VERSION 1 CAPS

GRADE 12
PHYSICAL SCIENCES

WRITTEN BY VOLUNTEERS

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The hydrocarbons ESCK9

Let us first look at a group of organic compounds known as the **hydrocarbons**.

DEFINITION: *Hydrocarbon*

An organic molecule which contains only carbon and hydrogen atoms with no other functional groups besides single, double or triple carbon-carbon bonds.

The hydrocarbons that we are going to look at are called **aliphatic compounds**. The aliphatic compounds are divided into *acyclic compounds* (chain structures) and *cyclic compounds* (ring structures). The chain structures are further divided into structures that contain only *single bonds* (**alkanes**), those that contain at least one *double bond* (**alkenes**) and those that contain at least one *triple bond* (**alkynes**).

Cyclic compounds (which will not be covered in this book) include structures such as a *cyclopentane ring*, which is found in insulating foam and in appliances such as fridges and freezers. Figure 4.14 summarises the classification of the hydrocarbons.

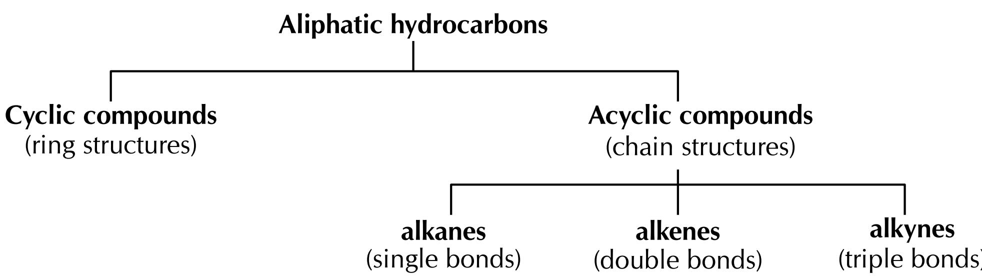


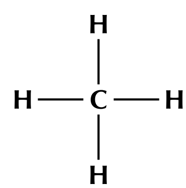
Figure 4.14: The classification of the aliphatic hydrocarbons.

We will now look at each of the acyclic, aliphatic hydrocarbon groups in more detail.

The alkanes

The alkanes are hydrocarbons that only contain *single covalent bonds* between their carbon atoms. This means that they are *saturated* compounds and are quite unreactive. The simplest alkane has only one carbon atom and is called **methane**. This molecule is shown in Figure 4.15.

(a)

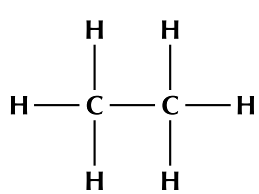


(b) CH_4

Figure 4.15: The **(a)** structural and **(b)** molecular formula representations of methane.

The second alkane in the series has two carbon atoms and is called **ethane**. This is shown in Figure 4.16.

(a)



(b) CH_3CH_3

(c) C_2H_6

(d)

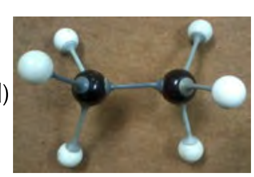
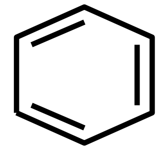


Figure 4.16: The **(a)** structural, **(b)** condensed structural and **(c)** molecular formula representations of ethane. **(d)** An atomic model of ethane.

FACT

An aliphatic compound is one that does not contain an aromatic ring:



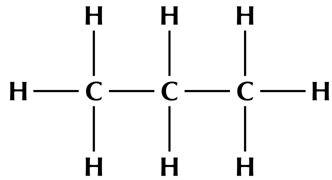
benzene

The simplest aromatic compound is benzene. There are aliphatic cyclic compounds, but if a compound contains an aromatic ring it is an aromatic compound, not an aliphatic one.

FACT
Some fungi use alkanes as a source of carbon and energy. One fungus *amorphotheca resinae* (also known as kerosene fungus) prefers the alkanes used in aviation fuel, and this can cause problems for aircraft in tropical areas.

The third alkane in the series has three carbon atoms and is called **propane** (Figure 4.2).

(a)



(b) $CH_3CH_2CH_3$ (c) C_3H_8

(d)

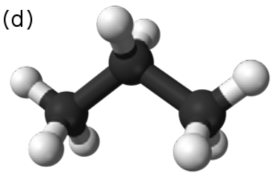


Figure 4.17: The **(a)** structural, **(b)** condensed structural and **(c)** molecular formula representations of propane. **(d)** A three-dimensional computer generated model of propane.

When you look at the molecular formula for each of the alkanes, you should notice a pattern developing. For each carbon atom that is added to the molecule, two hydrogen atoms are added. In other words, each molecule differs from the one before it by CH_2. This is called a *homologous series*.

DEFINITION: *Homologous series*

A homologous series is a series of compounds with the same general formula. All molecules in this series will contain the same functional groups.

