two chiral centres: each drawing must differ from the others, and you should draw exactly as many as the question says exist.
- **Octahedral complexes** with bidentate ligands also show optical isomerism: see the chemistry of transition elements note.

5. Classify a reaction or mechanism type (7 questions)

1. **Compare the reactant and product:** what was lost, what was gained, what joined?

2. **Match:**

- an H on a benzene ring replaced, using a catalyst such as $\text{AlCl}_3 \rightarrow$ **electrophilic substitution**;
- acyl chloride + water, alcohol, ammonia or amine, HCl lost $\rightarrow$ **addition-elimination** (or condensation);
- an ester or amide split by heating with water, acid or alkali $\rightarrow$ **hydrolysis**;
- an acid group turned into its ion by OH^- , or an amine into its ion by H^+ $\rightarrow$ **acid-base** (neutralisation).

3. Give the exact term. "Substitution" alone, or a description in place of the name, usually gets nothing.

Variation: "State the two types of reaction when X is heated with NaOH(aq) ": if X has an ester or amide, the answer is **hydrolysis** and **acid-base** (the carboxylic acid formed, and any $-\text{COOH}$ or phenol $-\text{OH}$ already present, reacts with the alkali to form its salt).

6. Explain why and how a drug is made as a single optical isomer (6 questions)

Mark schemes accept any of these; learn at least four, because a question may rule out the two most common ones.

Reasons to make one enantiomer:

- the other enantiomer is less active, differently active or inactive;
- the other enantiomer may cause harmful side effects;
- a smaller dose is needed (the drug is more potent);
- there is no need to separate the enantiomers afterwards;
- a higher yield of the active compound from the starting materials.

Disadvantages of making a racemic mixture: the enantiomers must be separated; the yield of the active drug is lower; the unwanted half is wasted. **Disadvantage of a single-isomer route:** it needs a chiral catalyst or enzyme, which can be expensive.

How to make just one: use a **chiral catalyst**, or an **enzyme**.

Answer with a specific reason. "Better", "safer", "cheaper" or "higher yield" with nothing more are too vague to score: say *what* is better and *why* (for example, "the other enantiomer may have harmful side effects").

7. Describe the shape and bonding of benzene (3 questions)

Three marks, from points like these; write them all:

1. Planar hexagonal ring; C–C–C (and C–C–H) bond angle **120°** .
2. Each carbon is sp^2 hybridised.
3. **σ bonds:** sp^2 orbitals overlap **head-on** (end-on) between carbons, and with H 1s orbitals.

4. **π bonds**: the remaining **p orbital** on each carbon overlaps **sideways** with those on both neighbours, above and below the ring.
5. This gives a **delocalised π system** of six electrons over all six carbons.

A labelled sketch helps only if you label the p orbitals and the π system; an unlabelled drawing earns nothing extra.

8. Deduce a molecular formula from a skeletal formula (3 questions)

1. **Count C**: every corner, line end and ring carbon, plus carbons inside written groups (CH_3 , COOH , OCH_3).
2. **Count H** carbon by carbon (a ring carbon with a substituent has no H), then add H on O and N.
3. **Count the other atoms** and write them in the order the question uses (often C, H, then the rest).
4. **Check the H number** with the rule: $2n + 2$, minus 2 per ring or double bond, plus 1 per N, minus 1 per halogen.

Variations you will meet:

- **After a reaction**: redraw the product, then count. Reducing each $\text{C}=\text{O}$ to $\text{CH}-\text{OH}$ (with NaBH_4) adds 2 H per $\text{C}=\text{O}$, and leaves $\text{C}=\text{C}$ alone; for example pentane-2,4-dione, $\text{C}_5\text{H}_8\text{O}_2$, becomes pentane-2,4-diol, $\text{C}_5\text{H}_{12}\text{O}_2$. Hydrolysing an ester gives the acid and the alcohol, so count the part the question asks for.
- **A part-filled formula** (some numbers already given): fill in the rest; the given numbers are a check on your counting.

