Unit 2: Nature's Chemistry

Student:

Topic 5
Systematic Organic in Context
Structures & Naming
Oxidation Reactions
Antioxidants
5.1 Systematic Organic in Context

This first lesson topic takes an overview of the Organic reactions met in this and previous courses and some of the contexts in which these reactions are met.

**Previous Chemistry**

This activity examines the systematic approach to the reactions met in previous courses.

**Substitution**

an atom or group will be removed from a normally saturated molecule to allow a different atom or group to take its place.

Normally, the product formed is also saturated and molecules react to form molecules.

*Equation using systematic names:*

\[
\text{methane} + \rightarrow \text{chloromethane} +
\]

*Equation using full structural formulae:*

\[
\begin{align*}
\text{H} & \\
\text{H—C—H} & + \\
\text{H} & \\
\end{align*}
\]

*Equation using shortened structural formulae:*

\[
\text{CH}_4(g) + \rightarrow +
\]
Cracking - a larger saturated molecule is broken apart to produce smaller molecules, at least one of which will be unsaturated.

Normally, a catalyst will be used. Sometimes only a couple of neighbouring hydrogen atoms will be 'cracked' off to produce a single unsaturated product. This reaction can also be called elimination.

Equation using systematic names:
\[
\text{propane} \quad \rightarrow \quad \text{propene} \quad +
\]

Equation using full structural formulae:
\[
\begin{align*}
\text{H} & \text{ H} & \text{ H} \\
\text{H—C—C—C—H} & \quad \rightarrow & \quad + \\
\text{H} & \text{ H} & \text{ H}
\end{align*}
\]

Equation using shortened structural formulae:
\[
\text{CH}_3\text{CH}_2\text{CH}_3(g) \quad \rightarrow \quad +
\]

Dehydration - a specific elimination reaction in which neighbouring hydrogen and hydroxyl group (—OH) will be 'cracked' off to produce an unsaturated product. The eliminated atoms form a stable water molecule.

Equation using systematic names:
\[
\text{propan-1-ol} \quad \rightarrow \quad \text{propene} \quad +
\]

Equation using full structural formulae:
\[
\begin{align*}
\text{H} & \text{ H} & \text{ H} \\
\text{H—C—C—C—OH} & \quad \rightarrow & \quad + \\
\text{H} & \text{ H} & \text{ H}
\end{align*}
\]

Equation using shortened structural formulae:
\[
\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} (l) \quad \rightarrow \quad +
\]

Elimination is the reverse reaction to addition.
Addition - a small molecule reacts with an unsaturated molecule and adds across the double bond to make a saturated product.

Many different molecules can be added and many of these reactions have their own names.

**Hydrogenation - add of hyd**

Equation using systematic names:

\[
\text{Ni catalyst} \quad \text{propene} + \text{hydrogen} \rightarrow
\]

Equation using full structural formulae:

\[
\begin{array}{c}
H \quad H \\
| \quad | \quad |
\end{array}
\begin{array}{c}
\text{H—C—C = C—H} \\
| \quad |
\end{array}
+ \quad \rightarrow
\begin{array}{c}
H \quad H \\
| \quad |
\end{array}
\begin{array}{c}
\text{H—C—C—C—H} \\
| \quad | \quad |
\end{array}
\]

Equation using shortened structural formulae:

\[
CH_3CHCH_2(g) + \rightarrow
\]

Hydrogenation is mainly used to convert highly unsaturated oils into more saturated fats. E.g. vegetable oil can be thickened and solidified to make margarine by hydrogenation.

**Halogenogenation - add of hal**

Equation using systematic names:

\[
\text{propene} + \rightarrow 1,2\text{-dibromopropane}
\]

Equation using full structural formulae:

\[
\begin{array}{c}
H \quad H \\
| \quad | \quad |
\end{array}
\begin{array}{c}
\text{H—C—C = C—H} \\
| \quad |
\end{array}
+ \quad \rightarrow
\begin{array}{c}
H \quad H \\
| \quad |
\end{array}
\begin{array}{c}
\text{H—C—C—C—H} \\
| \quad | \quad |
\end{array}
\]

Equation using shortened structural formulae:

\[
CH_3CHCH_2(g) + \rightarrow
\]

The add reaction with a halogen, usually bromine, remains the accepted test for unsaturation - the presence of a C = C double or C ≡ C triple bond.

