

Section D: Organic Chemistry

Chapter 18: Introducing Organic Chemistry

When you start doing organic chemistry, you are suddenly faced with a whole lot of new compounds with strange names and unfamiliar ways of drawing them. It can be quite scary!

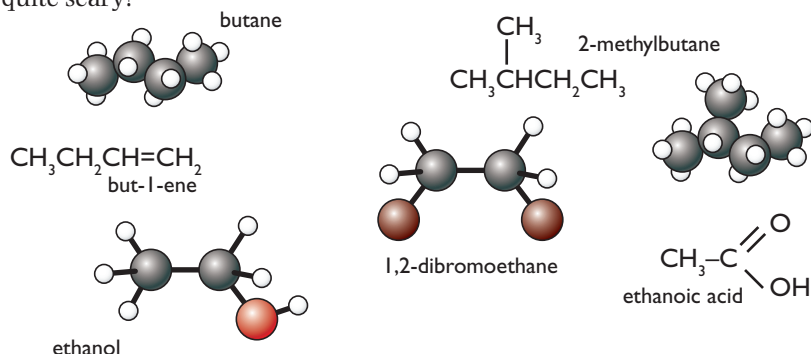


Figure 18.1 Organic chemistry involves a lot of new compounds.

The secret at the beginning is to spend a lot of time playing around with the subject – coding and decoding names, drawing structures and, above all, making models. If you are fortunate, your school will have models you can use. If you aren't so lucky, make your own out of children's modelling clay and matchsticks or small nails to use as bonds.

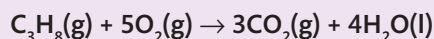
There is no point in going on to look at any detailed chemistry of the various compounds until you are confident that you can understand the names and how to draw the molecules on paper.

Types of formula for organic molecules

Molecular formulae

A molecular formula simply counts the numbers of each sort of atom present in the molecule, but tells you nothing about the way they are joined together. For example, the molecular formula of propane is C_3H_8 , and the molecular formula of ethene is C_2H_4 .

Molecular formulae are used very rarely in organic chemistry, because they don't give any useful information about the bonding in the molecule. You might use them in equations for the combustion of simple hydrocarbons where the structure of the molecule doesn't matter. For example:

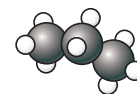


In almost all other cases, you use a structural formula.

Structural formulae

A structural formula shows how the atoms are joined up. There are two ways of representing structural formulae – they can be drawn as a displayed formula, or they can be written out as, for example, $CH_3CH_2CH_3$. You need to be confident about doing it either way.

There are literally millions of different organic compounds. They all contain carbon, and almost all contain hydrogen. Atoms such as oxygen or nitrogen or chlorine crop up quite commonly as well. This chapter introduces you to some of the important ideas that you need before you can start to make sense of organic chemistry.



A structural formula such as $CH_3CH_2CH_3$ shows exactly how the molecule is joined up. A molecular formula, C_3H_8 , doesn't give you the same sort of useful information about the molecule.

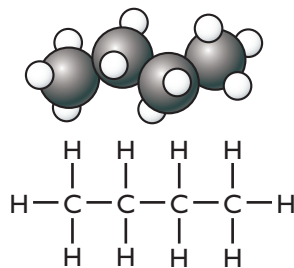


Figure 18.2 Butane

If you are asked to draw the structure for a molecule in a GCSE exam, always draw it in the fully displayed form. You can't lose any marks by doing this, whereas you might if you use the simplified form. If, on the other hand, you are just writing a structure in an equation, for example, you can use whichever version you prefer.

The best way to understand this is to make some models. If you don't have access to atomic models, use blobs of modelling clay joined together with bits of matchstick or small nails to represent the bonds. You will find that you can change the shape of the model by rotating the bonds. That's what happens in real molecules.

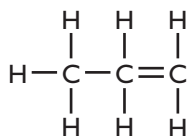


Figure 18.5 Propene.

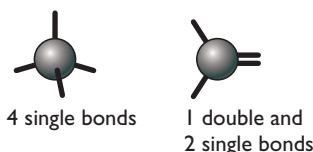


Figure 18.6 Arrangement of bonds.

Displayed formulae

A displayed formula (sometimes called a fully displayed formula) shows all the bonds in the molecule as individual lines. You need to remember that each line represents a pair of shared electrons.