The general formula is similar to both the molecular formula and the condensed structural formula. The functional group is written as it would be in the condensed structural formula (to make it more obvious), while the rest of the atoms in the compound are written in the same style as the molecular formula. The alkanes have the **general formula**: C_nH_{2n+2}.

- The alkanes are the most important source of fuel in the world and are used extensively in the chemical industry.
- Alkanes that contain four or less carbon atoms are gases (e.g. methane and ethane).
- Others are liquid fuels (e.g. octane, an important component of petrol).

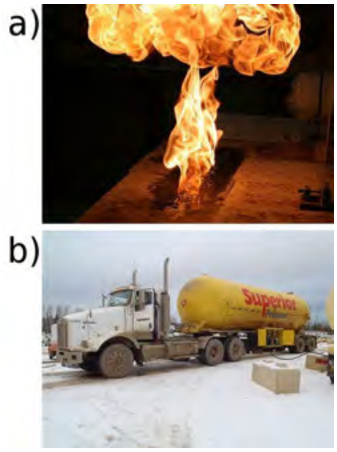


Figure 4.18: **(a)** Methane gas bubbles burning and **(b)** propane (under high pressure) being transported by truck.

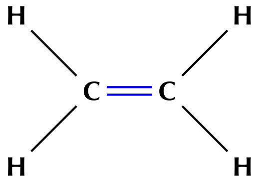
Figure 4.19: Liquid fuels that contain octane are kept in tanks at petrol stations.

The alkenes

In the alkenes there must be at least one double bond between two carbon atoms. This means that they are *unsaturated* and are *more reactive* than the alkanes. The simplest alkene is ethene (also known as ethylene), which is shown in Figure 4.20.

TIP
Note that if an alkene has two double bonds, it is called a **diene**.
If you don't understand the names of compounds, don't worry. We will go into more detail on this later in the chapter.

(a)



(b) CH_2CH_2

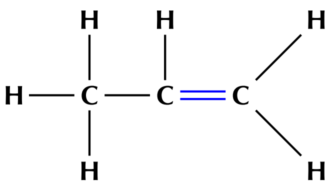
(c) C_2H_4

(d)

Figure 4.20: The **(a)** structural, **(b)** condensed structural and **(c)** molecular formula representations of ethene. **(d)** An atomic model of ethene.

As with the alkanes, the alkenes also form a homologous series. They have the **general formula**: C_nH_{2n}. The second alkene in the series would therefore be C_3H_6. This molecule is known as propene (Figure 4.21).

(a)



(b) CH_3CHCH_2 (c) C_3H_6

Figure 4.21: The **(a)** structural, **(b)** condensed structural and **(c)** molecular formula representations of propene.

There can be more than one double bond in an alkene as shown in Figure 4.22. The naming of these compounds is covered in Section 4.3, IUPAC naming and formulae.

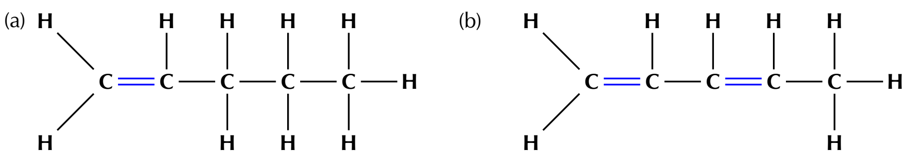


Figure 4.22: The structural representations of **(a)** pent-1-ene and **(b)** pent-1,3-diene.

The alkenes are more reactive than the alkanes because they are unsaturated. As with the alkanes, compounds that have four or less carbon atoms are gases at room temperature. Those with five or more carbon atoms are liquids.

The alkenes have a variety of uses:

- For example, ethene is a chemical compound used in plants to stimulate the ripening of fruits and the opening of flowers.

Figure 4.23: **(a)** Unripe (green) and ripe (yellow) bananas and **(b)** a flowering plant.

- Propene is an important compound in the petrochemicals industry. It is used to make polypropylene (see Section 4.7 for more information) and is also used as a fuel gas for other industrial processes.

FACT
Acetylene is the industrial name for the organic compound ethyne. The raw materials that are needed to make acetylene are calcium carbonate and coal. An important use of acetylene is in oxyacetylene gas welding. The fuel gas burns with oxygen in a torch. Because the combustion of alkenes and alkynes is exothermic an incredibly high heat is produced, which is hot enough to melt metal.

FACT
Liquid bromine is highly corrosive and toxic. Handle with extreme care!

Figure 4.24: A lamp made of polypropylene. Propene is used to make polypropylene.

The alkynes

In the alkynes there must be at least one triple bond between two of the carbon atoms. They are unsaturated compounds and are therefore more reactive than alkanes. Their **general formula** is C_nH_{2n-2}. For example **but-1-yne** has the molecular formula C_4H_6. The simplest alkyne is ethyne (Figure 4.25), also known as acetylene. Many of the alkynes are used to synthesise other chemical products.