The halogen is decolourised, usually by colourless, or green → colourless, or brown → colourless.
Hydrohalogenation - add of hydrogen halide

Equation using systematic names:

\[
\text{propene} + \text{hydrogen iodide} \rightarrow \text{1-iodo}
\]

Equation using full structural formulae:

\[
\begin{align*}
H & \quad H & \quad H \\
| & \quad | & \quad | \\
H & -C & -C = C & -H \\
| & \quad | & \quad | \\
& & & H
\end{align*}
\]

Equation using shortened structural formulae:

\[
\text{CH}_3\text{CHCH}_2(\text{g}) + \rightarrow 
\]

Hydrohalogenation is an alternative when only one halogen atom is wanted on the product molecule. Depending on the position of the double bond, however, more than one isomer is possible. In the above example, 2-iodopropane is another possible product.

Hydration - add of water

Equation using systematic names:

\[
\text{propene} + \text{water} \rightarrow \text{propan-1-ol}
\]

Equation using full structural formulae:

\[
\begin{align*}
H & \quad H & \quad H \\
| & \quad | & \quad | \\
H & -C & -C = C & -H \\
| & \quad | & \quad | \\
& & & H
\end{align*}
\]

Equation using shortened structural formulae:

\[
\text{CH}_3\text{CHCH}_2(\text{g}) + \rightarrow 
\]

Hydration of an alkene is an important method for making alcohols but, like the previous example, more than one product can be formed.

In this case, the second isomer would be propan-2-ol.

Propan-1-ol is a primary alcohol while propan-2-ol is a secondary alcohol. The significance of these labels will become clearer in later lessons.
Condensation - two smaller molecule react to join together and form a larger molecule, eliminating a small stable molecule, usually water through one molecule losing an $-H$ atom whilst the other molecule loses an $-OH$ (hydroxyl) group.

Equation using systematic names:

propanoic acid + ethanol $\rightarrow$

Equation using full structural formulae:

\[
\begin{align*}
&\text{H} \quad \text{H} \quad \text{O} \\
&\text{H} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{OH} \\
&\text{H} \quad \text{H} \\
\end{align*}
\]

\[
\begin{align*}
&\text{H} \quad \text{H} \quad \text{H} \\
&\text{H} \quad \text{C} \quad \text{C} \quad \text{H} \\
\end{align*}
\]

+ $\text{H} - \text{OH}$

Equation using shortened structural formulae:

\[
\begin{align*}
&\text{CH}_3\text{CH}_2\text{COOH} \quad (l) + \\
&\text{CH}_3\text{CH}_2\text{OH} \quad (l) \\
&\text{CH}_3\text{CH}_2\text{COOCH}_3\text{CH}_2 \quad (l)
\end{align*}
\]

The other main condensation reaction that you will meet will involve an acid reacting with an amine to form an amide. This is very similar to the ester forming reaction above.

\[
\begin{align*}
&\text{H} \quad \text{H} \quad \text{O} \\
&\text{H} \quad \text{C} \quad \text{C} \quad \text{OH} \\
&\text{H} \quad \text{H} \\
\end{align*}
\]

\[
\begin{align*}
&\text{H} \quad \text{H} \quad \text{H} \\
&\text{H} \quad \text{C} \quad \text{C} \quad \text{C} \\
&\text{H} \quad \text{H} \\
\end{align*}
\]

+ $\text{H} - \text{OH}$

This is the reaction used to join many amino acids together to form proteins.
This activity looks at some of the new reactions / families that you will meet in this Unit.

Much of the new Chemistry revolves round learning Oxidation in more detail.

As can be seen, there are 3 types of Alcohols to be learnt and they have different products - Aldehydes or Ketones, or none - when oxidised.

Ald are the intermediates formed when a Primary Alcohol is oxidised to eventually form an Acid.

Condensation becomes even more important - along with the reverse reaction, Hydrolysis.

Not just Est are formed by a Condensation reaction - Protein and Fats & Oils are also formed by Condensation and broken down by the Hydrolysis reaction.

So are the Salts of Fatty Acids formed when Alkaline Hydrolysis is done to a Fat or Oil.

Terpenes are natural hydrocarbons, found mainly in plants, formed by joining together smaller molecules called isoprene, 2-methylbuta-1,3-diene.

