# 8 Introduction to Organic Chemistry

## Types of formulae

1. For each of the following organic compounds:
   
   i. Write the molecular formula.
   
   ii. Draw out the displayed formulae for all the compounds.
   
   iii. Draw out the skeletal formulae for compounds A and E.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Molecular formula</th>
<th>Displayed formula</th>
<th>Skeletal formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>A ( \text{CH}_2\text{CHCN} )</td>
<td>( \text{C}_3\text{H}_3\text{N} )</td>
<td><img src="image" alt="Displayed formula for A" /></td>
<td><img src="image" alt="Skeletal formula for A" /></td>
</tr>
<tr>
<td>B ( \text{CH}_2=\text{CH} )</td>
<td>( \text{C}_4\text{H}_6 )</td>
<td><img src="image" alt="Displayed formula for B" /></td>
<td></td>
</tr>
<tr>
<td>C ( \text{C}_8\text{H}_8 )</td>
<td></td>
<td><img src="image" alt="Displayed formula for C" /></td>
<td><img src="image" alt="Skeletal formula for C" /></td>
</tr>
</tbody>
</table>

Trivia: A, B, and C are constituents in making ABS, a plastic found in many products, including LEGO® bricks.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Molecular formula</th>
<th>Displayed formula</th>
<th>Skeletal formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>D ( \text{CH}_2\text{OH} )</td>
<td>( \text{C}_8\text{H}_8\text{O}_2 )</td>
<td><img src="image" alt="Displayed formula for D" /></td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Compound</th>
<th>Molecular formula</th>
<th>Displayed formula</th>
<th>Skeletal formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>$\text{C}<em>{11}\text{H}</em>{12}\text{N}<em>{2}\text{O}</em>{5}\text{Cl}_2$</td>
<td><img src="image1" alt="Displayed formula" /></td>
<td><img src="image2" alt="Skeletal formula" /></td>
</tr>
<tr>
<td>F</td>
<td>$\text{C}<em>{18}\text{H}</em>{22}\text{O}_2$</td>
<td><img src="image3" alt="Displayed formula" /></td>
<td><img src="image4" alt="Skeletal formula" /></td>
</tr>
</tbody>
</table>
Types and mechanisms of organic reactions

2 Identify the types of reaction below:

(a) \[ \begin{array}{c}
\text{C} \equiv \text{C} \\
\text{H} \quad \text{H} \quad \text{H} \\
\text{H} \quad \text{H} \\
\end{array} \ + \begin{array}{c}
\text{H} \\
\text{H} \\
\end{array} \rightarrow \begin{array}{c}
\text{H} \\
\text{C} \quad \text{C} \\
\text{H} \quad \text{H} \\
\text{H} \quad \text{H} \\
\end{array} \]

(b) \[ \begin{array}{c}
\text{H} \quad \text{H} \\
\text{C} \quad \text{Cl} \\
\text{H} \quad \text{H} \\
\end{array} \rightarrow \begin{array}{c}
\text{C} \quad \text{H} \\
\text{H} \quad \text{Cl} \\
\end{array} \]

(c) \[ \begin{array}{c}
\text{C} \equiv \text{O} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array} + \begin{array}{c}
\text{N} \quad \text{N} \\
\text{O} \quad \text{N} \\
\text{O} \\
\text{O} \\
\end{array} \rightarrow \begin{array}{c}
\text{C} \equiv \text{N} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array} + \begin{array}{c}
\text{N} \quad \text{N} \\
\text{O} \quad \text{N} \\
\text{O} \\
\text{O} \\
\end{array}
\]

(d) \[ \begin{array}{c}
\text{H} \\
\text{C} \quad \text{O} \\
\text{H} \\
\text{H} \\
\end{array} + \begin{array}{c}
\text{H} \quad \text{O} \quad \text{H} \\
\text{H} \quad \text{O} \quad \text{H} \\
\text{H} \quad \text{O} \quad \text{H} \\
\text{H} \quad \text{O} \quad \text{H} \\
\end{array} \rightarrow \begin{array}{c}
\text{H} \\
\text{C} \quad \text{O} \\
\text{H} \\
\text{H} \\
\end{array} + \begin{array}{c}
\text{H} \quad \text{O} \quad \text{H} \\
\text{H} \quad \text{O} \quad \text{H} \\
\text{H} \quad \text{O} \quad \text{H} \\
\text{H} \quad \text{O} \quad \text{H} \\
\end{array}
\]

2 (a) Addition
(b) Elimination
(c) Condensation
(d) Hydrolysis

3 Draw the products of the following reactions, according to the mechanisms shown. Identify the electrophile, nucleophile, radical, carbocation, carbanion where applicable.