(a) H—C≡C—H (b) **CHCH** (c) C_2H_2

(d) 

Figure 4.25: The **(a)** structural, **(b)** condensed structural and **(c)** molecular representations of ethyne (acetylene). **(d)** An atomic model of ethyne.

Remember that organic molecules do not need to be straight chains. They can have branched groups as well, as shown in Figure 4.26.

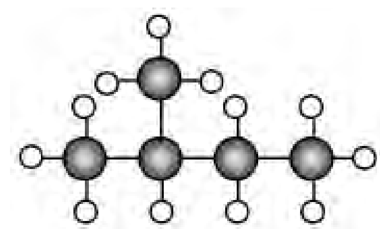


Figure 4.26: A methyl branched group on carbon 2 of butane (2-methylbutane).

A summary of the relative reactivity and the homologous series that occur in the hydrocarbons is given in Table 4.2.

Functional group	Homologous series	Reactivity
alk***ane***	C_nH_{2n+2}	low reactivity
alk***ene***	C_nH_{2n}	high reactivity
alk***yne***	C_nH_{2n-2}	high reactivity

Table 4.2: A summary of the homologous series of the hydrocarbons.

Experiment: Saturated vs. unsaturated compounds

Aim:
To study the effect of bromine water and potassium permanganate on saturated and unsaturated compounds.

Apparatus:
WARNING!

Liquid bromine (required to make bromine water) is a highly volatile, corrosive and toxic compound. Please handle with care: wear the appropriate safety clothing including gloves, labcoat, safety glasses and mask. Work in a fumehood. If you do not have the apparatus to handle liquid bromine safely, use potassium permanganate only.

- cyclohexane, cyclohexene, bromine water ($Br_2(aq)$), potassium permanganate ($KMnO_4$) in an acidic solution
- 4 glass containers (test tubes/beakers/shallow basins), two A4 sheets of paper
- 2 plastic pipettes

Method:

1. Label one piece of paper *A* and the other piece of paper *B*.
2. Place 20 ml of cyclohexane into a container and place the container on paper A.
3. Place 20 ml of cyclohexane into a container and place the container on paper B.
4. Repeat steps 2 and 3 with cyclohexene.
5. Take 12 ml of bromine water and add it to the beaker of cyclohexane on paper A. Observe any colour changes.
6. Repeat step 5 with the beaker of cyclohexene on paper A.
7. Take 12 ml of $KMnO_4$ and add it to the beaker of cyclohexane on paper B. Observe any colour changes.
8. Repeat step 7 with the beaker of cyclohexene on paper B.

Results:

Record your results in the table.

Cyclohexane is an *alkane*, cyclohexene is an *alkene*.

Compound	Initial colour	Solution added	Final colour
cyclohexane		bromine water	
cyclohexane		$KMnO_4$	
cyclohexene		bromine water	
cyclohexene		$KMnO_4$	

Questions:

- Which of these compounds (cyclohexane, cyclohexene) is saturated and which is unsaturated?
- What colour changes did you observe with the alkane compound?
- What colour changes did you observe with the alkene compound?
- Can you suggest a reason for the differences?

Discussion and conclusion:

Bromine water and $KMnO_4$ both have intense colours. Cyclohexane is a saturated, colourless liquid. When bromine water and $KMnO_4$ are added to the cyclohexane there is no reaction and the solution becomes the colour of the bromine water or $KMnO_4$.

Cyclohexene is also a colourless liquid, but it is unsaturated. This results in a reaction with bromine water and with $KMnO_4$. Cyclohexene will form a bromoalkane with bromine water. Bromoalkanes are colourless liquids and the solution will be colourless - liquid bromine is decolourised by cyclohexene. Similarly $KMnO_4$ will be decolourised by the cyclohexene.

Exercise 4 – 2: The hydrocarbons

1. Answer these questions on the hydrocarbons.
   a) What is the difference between the alkanes, alkenes and alkynes?
   b) Give the general formula for the alkynes

c) Of the alkanes, alkenes and alkynes which is:

i. saturated   ii. unsaturated

d) Which series is the least reactive? Explain why.

2. Draw the structural formulae for:

a) $CHCCH_3$ b) $CH_3CH_2CH_3$ c) CH_2CHCH_3

3. Fill in the table:

Compound	Saturated or unsaturated?
$CH_3CH_2CH_3$	
$H-C\equiv C-H$	
$CH_3CH_2CHCHCH_2CH_2CH_2CH_3$	
heptane	
$CH_2=CH-CH_2-CH_3$	

4. More questions. Sign in at Everything Science online and click 'Practise Science'.

Check answers online with the exercise code below or click on 'show me the answer'.

1. 27KY 2. 27KZ 3. 27M2

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The alcohols   ESCKB

An alcohol is any organic compound where there is a *hydroxyl* functional group (–OH) bound to a carbon atom. The **general formula** for a simple alcohol is $C_nH_{2n+1}OH$.

The simplest and most commonly used alcohols are methanol and ethanol (Figures 4.27 and 4.28).