Terpenes belong to a group of chemicals usually referred to as essential oils which should not be mixed up with edible oils (Fats & Oils) and mineral oils derived from Crude Oil and made by the Petrochemical industry.
**Functional Groups & Properties**

This activity explains the functional groups found in these molecules and their possible effect on the chemical and physical properties of the molecule.

<table>
<thead>
<tr>
<th>Family Name</th>
<th>Functional Group</th>
<th>Name of Group</th>
<th>Chemical Reactions</th>
<th>Intermolecular Forces</th>
<th>Solubility in Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>alkane</td>
<td>( -\text{C-C-} )</td>
<td>carbon to carbon single</td>
<td></td>
<td>london dispersion forces</td>
<td>insoluble</td>
</tr>
<tr>
<td>alkene</td>
<td>( -\text{C=C-} )</td>
<td>carbon to carbon double</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>alcohol</td>
<td>( -\text{C-O-H} )</td>
<td></td>
<td>oxidation condensation</td>
<td></td>
<td>very soluble</td>
</tr>
<tr>
<td>alcohol</td>
<td>( -\text{C=O} )</td>
<td>aldehyde</td>
<td></td>
<td></td>
<td>limited solubility</td>
</tr>
<tr>
<td>ketone</td>
<td>( -\text{C=O} )</td>
<td></td>
<td>none</td>
<td>polar-polar</td>
<td></td>
</tr>
<tr>
<td>acid</td>
<td>( -\text{C-OH} )</td>
<td>acid</td>
<td></td>
<td></td>
<td>insoluble</td>
</tr>
<tr>
<td>ester</td>
<td>( -\text{C-C-OH} )</td>
<td></td>
<td>carboxylate group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>amine</td>
<td>( -\text{C-N-H} )</td>
<td></td>
<td>condensation</td>
<td>hydrogen bonding</td>
<td>very soluble</td>
</tr>
<tr>
<td>amide</td>
<td>( -\text{C-N-C} )</td>
<td></td>
<td>amide link</td>
<td></td>
<td>only small amides soluble</td>
</tr>
</tbody>
</table>
As well as determining their Chemical Reactions, Functional Groups can also affect the Physical Properties. Properties such as Volatility, Solubility, Melting Points (Mpts) & Boiling Points (BPts) are determined by the strength of the intermolecular forces (existing between molecules).

For example, the vanilla bean produces a compound called vanillin, which is used as a flavouring additive in sweet foods such as ice cream. This molecule has effectively, 4 functional groups:-

The benzene ring and the ether group (—O—CH₃) are dealt with in Advanced Higher.

The hydroxyl group (—OH) and the carbonyl group (—CH=O) will be expected to be learnt well this year.

Within the same molecule there can be non-polar groups such as the aromatic benzene ring, whilst the ether and aldehyde groups are slightly polar.

Probably the most influential group will be the very polar hydroxyl group which is capable of hydrogen bonding and may make this molecule water soluble.
Context - Kitchen Chemistry

This activity demonstrates how much of the Organic Chemistry met in this Unit will be taught within the context of Kitchen Chemistry.

Flavour

Most of our ‘tasting’ is done through our noses, so most flavour molecules are volatile (weak intermolecular forces) such as:

- **esters** - many have sweet fruity smells - e.g. ‘pear drops’ - pentyl ethanoate
- **aldehydes** - can however be oxidised over time resulting in (sometimes unpleasant) changes in flavour
- **terpenes** - ‘essential oils’ are responsible for many distinctive flavours such as cinnamon and ginger as well as oranges and lemons.
- **acids** - such as vinegar, ethanoic acid are used to introduce ‘sour’ flavours

Cooking

Cooking can dissolve out the flavour molecules so whilst many foods can be safely cooked in water, others are better cooked in oil.

Cooking also effects the structure of, in particular, **proteins** which can result in significant change in the texture of certain foods during cooking.

Texture

**Protein structure** has an important impact on the texture of food and can be effected by changes in temperature (cooking) and changes in pH (marinading in acids such as vinegar, ethanoic acid).

Foods, such as curries, often ‘separate’ into ‘water layer’ and ‘oil layer’ as a result of differences in solubility (different intermolecular forces).

Colour

Colour can arise in many ways but larger **terpenes** are often responsible for the yellow, orange or red colour of so many foods - e.g. carotene in carrots.