The diagram shows a model of butane, together with its displayed formula. Notice that the way the displayed formula is drawn bears no resemblance to the shape of the actual molecule. Displayed formulae are always drawn with the molecule straightened out and flattened. They do, however, show exactly how all the atoms are joined together.

The normal way to draw a structural formula

For anything other than the smallest molecules, drawing a fully displayed formula is very time-consuming. You can simplify the formula by writing, for example, CH_3 or CH_2 instead of showing all the carbon–hydrogen bonds.

Butane could be written quite quickly as $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ – and this shows all the necessary detail. But you have to be very careful. For example, all the structures in Figure 18.3 represent butane, even though they look different:

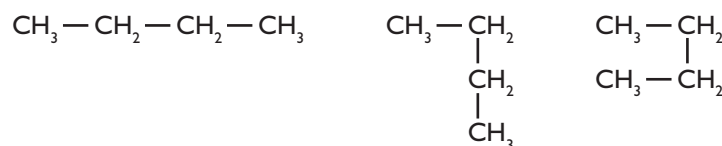


Figure 18.3 All three structures represent butane.

Each structure shows four carbon atoms joined up in a chain, but the chain has simply twisted. This happens in real molecules as well.

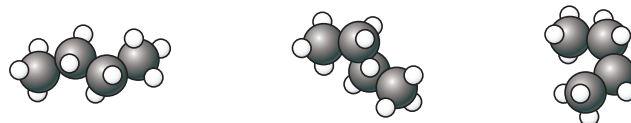


Figure 18.4 All three molecules represent butane.

Not one of the structural formulae accurately represents the shape of butane. The convention is to write it with all the carbon atoms in a straight line.

A molecule like propene, C_3H_6 , has a carbon–carbon double bond. That is shown by drawing two lines between the carbon atoms to show the two pairs of shared electrons. You would normally write this in a simplified structural formula as $\text{CH}_3\text{CH}=\text{CH}_2$.

Making your own models

Make sure you have the bonds (the matchsticks or nails) pointing in the right directions. If there are four single bonds around a carbon atom, they are arranged as shown in Figure 18.6. If you tip the model over so that it is standing on three different 'legs', it should still look exactly the same.

If you have two single bonds and a double bond around a carbon atom, the arrangement in space is different. All the bonds lie in the same plane.

Naming organic compounds

Names for organic compounds can appear quite complicated, but they are no more than a code that describes the molecule. Each part of a name tells you something specific about the molecule. One part of a name tells you how many carbon atoms there are in the longest chain, another part tells you whether there are any carbon-carbon double bonds, and so on.

Coding the chain length

Look for the code letters in the name – these are given in Table 18.1.

| Code letters | Number of carbons in chain |
|--------------|----------------------------|
| meth | 1 |
| eth | 2 |
| prop | 3 |
| but | 4 |
| pent | 5 |

Table 18.1: Coding the chain length.

For example, **butane** has a chain of four carbon atoms. **Propane** has a chain of three carbon atoms.

Coding for the type of compound

Alkanes

Alkanes are a family of similar hydrocarbons (compounds of carbon and hydrogen only) in which all the carbons are joined to each other with single covalent bonds. Compounds like this are coded with the ending '**ane**'. For example, **ethane** is a two-carbon chain (because of 'eth') with a carbon-carbon single bond, CH_3CH_3 .

Alkenes

Alkenes are a family of hydrocarbons which contain a carbon-carbon double bond. This is shown in their name by the ending '**ene**'. For example, **ethene** is a two-carbon chain containing a carbon-carbon double bond, $\text{CH}_2=\text{CH}_2$. With longer chains, the position of the double bond could vary in the chain. This is shown by numbering the chain and noting which carbon atom the double bond *starts* from.

| Formula | Name | Description |
|--|-----------|--|
| $\text{CH}_2=\text{CHCH}_2\text{CH}_3$ | but-1-ene | a four-carbon chain with a double bond starting on the first carbon |
| $\text{CH}_3\text{CH}=\text{CHCH}_3$ | but-2-ene | a four-carbon chain with a double bond starting on the second carbon |

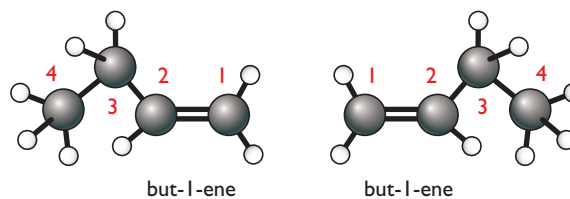
Table 18.2: Indicating the position of the double bond.