(a) \[ \begin{array}{c}
\text{H} \\
\text{C} \equiv \text{N} \\
\end{array} \rightarrow \begin{array}{c}
\text{H} \\
\text{C} \quad \text{N} \\
\end{array} \]

(b) \[ \begin{array}{c}
\text{H} \\
\text{O} \quad \text{H} \\
\end{array} \rightarrow \begin{array}{c}
\text{H} \quad \text{O} \\
\text{H} \quad \text{O} \\
\end{array} \]

Electrophile Nucleophile

(c) \[ \begin{array}{c}
\text{H} \\
\text{C} \quad \text{H} \\
\end{array} \rightarrow \begin{array}{c}
\text{C} \quad \text{H} \\
\text{H} \\
\end{array} \]

Radical

Radical
Isomerism

A hydrocarbon Q consists of 86% carbon by mass.

(a) Calculate the empirical formula of compound Q.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass in 100 g/ g</td>
<td>86</td>
<td>14</td>
</tr>
<tr>
<td>No. of moles</td>
<td>86</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>12.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>= 7.167</td>
<td>= 14</td>
</tr>
<tr>
<td>Ratio</td>
<td>= 7.167</td>
<td>= 7.167</td>
</tr>
<tr>
<td></td>
<td>= 1</td>
<td>= 1.953</td>
</tr>
<tr>
<td>Simplest ratio</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Empirical formula is CH₂.

(b) 5.0 g of Q was found to occupy 2.0 dm³ at s.t.p. Deduce the molecular formula of Q.

Let molecular formula of Q be (CH₂)_x

Using pV = nRT ⇒ pV = \( \frac{m}{M_r} \)RT

\[ M_r = \frac{m}{pV} \]

\[ x(12.0 + 2.0) = \frac{5.0}{10100 \times 0.0020} \times 8.31 \times 273 \]

\[ x = 4.01 \approx 4 \]

∴ Molecular formula of Q is C₄H₈.

(c) Compound Q exists as a pair of geometric isomers. Draw the structural formulae for these two isomers of Q.

(d) Compound P is a structural isomer of Q and does not show geometric isomerism. Suggest a structure for P.
5 The formula for \( R \) shown below is ambiguous in that it could represent more than one isomer.

\[
\text{CH}_3\text{CH(OH)C}_3\text{H}_7
\]

\( R \)

By considering all three types of isomerism (structural, geometric and optical), draw the formulae of the four isomers that \( R \) could represent.

In each case, identify the type(s) of isomerism present.

Structural isomerism between 1 and 3.
Geometric isomerism between 1 and 2, and between 3 and 4.

6 Vanilloids are a group of organic compounds found naturally in spices such as ginger and cloves. The general structure of a vanilloid is shown below (where ‘R’ represents a side chain).

Compounds \( Y \) and \( Z \) are vanilloids with molecular formula \( \text{C}_{10}\text{H}_{12}\text{O}_2 \). Compound \( Y \) has stereoisomers while compound \( Z \) does not.

Draw all the possible structures of compounds \( Y \) and \( Z \).

(N13/2/3(c) modified)
Glyceraldehyde, shown below, is a chiral molecule, which exists as two enantiomers, D-glyceraldehyde, and L-glyceraldehyde.

(a) Identify the chiral centre (*).

(b) In the following table, indicate

(i) whether the mixtures of the enantiomers of glyceraldehyde would result in an optically active sample, and

(ii) the direction in which samples II - V will rotate plane polarised light.