Energy

Whilst **carbohydrates**, our main ‘energy food’, are not covered in this course, **proteins** also contribute energy whilst **fats & oils** are our most concentrated source of energy.

Additives

**Antioxidants** - can be added to food, though many foods already contain Vitamin C - a natural antioxidant

**Emulsifying agents** - are used to prevent ‘water layers’ and ‘oily layers’ from separating. These molecules are often made from fats & oils and behave in exactly the same way as soap molecules. Milk contains natural emulsifiers.

In addition, many reactions triggered by **UV light**, such as the substitution reaction between alkanes and bromine, involve the production of **free radicals**. Free radicals start chain reactions which are responsible for the ageing of your skin. Sun cream contains chemicals designed to absorb UV before it reaches your skin.

**Vitamin E** and **melatonin** are natural free radical scavengers that can help counter the effect of free radicals. Many **cosmetic** products contain free radical scavengers which react with free radicals to form stable molecules and prevent chain-reactions starting.
5.2 Naming Molecules

This lesson largely revises the principles behind naming and how they can be applied in more complex molecules.

**Naming Alkanes**

This activity deals with how to name branched alkanes using systematic names, i.e. names that follow a very definite system which is based on the structure of the molecule.

In a *straight* chain hydrocarbon, all the carbon atoms in the molecule are linked one after the other in a *single* continuous chain.

In a *branched* chain hydrocarbon, the molecule has one or more *side* chains of carbon atoms off the main chain.

Due to *branching*, it is possible to have different structural arrangements for the same molecular formula. *Butane*, $C_4H_{10}$, has two different structures called *iso*. Clearly both of them cannot have exactly the same name.

**Naming Rules for Alkanes**

1. The *longest chain* defines the main chain and the last part of the name
2. *Numbering* of the main chain starts from the end that gives the lower overall number positions for side branches
3. *Side branch* names end in *‘-yl’* and depend on the number of carbon atoms in them: *methyl* for 1 carbon, *ethyl* for 2 carbon atoms, *propyl* for 3 carbon atoms, etc.
4. *Alphabetical order* is used if different side branches appear in the same structure (*ethyl* before *methyl*).
5. *Hyphens* are used before or after numbers that come next to letters within a name (2-ethyl-3-methyl..)
6. *Commas* are used between numbers showing more than one of the same side branch (2,2,3-trimethyl..)

<table>
<thead>
<tr>
<th>Full structural formula</th>
<th>Systematic name</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H} \quad \text{H} \quad \text{C} \quad \text{H}$</td>
<td>2-methylhexane</td>
</tr>
<tr>
<td>$\text{H} \quad \text{C} \quad \text{H} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{H}$</td>
<td>2,3-dimethylpentane</td>
</tr>
<tr>
<td>$\text{H} \quad \text{C} \quad \text{H} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{H}$</td>
<td>3-ethyl-2,4-dimethylhexane</td>
</tr>
</tbody>
</table>
### Shortened Structural Formulae

This activity is about writing and using shortened structural formulae for alkanes.

<table>
<thead>
<tr>
<th>Systematic Name</th>
<th>Full Structural Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-methylpentane</td>
<td></td>
</tr>
<tr>
<td>4,4-dimethyloctane</td>
<td></td>
</tr>
<tr>
<td>5-ethyl-2-methylheptane</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Full Structural Formula</th>
<th>Shortened Structural Formula</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Shortened Structural Formula</th>
<th>Systematic Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl(CH₃)₂</td>
<td>CH₃CH₂CH(CH₃)₂CH₂CH₂CH₃</td>
</tr>
<tr>
<td>CH₂CH₃</td>
<td>CH₃CH₂CH₂CH₂CHCH₃</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Systematic Name</th>
<th>Shortened Structural Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-methylpentane</td>
<td></td>
</tr>
<tr>
<td>2,4-dimethylhexane</td>
<td></td>
</tr>
</tbody>
</table>
This activity considers how to use systematic names to indicate both the positions of side branches and the position of the double bond in the alkene structure.

There are even more iso possible in the alkene family. Again there are str -chain alkenes and bra -chain alkenes.

In addition, it is possible to change the pos of the dou bond to introduce even more different struc formulae.