9. Name an aromatic compound (2 questions)

Usually one mark for the systematic name of a benzene compound drawn as a skeletal formula, often an isomer of another compound in the question.

1. **Find the parent**: $-\text{OH}$ on the ring $\rightarrow$ phenol; $-\text{NH}_2$ on the ring $\rightarrow$ phenylamine; $-\text{COOH}$ on the ring $\rightarrow$ benzoic acid. With only groups such as CH_3 , Cl , Br or NO_2 , the parent is benzene.
2. **Number the ring**: the parent group's carbon is 1; go round the way that gives the other groups the lowest numbers.
3. **Write the prefixes** in alphabetical order with their numbers, using di- or tri- for repeats (the multiplier doesn't count for the alphabetical order), then the parent: 2,6-dimethylphenol; 4-chloro-3-methylphenylamine.
4. **Check** that the name gives back the same structure: draw it from your name.

For example, a phenylamine with methyl groups on the two carbons next to the NH_2 is 2,6-dimethylphenylamine, not 1,3-dimethyl-2-aminobenzene. With no parent group, give the lowest set of numbers: 1-methyl-4-nitrobenzene.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **B1** mark for a correct result on its own, with no method needed.
-

Example 1

When hydrogen bromide adds to but-1-ene, $\text{CH}_2=\text{CHCH}_2\text{CH}_3$, the main product is 2-bromobutane, $\text{CH}_3\text{CHBrCH}_2\text{CH}_3$.

(a) 2-bromobutane is chiral, but its isomer 2-bromo-2-methylpropane, $(\text{CH}_3)_3\text{CBr}$, is not. Explain this difference. **[2]**

(b) Draw three-dimensional diagrams of the two enantiomers of 2-bromobutane. **[2]**

(c) State two properties in which the two enantiomers are the same, and the two properties in which they can differ. **[2]**

(d) The 2-bromobutane made from but-1-ene has no effect on plane-polarised light. Explain why. **[2]**

(a) In 2-bromobutane, carbon 2 is joined to four different groups: H, Br, CH_3 and C_2H_5 , so it is a chiral centre.

B1 In 2-bromo-2-methylpropane the carbon carrying Br is joined to three identical CH_3 groups, and every other carbon is a CH_3 , so there is no chiral centre. **B1**

(b) Chiral carbon in the middle with, for example, Br and CH_3 as plain lines, C_2H_5 on a wedge and H on a dashed bond; the second drawing is its reflection, as in the 2-hydroxypropanenitrile figure. **B1** for one correct 3D drawing, **B1** for a second that is its mirror image and not the same molecule.

(c) Same: any two physical or chemical properties, such as boiling point and the rate of reaction with aqueous hydroxide ions (or melting point, density, solubility). **B1** Differ: the direction in which they rotate plane-polarised light, and their biological activity. **B1**

(d) H^+ adds first, giving the intermediate carbocation $\text{CH}_3\overset{+}{\text{C}}\text{HCH}_2\text{CH}_3$, which is planar (trigonal planar) at carbon 2, so Br^- is equally likely to attack it from either side: the new chiral centre forms either way round equally often, giving a **racemic mixture**, equal amounts of the two enantiomers. **B1** They rotate the plane of polarised light by the same angle in opposite directions, so the rotations cancel. **B1**

Example 2

Methylbenzene, $\text{C}_6\text{H}_5\text{CH}_3$, is nitrated with a mixture of concentrated nitric and sulfuric acids. One product is 1-methyl-4-nitrobenzene.