How do you know which end of the chain to number from? The rule is that you number from the end which produces the smaller numbers in the name.

You have to learn these! The first four are the tricky ones because there isn't any pattern. 'pent' means five (as in **pentagon**), and following on from this are other logical ones. A six-carbon chain, for example, is coded as 'hex', meaning six (as in **hexagon**).

In more complicated molecules, the presence of the code '**an**' in the name again shows that the carbons are joined by single bonds. For example, you can tell that propan-1-ol contains three carbon atoms ('prop') joined together by carbon-carbon single bonds ('an'). The coding on the end gives you more information about the molecule. You will meet this later in the chapter.

Don't worry too much about this. It isn't a big issue at GCSE, but it does arise from time to time later on in this chapter.

Figure 18.7 *But-1-ene.*

Both parts of Figure 18.7 show the same molecule, but in one case it has been flipped over so that what was originally on the left is now on the right, and *vice versa*. It would be silly to change the name every time the molecule moved! Both of them are called but-1-ene.

Coding for branched chains

Hydrocarbon chains can have side branches on them. You are only likely to come across two small side chains, shown in Table 18.3.

| Side chain | Coded |
|-----------------------------------|--------|
| CH ₃ - | methyl |
| CH ₃ CH ₂ - | ethyl |

Table 18.3: Coding for branched chains.

The name of a molecule is always based on the longest chain you can find in it. The position of the side chain is shown by numbering, exactly as before.

The longest chain in the molecule in Figure 18.8 has four carbon atoms (**'but'**) with no double bonds (**'ane'**). The name is based on butane. There is a **methyl** group branching off the **number 2** carbon. (Remember to number from the end that produces the smaller number.) The compound is called 2-methylbutane.

Where there is more than one side chain, you describe the position of each of them.

The longest chain in the molecule in Figure 18.9 has three carbon atoms and no double bonds. Therefore the name is based on propane.

There are two methyl groups attached to the second carbon. The compound is 2,2-dimethylpropane. The **'di'** in the name shows the presence of the two methyl groups. **'2,2-'** shows that they are both on the second carbon atom.

You can reverse this process and draw a structural formula from a name. All you have to do is decode the name.

For example, what is the structural formula for **2,3-dimethylbut-2-ene**?

Start by looking for the code for the longest chain length. **'but'** shows a four-carbon chain. **'ene'** shows that it contains a carbon-carbon double bond starting on the second carbon atom (**'-2-ene'**). There are two methyl groups (**'dimethyl'**) attached to the second and third carbon atom in the chain (**'2,3-'**). All you have to do now is to fit all this together into a structure.

Start by drawing the structure without any hydrogen atoms on the main chain. It doesn't matter whether you draw the CH₃ groups pointing up or down. Then add enough hydrogens so that each carbon atom is forming four bonds. Figure 18.10 shows how your thinking would work.

Notice that the count of the number of carbons in the side chain is coded exactly as before. 'meth' shows a one-carbon side chain. 'eth' shows two carbons. The 'yl' shows that the group is attached to something else.

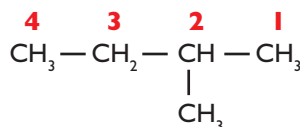


Figure 18.8 Number from the end that produces the smaller number.

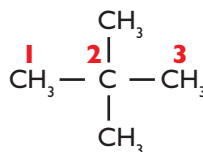


Figure 18.9 Describe the position of each side chain.

It is much more important to be able to decode names to give structures than the other way around. If you don't know what a teacher or an examiner is talking about, you are completely lost!

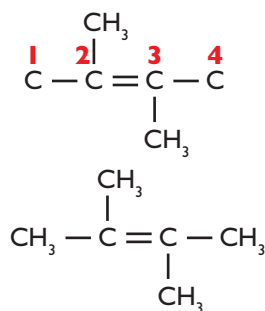


Figure 18.10 First draw the structure, then add hydrogens.