### Branched Alkene Structures

<table>
<thead>
<tr>
<th>Name:</th>
<th>5-methyloct-2-ene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Structural Formula:</td>
<td></td>
</tr>
<tr>
<td>Shortened Structural Formula:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Structural Formula:</td>
<td></td>
</tr>
<tr>
<td>Shortened Structural Formula:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Structural Formula:</td>
<td></td>
</tr>
<tr>
<td>Shortened Structural Formula:</td>
<td>CH₃ CH₃ CH₂CH₂CHCH₃</td>
</tr>
</tbody>
</table>
### Alkanols

This activity revises the alkanol family

The **functional group** in alkanols is the **Hydroxyl** group.

The **alkane** can be thought of as ‘**substituted alkanes**’ - a **hydrocarbon** chain with the **hydroxyl** group replacing one of the **hydrogen** atoms.

Like **water**, **alkanols** are **covalent** molecules and, as a result, are very **poor conductor** of electricity.

Like **water**, **alkanols** have a **polar** O—H bond which allows **hydrogen bonding** between molecules. As a result, water and smaller alkanols will ‘**dissolve**’ in each other as the **strength** of their **intermolecular forces** are very **similar**.

As well as sharing the same **general formula**, the **physical properties** of the alkanols such as **melting point** (inc), **boiling point** (inc) and **solubility in water** (dec) show a steady trend as the **molecular size** increases. For these reasons, the alkanols can be described as a **homo series**.

<table>
<thead>
<tr>
<th>Property</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td></td>
</tr>
<tr>
<td>Solubility</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
</tr>
<tr>
<td>Conduction</td>
<td></td>
</tr>
<tr>
<td>Burning</td>
<td></td>
</tr>
</tbody>
</table>
**Combustion of Ethanol**

This activity is about the products of combustion reaction of ethanol

\[
\text{ethanol} + \rightarrow +
\]

\[
C_2H_5OH + \rightarrow +
\]

The combustion of ethanol can be referred to as oxidation on the basis that the carbon and hydrogen are ‘gaining oxygen’. Later in this topic mild oxidation of alcohols will lead to totally different, and much more important, products - aldehydes, ketones and carboxylic acids.

**Straight-Chain Alkanols**

This activity considers how to use systematic names to indicate the position of the hydroxyl group in isomers

The position of the hydroxyl group can change to produce isomers without the need to introduce branches.

<table>
<thead>
<tr>
<th>Full Structural</th>
<th>- C - C - C-</th>
<th>- C - C - C-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortened Structural</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systematic Name</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
C_3H_6O \quad \text{Isomers don't have to be from the same homologous series}
\]

---

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### Straight-Chain Alkanols

<table>
<thead>
<tr>
<th>Name:</th>
<th>heptan-4-ol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Structural Formula:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name:</th>
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<tr>
<td><strong>Full Structural Formula:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Structural Formula:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
<td>CH₃CH₂CH₂CH₂CH₂CH₂CH₂OH</td>
</tr>
</tbody>
</table>

### Branched-Chain Isomers

This activity considers how to use systematic names to indicate both the position of the hydroxyl group and the branch position in isomers of branched-chain alkanols.

The ‘longest chain’ must include the functional group. The chain is numbered from the end nearest the functional group.

**Example A**

```
H
H-C-H
H H H H
H-C-C-C-C-C-O-H
H H H H H
```

**Example B**

```
H
H-C-H
H H H H H
H-C-C-C-C-C-C-H
H O H H H H H
```
### Branched-Chain Alkanols

<table>
<thead>
<tr>
<th>Name:</th>
<th>2-methylpentan-1-ol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Structural Formula:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Shortened</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Structural Formula:</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Structural Formula:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Shortened</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Structural Formula:</strong></td>
<td></td>
</tr>
</tbody>
</table>

#### Primary, Secondary & Tertiary

This activity relates the classification of alcohols to their molecular structures.

This is an example of a **primary alcohol**.

It is so-called because only one carbon is directly attached to the carbon with the hyd group. The hyd group is at the end of the chain.

**Systematic Name**

<table>
<thead>
<tr>
<th>Mild oxidation:</th>
<th>Primary alcohol</th>
<th>Aldehyde</th>
<th>Carboxylic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>C—OH</td>
<td>C = O</td>
<td>C = O</td>
</tr>
</tbody>
</table>

---

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**CFE New Higher**
This is an example of a **secondary alcohol**.

It is so-called because *two carbons* are directly attached to the carbon with the **hydroxyl** group.

The **hydroxyl** group is *along the chain*.