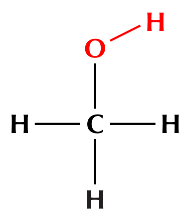
(a)  (b) CH_3OH (c) CH_4O

Figure 4.27: The **(a)** structural, **(b)** condensed structural and **(c)** molecular formula representations of methanol.

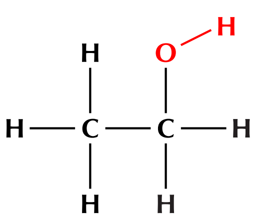
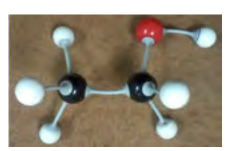
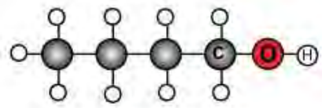
(a)  (b) CH_3CH_2OH (c) C_2H_6O (d) 

Figure 4.28: The **(a)** structural, **(b)** condensed structural and **(c)** molecular formula representations of ethanol. **(d)** An atomic model of ethanol.

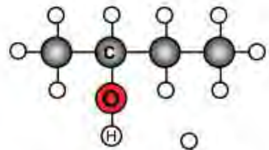
There are three possible types of carbon atoms - primary, secondary and tertiary. A *primary* carbon is attached to only one other carbon atom. A *secondary* carbon is attached to two other carbon atoms, while a *tertiary* carbon atom is attached to three other carbon atoms.

There can be a functional group attached to these different types of carbon atom. When a hydroxyl (–OH) functional group is attached to a primary carbon atom it is called a **primary alcohol**. For a **secondary alcohol** the hydroxyl is bonded to a secondary carbon atom. When the hydroxyl is bonded to a tertiary carbon atom it is a **tertiary alcohol**. Examples are given below.

(a) **Primary Alcohols** (C atom at the end of a chain)
-OH (hydroxyl group) is bonded to a carbon atom that is bonded to only one other carbon atom
butan-1-ol



(b) **Secondary Alcohols** (C atom inside a chain)
-OH group is bonded to a carbon atom that is bonded to two other carbon atoms
butan-2-ol



(c) **Tertiary Alcohols** (needs a branched chain)
-OH group is bonded to a carbon atom that is bonded to three other carbon atoms
2-methylpropan-2-ol

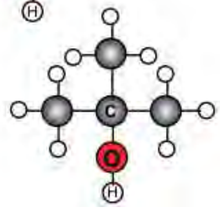


Figure 4.29: A **(a)** primary (butan-1-ol), **(b)** secondary (butan-2-ol) and **(c)** tertiary (2-methylpropan-2-ol) alcohol.

FACT

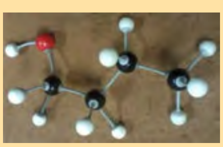
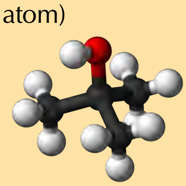
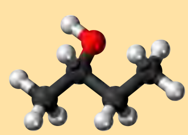
Methanol is toxic. If ingested it forms formic acid or formate salts, which damage the central nervous system and can cause *blindness*, *coma* or *death*.

The alcohols have a number of different uses:

- methylated spirits is ethanol with methanol added
- all alcohols are toxic, but in low concentrations ethanol can be used in alcoholic drinks
- ethanol is the only alcohol used in alcoholic drinks
- ethanol is used as an industrial solvent
- methanol and ethanol can both be used as a fuel and they burn more cleanly than petrol or diesel.
- ethanol is used as a solvent in medical drugs, perfumes and plant essences
- ethanol is an antiseptic

Exercise 4 – 3: The alcohols

Give the structural and condensed structural formula for the following alcohols. State, with reasons, whether the compound is a primary, secondary, or tertiary alcohol.
(Note: a black ball represents a carbon atom, a white ball represents a hydrogen atom, and a red ball represents an oxygen atom)

1. 
2. 
3. 
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Check answers online with the exercise code below or click on 'show me the answer'.

1. 27M3 2. 27M4 3. 27M5

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FACT
CFC stands for *chlorofluorocarbons*. Due to their low toxicity and low reactivity, CFCs were widely used in refrigeration and as propellants in aerosols. However, the low reactivity means that CFCs can get into the upper atmosphere where they are degraded by UV light and damage the ozone layer.

FACT
Chloroform ($CHCl_3$) was used as an anesthetic for years. However, aside from causing dizziness, fatigue and headaches, it was discovered to be toxic, often fatally so. Even non-fatal doses can cause damage to the kidneys and liver. Chloroform can sometimes be found in cough syrups, although not often anymore.

Alkyl halides ESCKC

Alkyl halides are hydrocarbons with one hydrogen atom replaced by a halogen atom (F, Cl, Br, I). The **alkyl** is due to the fact that a hydrocarbon branched group has the suffix *-yl* and is one of the three hydrocarbons: alk*anes*, alk*enes* or alk*ynes*. These *alkyl* groups contain one or more halogen atoms, which leads to the name alkyl halides. Our focus will be on the alk*ane* alkyl halides also known as the haloalkanes (or halogenoalkanes) (see Table 4.1).