(a) State the hybridisation of a ring carbon in methylbenzene and of the carbon in the CH_3 group, and the bond angles around each. [2]

(b) With the help of a labelled sketch, explain why the six ring carbons and the carbon of the CH_3 group all lie in one plane, and why all six C–C bonds in the ring are the same length. [3]

(c) Name the type of reaction (mechanism) in each of these:

(i) the nitration of methylbenzene: $\text{C}_6\text{H}_5\text{CH}_3 + \text{HNO}_3 \rightarrow \text{CH}_3\text{C}_6\text{H}_4\text{NO}_2 + \text{H}_2\text{O}$ [1]

(ii) $\text{CH}_3\text{CH}_2\text{COCl} + \text{CH}_3\text{NH}_2 \rightarrow \text{CH}_3\text{CH}_2\text{CONHCH}_3 + \text{HCl}$ [1]

(d) Name the organic product of (c)(ii) and state whether it is a primary, secondary or tertiary amide. [2]

(a) Ring carbon: sp^2 , bond angles 120° . **B1** CH_3 carbon: sp^3 , bond angles 109.5° (it has four single bonds).

B1

(b) Sketch: a hexagon of carbons with a p orbital drawn up and down from each ring carbon, the lobes overlapping sideways, labelled "p orbital" and "delocalised π system" above and below the ring. **B1** The p orbitals can only overlap sideways if they are parallel, so all six ring carbons must be in one plane; the sp^2 orbital each ring carbon uses for its σ bond to the next atom is in that plane too, so the CH_3 carbon lies in the plane. **B1** The six π electrons are delocalised evenly over all six carbons, so every ring C–C bond is the same, between a single and a double bond. **B1**

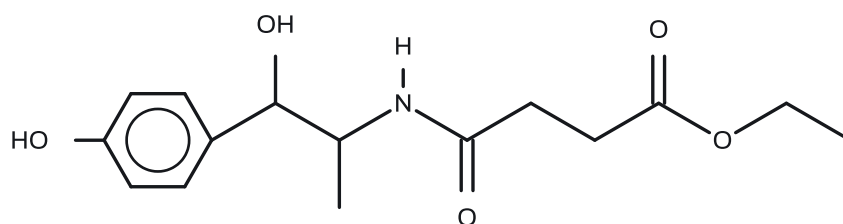
(c)(i) An H on the ring is replaced by NO_2 , attacked by the electrophile NO_2^+ made by the acid mixture: **electrophilic substitution**. **B1**

(ii) An acyl chloride reacting with a nucleophile (the amine) with loss of HCl : **addition–elimination** (condensation is also accepted). **B1**

(d) Three carbons including the $\text{C}=\text{O}$ carbon: propanamide, with a methyl group on the N: **N-methylpropanamide**. **B1** The N carries one carbon besides the $\text{C}=\text{O}$ carbon (and one H), so it is a **secondary amide**. **B1**

Example 3

Compound K is a possible new drug.



compound K

- (a) Apart from its benzene ring, K has four functional groups, each containing oxygen or nitrogen. Identify them, saying which atoms of K make up each one. **[2]**
- (b) State the number of chiral centres in K and the number of stereoisomers of K. **[2]**
- (c) Give the molecular formula of K. **[1]**
- (d) K is boiled under reflux with an excess of NaOH(aq). Say which links in K are broken, and what happens to the acidic –OH groups. Give the name for each kind of change. **[2]**
- (e) Only one stereoisomer of K is active. Give two reasons why the drug company would make only this stereoisomer, and state how it could be made. **[3]**
- (a)** Phenol (the OH joined to the ring), alcohol (the OH on the chain carbon), amide (the C(=O)–NH), ester (the C(=O)–O–C near the end). **B2** for all four, **B1** for any two.
- (b)** Going along the chain: the CH(OH) carbon is joined to H, OH, the ring and the rest of the chain, so it is chiral; the CH(CH₃) carbon is joined to H, CH₃, NH and CH(OH), so it is chiral too. No other carbon qualifies (CH₂, CH₃, ring and C=O carbons can't be chiral). **Two** chiral centres. **B1** Stereoisomers: $2^2 = 4$. **B1**
- (c)** Carbons: ring 6, CH(OH) 1, CH(CH₃) 2, C=O 1, CH₂CH₂ 2, ester C=O 1, ethyl 2: 15. Hydrogens: ring 4, phenol OH 1, CH(OH) 2, CH(CH₃) 4, NH 1, CH₂CH₂ 4, ethyl 5: 21. One N and five O. C₁₅H₂₁NO₅. **B1** (Check: $2(15) + 2 = 32$; minus 8 for the benzene ring and 4 for the two C=O leaves 20; plus 1 for the N gives 21.)
- (d)** The ester and amide links are split by water and hydroxide ions: **hydrolysis**. **B1** The carboxylic acid groups this forms, and the phenol –OH, lose H⁺ to the hydroxide ions and become ions: **acid–base** (neutralisation). **B1**
- (e)** Any two reasons for **B1 B1**: the other stereoisomers may cause harmful side effects; a smaller dose is needed; no need to separate the stereoisomers; less starting material is wasted, so a higher yield of the active compound. How: use a **chiral catalyst** (or an enzyme) in the synthesis. **B1**