Structural isomerism

Structural isomers are molecules with the same molecular formula, but with different structural formulae. Examples will make this clear.

Structural isomerism in the alkanes

Isomers of butane, C₄H₁₀

If you had some atomic models and picked out four carbon atoms and 10 hydrogen atoms, you would find it was possible to fit them together in more than one way. The two different molecules formed are known as **isomers**. Both have the molecular formula C₄H₁₀, but they have different structures. **Structural isomerism** is the existence of two or more different structures with the same molecular formula.

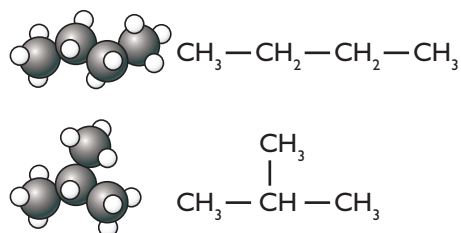


Figure 18.11 Structural isomers.

If you look carefully at the models in Figure 18.11, you can see that you couldn't change one into the other just by bending or twisting the molecule. You would have to take the model to pieces and rebuild it. That's a simple way of telling that you have isomers.

The 'straight chain' isomer is called butane. The branched chain has a three-carbon chain with no carbon–carbon double bond ('propane'), with a methyl group on the second carbon. The name is 2-methylpropane.

Isomers of pentane, C₅H₁₂

There are three isomers of pentane, shown in Figure 18.12.

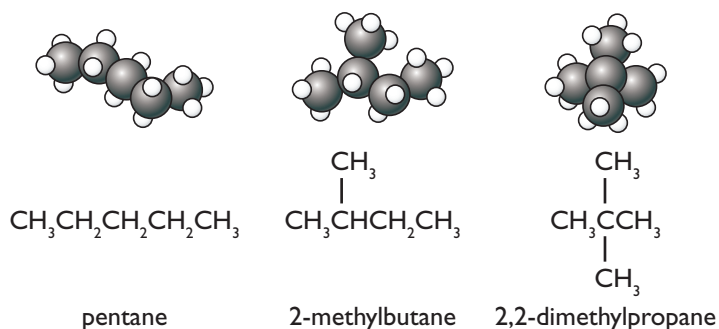


Figure 18.12 The three isomers of pentane.

Students frequently think they can find another isomer as well. If you look closely at this 'fourth' isomer (Figure 18.13), you will see that it is just 2-methylbutane rotated in space.

To avoid this sort of problem, always draw your isomers so that the longest carbon chain is drawn horizontally. Check each isomer after you have drawn it, to be sure you have done that.

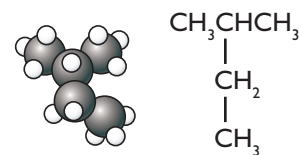


Figure 18.13 There is no fourth isomer of pentane.

Warning! Don't confuse the word **isomer** with **isotope**. Isotopes are atoms with the same atomic number but different mass numbers.

You aren't going to be asked to name or draw cyclopropane in a GCSE exam, but it is interesting to see why it is called what it is!

If you aren't comfortable with the names, see pages 151–152 on organic names.

Ethanol is what is commonly known just as 'alcohol'.

Structural isomerism in the alkenes

Ethene and propene

Ethene, $\text{CH}_2 = \text{CH}_2$, doesn't have any isomers. Propene, $\text{CH}_3\text{CH} = \text{CH}_2$, doesn't have a structural isomer that is still an alkene. (If you are interested, you can find a structural isomer of C_3H_6 that doesn't have a carbon–carbon double bond by joining the carbon atoms in a ring. It is called cyclopropane – which says 'a ring of three carbons with only single bonds between them'.)

Butene, C_4H_8

Butene has three structural isomers containing a carbon–carbon double bond.

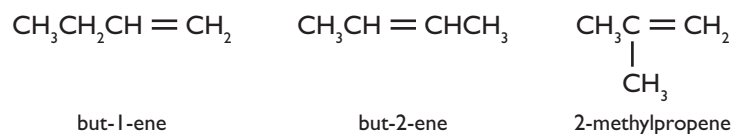


Figure 18.14 The three structural isomers of butene.