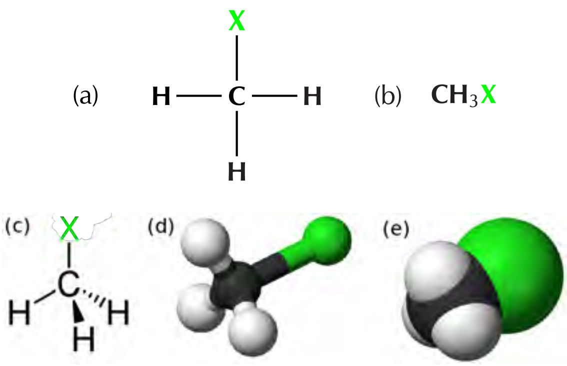


Figure 4.30: Representations of a halomethane where X can be F, Cl, Br or I: **(a)** structural, **(b)** molecular formula, **(c)** 3-D line drawing, **(d)** 3-D ball and stick model and **e)** 3-D space-filling model.

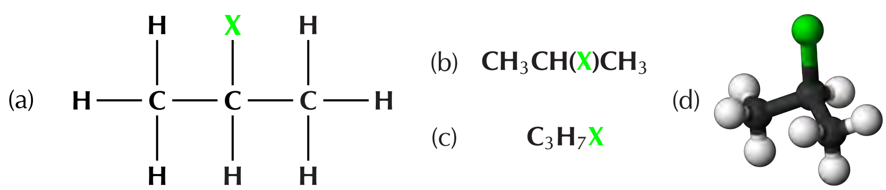


Figure 4.31: Representations of 2-*halo*propane where X can be F, Cl, Br or I: **(a)** structural, **(b)** condensed structural, **(c)** molecular formula and **(d)** a ball and stick model.

Note that the halogen atom is called a *substituent*.

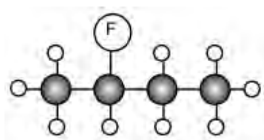


Figure 4.32: A fluorine atom as a substituent on carbon 2 of butane (2-fluorobutane).

Remember the branched chain shown in Figure 4.26. That branched chain is also called a substituent.

DEFINITION: *Substituent*

A substituent is *an atom or group of atoms* bonded to a carbon chain. This can be an inorganic atom (e.g. halogen) or an alkyl group that is shorter than the main group.

An organic compound is always named in accordance with the longest chain of carbon atoms that contains the functional group. If the substituent is an alkyl group it is known as a branched chain.

Some uses of haloalkanes include:

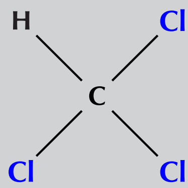
- in fire extinguishers
- as aerosol propellants
- in refrigeration
- generating foamed plastics
- solvents in dry cleaning processes (not actually *dry*, but no water is required)

Extension

Chloroform

Haloalkanes can contain more than one halogen atom. Chloromethanes are substances that can be used as anaesthetics during operations. One example is trichloromethane, also known as *chloroform* (Figure 4.33).

(a)



(b) $CHCl_3$

Figure 4.33: The **(a)** structural and **(b)** molecular formula representations of trichloromethane (chloroform).

Exercise 4 – 4: Haloalkanes

1. Answer these questions on the haloalkanes.
   a) Give the general formula for the haloalkanes with only one halogen atom
   b) Are haloalkanes saturated compounds?
2. Draw the structural formulae for:
   a) $CH_2(Br)CH_2CH_3$
   b) $CH_3CH(Cl)CH_2CH_3$
   c) $CH_2(F)CH_3$
3. More questions. Sign in at Everything Science online and click 'Practise Science'.

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1. 27M6 2. 27M7

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Carbonyl-containing compounds ESCKD

The carbonyl group consists of a carbon atom that is joined to an oxygen by a double bond (see Figure 4.34).

In Figure 4.34 **R′** and **R** are used to represent the rest of the atoms in the molecule. For example **R** could represent an alkyl chain, or a hydrogen atom.

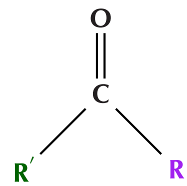


Figure 4.34: A compound containing a carbonyl group.

Aldehydes and ketones

If the functional group is on the *end* of the carbon chain, the organic compound is called an **aldehyde** (Figure 4.35 (a)). Being at the *end* of the chain means that **R′** or **R** represents a hydrogen atom. The simplest aldehyde is *methanal*.

(a) (b)

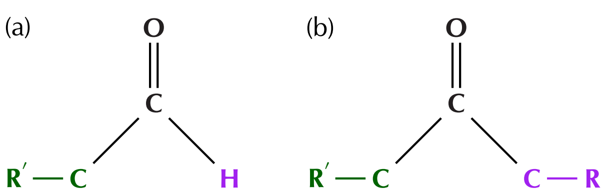
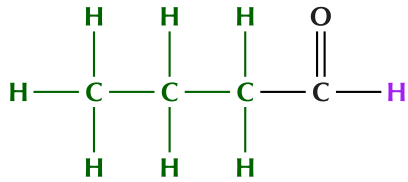


Figure 4.35: **(a)** An aldehyde and **(b)** a ketone.