Common mistakes

- **Incomplete definition of enantiomers.** "Non-superimposable molecules" is not enough: they are non-superimposable **mirror images**. Examiners report this every time the definition is asked.
- **Leaving "plane" or "polarised" out.** Optically active means it rotates the **plane** of **plane-polarised** light. Answers that just say "rotates light" or "reacts with light" miss the mark.
- **Racemic mixture without "equal".** A racemic mixture has **equal amounts** of both enantiomers; "a mixture of the two isomers" is not enough.
- **Vague drug reasons.** "Higher yield" or "cheaper" with nothing else gains no credit. Say what the other enantiomer does (inactive, harmful side effects) or name a specific consequence (lower dose, no separation needed).
- **Not knowing how to make one enantiomer.** The answer examiners want is a **chiral catalyst** or an **enzyme**; many candidates leave it blank.

- **Adding instead of multiplying.** Three chiral centres give $2^3 = 8$ stereoisomers, not 6.
- **Missing chiral centres in rings, or at carbons joined to N.** Test every CH, including ring carbons, by going round the ring both ways.
- **Wrong group names.** Amide confused with amine, ketone written for the C=O of an ester or acid, "carboxylic" without "acid", alcohol written for a phenol (or the reverse). Name what the group is joined to.
- **Benzene answers with the angle and the π bonds but no σ bonds.** The mark schemes want both: σ from **head-on** overlap of sp^2 orbitals, π from **sideways** overlap of p orbitals. Also don't forget to say the ring is **planar**, and the carbons are sp^2 (not sp^3).
- **Molecular formula mistakes:** forgetting the hidden H on ring carbons, counting H on a substituted ring carbon, or giving a structural formula when a molecular formula is asked for.
- **Calling an addition–elimination "electrophilic substitution"** (or the reverse). Electrophilic substitution happens to a benzene ring; addition–elimination happens at the C=O of an acyl chloride.

How to get the marks

- **"State" or "name the type"** needs the term itself: electrophilic substitution, addition–elimination, hydrolysis, acid–base, racemic, enantiomers, optical.
- **"Define"** needs the standard idea in full: mirror images **and** non-superimposable; **equal** amounts; rotates the **plane** of plane-polarised light.
- **"Describe"** the effect on polarised light: say what each enantiomer does (rotates the plane), by how much (the same angle), and which way (opposite directions).
- **"Explain" or "describe and explain" the shape of benzene** is usually three marks for three separate points; write at least four in short bullet points so none is missed.
- **"Identify all" / "circle all" chiral carbons:** one mark needs every chiral carbon marked and none extra, so check each CH before you finish.
- **"Name all the functional groups":** often any two for one mark, all four for two. Write every one you find, with full names (carboxylic acid, not "carboxyl" or "acid" alone, although "carboxyl" is sometimes allowed), and leave out any group the question has already given.
- **"Suggest" a reason** for making one enantiomer: any sensible specific reason is credited. Give a different reason for each mark, and don't repeat a reason the question has ruled out.
- **"Draw three-dimensional diagrams":** wedge and dashed bonds at the chiral carbon, all four groups written out, two drawings that are mirror images. Each correct drawing is usually a mark on its own.
- **Molecular formulas** must be exactly right, with every atom; one wrong H loses the mark.