<table>
<thead>
<tr>
<th>Sample Mixture</th>
<th>Percentage of D-glyceraldehyde in the sample (%)</th>
<th>Percentage of L-glyceraldehyde in the sample (%)</th>
<th>Comment</th>
<th>Is the sample optically active? (Yes/No)</th>
<th>Direction of rotation of plane polarized light</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>100</td>
<td>0</td>
<td>Pure D enantiomer</td>
<td>Yes</td>
<td>clockwise</td>
</tr>
<tr>
<td>II</td>
<td>75</td>
<td>25</td>
<td>-</td>
<td>Yes</td>
<td>clockwise</td>
</tr>
<tr>
<td>III</td>
<td>50</td>
<td>50</td>
<td>Racemic mixture</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>IV</td>
<td>25</td>
<td>75</td>
<td>-</td>
<td>Yes</td>
<td>counter-clockwise</td>
</tr>
<tr>
<td>V</td>
<td>0</td>
<td>100</td>
<td>Pure L enantiomer</td>
<td>Yes</td>
<td>counter-clockwise</td>
</tr>
</tbody>
</table>

(c) Two samples of glyceraldehyde were analysed for optical activity. It was found that one sample was optically active, while the other was optically inactive. Suggest reasons to explain this.

The sample that is optically active could contain either pure D or L isomer, or it could contain both isomers, but one of the isomers is in excess. The sample that is optically inactive is a racemic mixture of both isomers (50% of each isomer).
The effect of plane polarized light on tartaric acid (2,3-dihydroxybutanedioic acid), HO₂CCH(OH)CH(OH)CO₂H was investigated by Louis Pasteur.

Pasteur identified three different types of tartaric acid molecule.

Molecule A rotated plane polarized light to the right
Molecule B rotated plane polarized light to the left
Molecule C had no effect on plane polarized light

(a) Label any chiral centres with an asterisk (*)
(b) Suggest an explanation for the observations that Pasteur made.

(A, B and C are stereoisomers of one another. Tartaric acid has two chiral centres and is expected to have 4 stereoisomers, of which there are 2 enantiomeric pairs. This is not the case here. A and B are enantiomers of each other, hence A rotates plane-polarised light to the right and B rotates plane-polarised light to the left. The structures of A and B (A and B’s identity can be swapped) are shown below:

(�: It is not possible to tell from the structure the direction in which plane-polarised light is rotated. We can only do this by direct measurement using a polarimeter.)

However, the stereoisomer C has a plane of symmetry down the centre of the molecule, hence its mirror image is superimposable on itself. Thus C is a meso compound, is not a chiral molecule and will not rotate plane-polarised light.
MCQ

9 Two organic isomers are known to contain the same functional groups. Assess the following statements about the two molecules:

(a) They have the same empirical formula. Must be true/Sometimes true/Must be false
(b) They have the same boiling point. Must be true/Sometimes true/Must be false
(c) They have the same chemical properties. Must be true/Sometimes true/Must be false
(d) They have the same solubility in water. Must be true/Sometimes true/Must be false

10 What is the maximum number of stereoisomers for the molecule shown below?

![Molecule Image]

A. $2^8$  B. $2^9$  C. $2^{10}$  D. $2^{11}$

11 The bond lengths in propyne differ from those which might be expected.

The carbon-carbon bond length in ethane is 0.154 nm and in ethyne 0.120 nm. The single C2-C3 bond in propyne, however, is shorter than the single bond in ethane: it is 0.146 nm.

What helps to explain this C2-C3 bond length in propyne?

A. It has partial sp$^2$-sp$^2$ character
B. It is an sp-sp$^3$ overlap
C. The sp$^3$-sp$^3$ bonding is pulled shorter by a p-p (π-bond) overlap
D. The electrons in the C3 carbon atom are attracted towards the π-bonds between C1 and C2

Self-practice Questions

GCE A-level Chemistry Paper

1 N13 P1 Q20  10 N04 P1 Q20
2 N13 P1 Q39  11 N04 P1 Q37
3 N13 P3 Q4(a)  12 N03 P2 Q4
4 N12 P1 Q19  13 N03 P1 Q20
5 N11 P1 Q19
6 N11 P1 Q33
7 N11 P1 Q37
8 N05 P1 Q21
9 N05 P1 Q37