TIP
Note that the condensed structural formula for an aldehyde ends in **CHO** not COH. This is because COH could be confused with the hydroxyl (–OH) group of an alochol.

FACT
The molecular formulae representations for butanal and butanone are identical (C_4H_8O). This is why structural and condensed structural representations are necessary.

The aldehyde containing 4 carbon atoms, butanal, is illustrated in Figure 4.2. In this example **R** represents H and **R′** represents $CH_3CH_2CH_2$.

(a) 

(b) $CH_3CH_2CH_2CHO$ (c) C_4H_8O

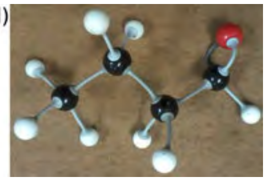
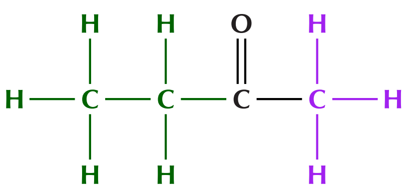
(d) 

Figure 4.36: The **(a)** structural, **(b)** condensed structural and **(c)** molecular formula representations of butanal. **(d)** An atomic model of butanal.

Some uses of aldehydes include:

- in resins (over 6 million tons of formaldehyde are produced per year)
- in the production of plasticisers and alcohols used in detergents
- in perfumes and flavourants

If the carbonyl group is in the middle of the carbon chain, the compound is called a **ketone** (Figure 4.35 (b)). Being in the *middle* of the chain means that **R′** and **R** *cannot* represent H. The simplest ketone is *propanone* (also known as acetone, the compound in nail varnish remover), which contains three carbon atoms. The ketone containing 4 carbon atoms, butanone, is illustrated in Figure 4.2.

(a) 

(b) $CH_3CH_2COCH_3$ (c) C_4H_8O

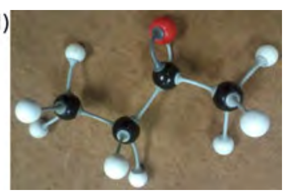
(d) 

Figure 4.37: The **(a)** structural, **(b)** condensed structural and **(c)** molecular formula representations of butanone. **(d)** An atomic model of butanone.

Some uses of ketones include:

- as solvents
- in the production of polymers
- in the production of pharmaceuticals

The **general formula** for both the aldehydes and ketones can be written as: $C_nH_{2n}O$. This means that they cannot be told apart from their general formula alone. There are more complex general formulas that allow aldehydes and ketones to be distinguished, but they are not covered in this book.

Carboxylic acids

Carboxylic acids are organic acids that are characterised by having a carboxyl group, written as –COOH. In a carboxyl group a carbon atom is double-bonded to an oxygen atom (carbonyl group), and it is also bonded to a hydroxyl group (**R**). The simplest carboxylic acid, methanoic acid, is shown in Figure 4.38 and ethanoic acid is shown in Figure 4.2.

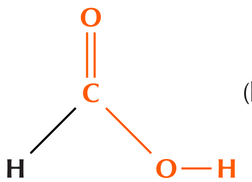
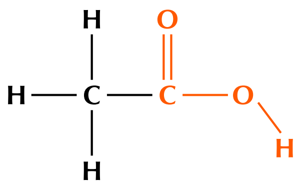
(a)  (b) **HCOOH** (c) $\mathbf{CH_2O_2}$

Figure 4.38: The **(a)** structural, **(b)** condensed structural and **(c)** molecular formula representations of methanoic acid.

(a)  (b) $\mathbf{CH_3COOH}$ (c) $\mathbf{C_2H_4O_2}$

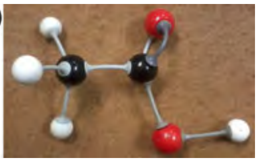
(d) 

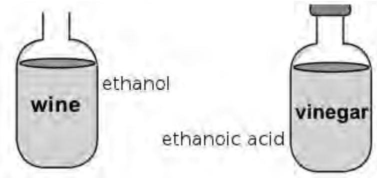
Figure 4.39: The **(a)** structural, **(b)** condensed structural and **(c)** molecular formula representations of ethanoic acid. **(d)** An atomic model of ethanoic acid.

FACT

A certain type of ant, called formicine ants, manufacture and secrete formic acid, which is used to defend themselves against other organisms that might try to eat them.

Carboxylic acids are widespread in nature. Methanoic acid (also known as *formic acid*) has the formula HCOOH and is found in insect stings. Ethanoic acid (CH_3COOH), or *acetic acid*, is the main component of vinegar. More complex organic acids also have a variety of different functions. Benzoic acid for example, is used as a food preservative. Carboxylic acids have the **general formula**: $\mathbf{C_nH_{2n+1}COOH}$.