Quick check

1. Give the systematic names of (a) $\text{CH}_3\text{CH}_2\text{CH}_2\text{COCl}$ and (b) $\text{CH}_3\text{CONHCH}_2\text{CH}_3$, and classify (b) as a primary, secondary or tertiary amide.
2. (a) Give the molecular formula of 2,4-dinitrophenol. (b) Give the molecular formula of ethyl 4-aminobenzoate, $\text{H}_2\text{NC}_6\text{H}_4\text{COOCH}_2\text{CH}_3$, and calculate its M_r . (c) Name its three functional groups.

3. State the number of chiral centres in (a) 3-methylcyclohexan-1-ol, (b) 4-methylcyclohexan-1-ol and (c) pentane-2,3-diol, $\text{CH}_3\text{CH}(\text{OH})\text{CH}(\text{OH})\text{CH}_2\text{CH}_3$. How many stereoisomers does (c) have?
4. Name the type of reaction: (a) $\text{CH}_3\text{COCl} + \text{CH}_3\text{OH} \rightarrow \text{CH}_3\text{COOCH}_3 + \text{HCl}$; (b) $\text{C}_6\text{H}_6 + \text{CH}_3\text{CH}_2\text{Cl} \rightarrow \text{C}_6\text{H}_5\text{CH}_2\text{CH}_3 + \text{HCl}$, with an AlCl_3 catalyst; (c) methyl propanoate heated with dilute sulfuric acid, forming propanoic acid and methanol.
5. One enantiomer of a painkiller relieves pain; the other has no effect on pain but can damage the liver. (a) Give two disadvantages of selling the drug as a racemic mixture. (b) Explain how a chiral catalyst helps.

Answers

- (a) Four carbons including the C=O carbon: **butanoyl chloride**. (b) Two carbons in the acyl part and an ethyl group on the N: **N-ethylethanamide**. The N carries one carbon besides the C=O carbon, so it is a **secondary** amide.
- (a) A benzene ring with OH on carbon 1 and NO₂ groups on carbons 2 and 4: three ring carbons still carry H, plus the H of the OH, so C₆H₄N₂O₅. (b) C: 6 + 1 + 2 = 9; H: 2 + 4 + 5 = 11; so C₉H₁₁NO₂. $M_r = 9(12.0) + 11(1.0) + 14.0 + 2(16.0) = 165.0$. (c) Amine (a primary amine, NH₂ on the ring), ester, and arene.
- (a) **2**: carbon 1 (H, OH, and two different ring paths) and carbon 3 (H, CH₃ and two different ring paths). (b) **0**: carbons 1 and 4 each have two identical paths round the ring. (c) **2** (carbons 2 and 3), so $2^2 = 4$ stereoisomers.
- (a) **Addition–elimination** (or condensation). (b) **Electrophilic substitution**. (c) **Hydrolysis**.
- (a) Any two: half of each dose does nothing for the pain, so a larger dose is needed; the other enantiomer may damage the liver (a harmful side effect); separating the enantiomers afterwards is costly and wastes half the product. (b) A chiral catalyst (or an enzyme) is itself a single enantiomer, so it makes the reaction form (almost) only one enantiomer of the product: no separation step, less waste, and a higher yield of the active drug.

Past questions to try

- 9701/42/O/N/25 Q8**: part (g), the effect of two enantiomers on plane-polarised light and the name for an equal mixture.
- 9701/42/M/J/23 Q6**: counting chiral centres in a drug, a benefit and a drawback of one pure optical isomer, and naming four functional groups.
- 9701/42/F/M/22 Q4**: part (a), functional groups and chiral centres in two molecules, and (c) a molecular formula and two reaction types.
- 9701/43/M/J/23 Q4**: part (a) the bonding in benzene, and (c) naming an aromatic amine.