Notice the way that you can vary the position of the double bond as well as branching the chain.

A quick introductory look at the alcohols

Alcohols all contain an $-\text{OH}$ group attached to a hydrocarbon chain. This is coded for in the name by the ending '-ol'.

Figure 18.15 shows four small alcohols.

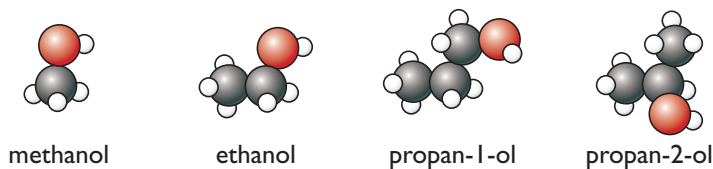


Figure 18.15 Four small alcohols.

Notice the way the names work. Notice that they all end with '-ol', showing the $-\text{OH}$ group. Notice the way the number of carbons in the chain is counted exactly as before with 'meth', 'eth' and 'prop'.

And notice the possibility of structural isomerism in the two different propanols. The $-\text{OH}$ group can be attached to the end of the chain (in propan-1-ol) or to the second carbon in the chain (as in propan-2-ol). These are structural isomers because there is no way that you can bend or twist one of the molecules to make the other. A model would have to be taken to pieces to get from one to the other.

End of Chapter Checklist

You should now be able to:

- ✓ understand the difference between a molecular and a structural formula for an organic compound
- ✓ draw fully displayed structural formulae for simple compounds
- ✓ know that displayed formulae are often simplified by not showing all the bonds in groups such as CH_3 and CH_2
- ✓ know that organic names are just coded descriptions of the molecules
- ✓ use their names to draw structures for simple hydrocarbons containing either single or double carbon-carbon bonds limited to up to five (alkanes) or four (alkenes) carbon atoms
- ✓ work out the names of a similar range of compounds, given their structures
- ✓ recognise the presence of an $-\text{OH}$ group in an alcohol by the ending '-ol' in its name
- ✓ understand what is meant by structural isomerism
- ✓ draw the structures of isomers in simple cases (molecules no bigger than those in this chapter).

Questions

Note: the questions below deliberately include some examples which are slightly beyond the level which you would expect to meet in a GCSE exam. None of them are difficult, though, if you have read the chapter.

- 1 a) Write down the names of the following hydrocarbons:
- CH_4
 - $\text{CH}_3\text{CH}_2\text{CH}_3$
 - $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$
 - $\text{CH}_3\text{CH}=\text{CH}_2$
 - $\text{CH}_2=\text{CH}_2$
 - $\text{CH}_2=\text{CHCH}_2\text{CH}_3$
- b) Draw fully displayed formulae (showing all the bonds) for:
- butane
 - ethane
 - but-2-ene
 - propane
 - methanol
 - 2-methylpropane
 - 2-methylpropene
 - pent-1-ene
- 2 a) What do you understand by the term *structural isomerism*?
- There are two structural isomers of C_4H_{10} . Draw their structures and name them.
 - There are five structural isomers of C_6H_{14} . Draw their structures and name them. (A six-carbon chain is coded as 'hex'.)
 - How many structural isomers can you find with a molecular formula C_4H_8 ? You don't need to restrict yourself to compounds with carbon-carbon double bonds. Draw their structures and name as many as you can.
- 3 a) Draw the structures for the following structural isomers of $\text{C}_4\text{H}_9\text{OH}$. (Note: this is beyond anything you will be asked to do at GCSE. The answer to the first one is shown to give you hints as to how to work out the others.)
- butan-1-ol (Answer: $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$)
 - butan-2-ol
 - 2-methylpropan-1-ol
 - 2-methylpropan-2-ol
- b) (This question is even further beyond GCSE!) How many structural isomers of $\text{C}_5\text{H}_{11}\text{OH}$ can you find? Draw their structures, making sure that you always draw them with the longest carbon chain horizontal to avoid duplicate ones. Name as many as you can.
- c) Can you find one or more structural isomers with the same molecular formula ($\text{C}_5\text{H}_{12}\text{O}$) which don't contain an $-\text{OH}$ group? You won't be able to name any of these. Feel very pleased with yourself if you manage to find some!