Ethanoic acid can be produced through the oxidation of ethanol upon exposure to the oxygen in air. This is why wine that is left too long can taste acidic. Wine can easily go sour if exposed to the oxygen molecules (O_2) in the air, especially if the weather is warm.



ethanol + **oxygen** ⟶ **ethanoic acid** + **water**

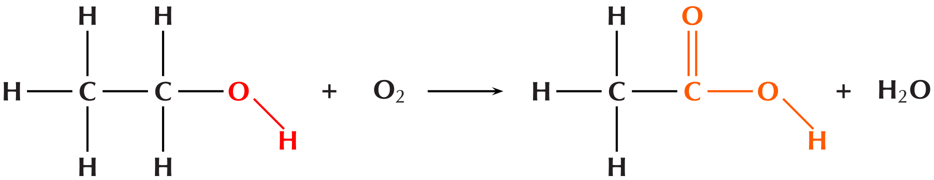
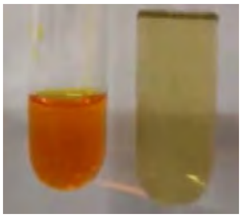


Figure 4.40: The oxidation of wine.

The oxidation of ethanol to ethanoic acid can also be seen in the reaction of ethanol with potassium dichromate:

$$2(Cr_2O_7)^{2-}(aq) + 3C_2H_5OH(aq) + 16H^+(aq) \rightarrow 4Cr^{3+}(aq) + 3CH_3COOH(aq) + 11H_2O(\ell)$$

The colour change that occurs is shown in the image below and the following video:

$\mathbf{K_2Cr_2O_7}$  $\mathbf{K_2Cr_2O_7}$ **+ ethanol**

See video: 27M8 at www.everythingscience.co.za

Figure 4.41: The different colours of potassium dichromate (left) and potassium dichromate and ethanol (right). (Screenshot taken from video by beggar098 on YouTube)

TIP
Esters will be dealt with in much greater detail in Section 4.7.

Case study: Breathalysers

Read the following extract taken from HowStuffWorks (12/08/13):

*The **Breathalyzer** device contains:*

- *A system to sample the breath of the suspect*
- *Two glass vials containing the chemical reaction mixture*
- *A system of photocells connected to a meter to measure the color change associated with the chemical reaction*

To measure alcohol, a suspect breathes into the device. The breath sample is bubbled in one vial through a mixture of sulfuric acid, potassium dichromate, silver nitrate and water. The principle of the measurement is based on the following chemical reaction:

$$2K_2Cr_2O_7(aq) + 3CH_3CH_2OH(aq) + 8H_2SO_4(aq) \rightarrow$$
$$2Cr_2(SO_4)_3(aq) + 2K_2SO_4 + 3CH_3COOH(aq) + 11H_2O(\ell)$$

In this reaction:

1. *The **sulfuric acid removes the alcohol from the air** into a liquid solution.*
2. *The **alcohol reacts with potassium dichromate** to produce: chromium sulfate, potassium sulfate, acetic acid, water*

*The silver nitrate is a **catalyst**, a substance that makes a reaction go faster without participating in it. The sulfuric acid, in addition to removing the alcohol from the air, also might provide the acidic condition needed for this reaction.*

*During this reaction, the reddish-orange dichromate ion **changes color** to the green chromium ion when it reacts with the alcohol; the degree of the color change is directly related to the level of alcohol in the expelled air. To determine the amount of alcohol in that air, the reacted mixture is compared to a vial of unreacted mixture in the **photocell system**, which produces an **electric current** that causes the needle in the meter to move from its resting place. The operator then rotates a knob to bring the needle back to the resting place and reads the level of alcohol from the knob – the more the operator must turn the knob to return it to rest, the greater the level of alcohol.*

Break into groups of three or four. Research breathalysers and then report your information to the class.

Make sure to cover the following areas:

- The effect of alcohol on the body
- The effect of alcohol on reaction times
- The origins of the breathalyser
- The term *mouth alcohol* and its effect on breathalyser tests.

Esters

When an alcohol reacts with a carboxylic acid, an **ester** is formed. Most esters have a characteristic smell. In the reaction a molecule of water is removed from the two compounds and a new bond is formed between what remains of the alcohol and the carboxylic acid. A **catalyst** is required in this reaction, in this case it must be an inorganic acid (e.g. H_2SO_4). An example is shown in Figure 4.42.

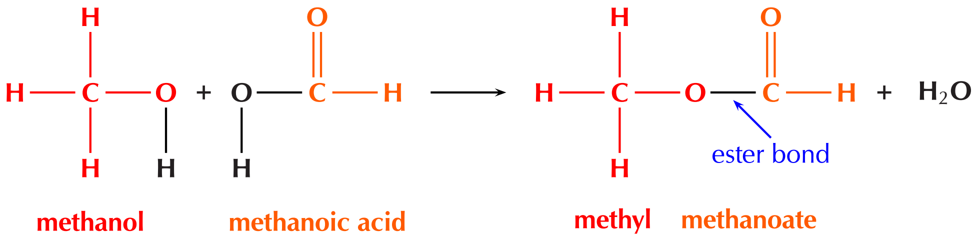


Figure 4.42: The formation of an ester and water from an alcohol and carboxylic acid.

FACT
The esterification process is reversible with large quantities of water (although it can be slow). In an acidic environment the reaction speeds up. Reversible reactions are covered in greater detail in Chapter 8.

The esterification process with methanol and methanoic acid is shown with atomic models in Figure 4.43. Esters have the **general formula**: $C_nH_{2n}O_2$. This general formula can also be applied to carboxylic acids, but the more complex general formula for esters alone is not covered in this book.

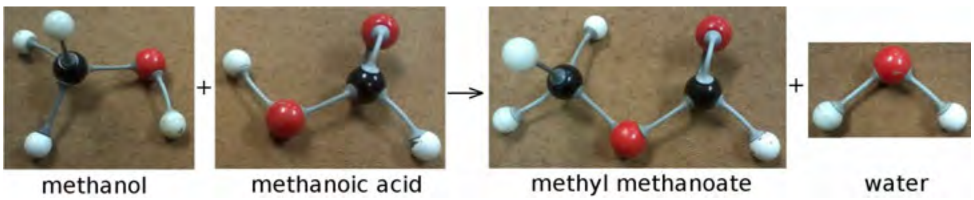


Figure 4.43: The esterification process of methanol and methanoic acid to methyl methanoate and water, shown with three-dimensional model kits.

Some common uses for esters are:

- in cosmetics and beauty products because they typically have a fruity smell, making them good as artificial flavourants and scents
- in nail varnish remover and model plane glue
- as solvents for non-water soluble compounds (e.g. oils, resins) because the ester of a specific carboxylic acid will be less water soluble than the carboxylic acid
- as plasticisers because esters can make a compound less brittle, and more flexible

Exercise 4 – 5: Carbonyl compounds

1. Answer these questions on carbonyl compounds.
   a) What other functional group does a carboxylic acid have in addition to a carbonyl group?
   b) What is the main difference between aldehydes and ketones
   c) What two reactants are required to make an ester?
   d) How is ethanoic acid produced?
2. Draw the structural formulae for each of the following compounds. What series does each compound belong to?
   a) CH_3COCH_3 b) CH_3CH_2COOH c) CH_3CH_2CHO d) CH_3COOCH_3
3. More questions. Sign in at Everything Science online and click 'Practise Science'.

Check answers online with the exercise code below or click on 'show me the answer'.

1. 27M9 2. 27MB

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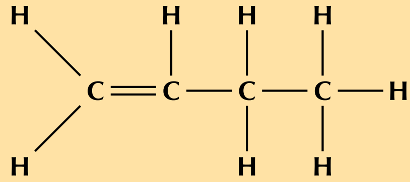
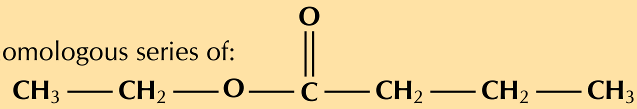
Exercise 4 – 6: Functional groups

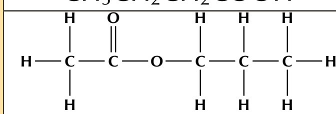
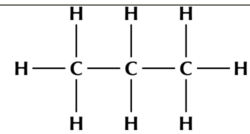
1. Write down the:
   a) name of the homologous series of:
   $CH_3CH(CH_3)CH_2CH(CH_3)CH_2CH_3$
   b) general formula of:



   c) name of the homologous series of:



   d) structural formula of: CH_3CH_2COOH
2. Look at the list of organic compounds in the table below:

Organic compound	Homologous series
$CH_3CH_2CH_2COOH$	
	
CH_3CHO	
	
$CH_3CCCH_2CH_2CH_2CH_3$	

   a) Complete the table by identifying the functional group of each compound.
   b) Give the structural representation of the compounds represented by condensed structural formulae.
3. A chemical reaction takes place and ethyl methanoate is formed.
   a) Identify the homologous series to which ethyl methanoate belongs?
   b) Name the two types of reactants used to produce this compound in a chemical reaction.
   c) Give the structural formula of ethyl methanoate ($HCOOCH_2CH_3$).
4. The following reaction takes place: $CH_3CHCH_2(g) + H_2(g) \rightarrow CH_3CH_2CH_3(g)$
   a) Give the name of the homologous series of the organic compound in the reactants.
   b) What is the name of the homologous series of the product?
   c) Which compound in the reaction is a saturated hydrocarbon?
5. More questions. Sign in at Everything Science online and click 'Practise Science'.

Check answers online with the exercise code below or click on 'show me the answer'.

1. 27MC 2. 27MD 3. 27MF 4. 27MG

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