This is an example of a **tertiary alcohol**.

It is so-called because *three carbons* are directly attached to the carbon with the **hydroxyl** group.

The **hydroxyl** group is at *a branched position* of the chain.

---

**Ring Structures**

\[
\begin{array}{c}
\text{Systematic Name} \\
\text{mild oxidation :} \\
\text{secondary alcohol} \\
\text{OH} \\
\text{C—C—C} \\
\text{H} \\
\end{array}
\]

\[
\begin{array}{c}
\text{Systematic Name} \\
\text{mild oxidation :} \\
\text{tertiary alcohol} \\
\text{OH} \\
\text{C—C—C} \\
\text{CH}_3 \\
\end{array}
\]

---

**Cycloalkanols** are examples of **secondary** alcohols because there are *two carbons* attached to the carbon with the **hydroxyl** group - the hydroxyl group is ‘along the chain’.

Cycloalkanols are *not isomers* of alkanols, because there are *two less hydroxyl* groups in a ring structure compared to the equivalent chain structure.
Hydroxyl Group as Substituent

This activity demonstrates how the hydroxyl group is named in molecules with more important groups present.

In this molecule the carb acid group, —COOH, is more imp and the presence of the —OH is signified by the use of the prefix 'hydroxy' rather than the normal suffix '-ol'.

2-hydroxy-3-methylbutanoic acid

Other groups that you might meet as suffixes:-
—NH₂ amine becomes amino
—COOH carboxylic becomes carboxyl

You are already familiar with:-
CH₄ methane becoming methyl

But may also see:-
—O—CH₃ becoming methoxy

More Than One Hydroxyl Group

This activity looks at the structures and names of two alcohols which have more than one hydroxyl group

The common name for this alcohol is gly .
It is used as anti in car rad .
It contains two hyd group and can be referred to as a dih alcohol or a diol.

The common name for this alcohol is gly .
It has various culinary uses including ice-c
It contains three hyd group and can be referred to as a trih alcohol or a triol.
This activity considers the structures and systematic names of the alkanal series of aldehydes.

An alkanal is a compound which contains the carbonyl group at the end position of a hydrocarbon chain in which all the carbon atoms are linked by single bonds.

The functional group of an aldehyde contains the carbonyl group and a hydrogen atom - —CHO.

\[
\text{CH}_3\text{CHO}
\]

The longest carbon chain includes the functional group, so this molecule is named as ethanal.

The chain is always numbered from the end with the —CHO functional group.

<table>
<thead>
<tr>
<th>Alkanal Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name:</strong></td>
</tr>
<tr>
<td><strong>Full Structural Formula:</strong></td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
</tr>
<tr>
<td><strong>Name:</strong></td>
</tr>
<tr>
<td><strong>Full Structural Formula:</strong></td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
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<td><strong>Name:</strong></td>
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</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
</tr>
<tr>
<td><strong>Name:</strong></td>
</tr>
<tr>
<td><strong>Full Structural Formula:</strong></td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
</tr>
</tbody>
</table>
This activity considers how to apply systematic names to the alkanone family of ketones.

An *alkanone* is a compound which contains the *carbonyl* group at a position within a hydrocarbon chain where all the carbon atoms are linked by single bonds.

The *functional group* of a ketone is simply the *carbonyl* group by itself.

\[ CH_3COCH_3 \]

The longest carbon chain must include the *functional group*. This molecule is named as *propanone*.

The chain is always numbered from the end nearest the \(-\text{CO}-\) functional group.

### Alkanone Structures

<table>
<thead>
<tr>
<th>Name:</th>
<th>4-methylhexan-2-one</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Structural Formula:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
<td></td>
</tr>
<tr>
<td>Name:</td>
<td></td>
</tr>
<tr>
<td><strong>Full Structural Formula:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
<td></td>
</tr>
<tr>
<td>Name:</td>
<td></td>
</tr>
<tr>
<td><strong>Full Structural Formula:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
<td></td>
</tr>
</tbody>
</table>
**Alkanoic acids**

This activity considers the structures, formulae and systematic names of some of the members of the alkanoic acid family.

Any molecule that contains the *carb* group, —COOH, can be considered as a *carboxylic acid*. The molecule could have a *cha* structure, a *ri* structure, it could be *urated* (C—C) or *urated* (C=C or C≡C).

The *alkanoic acids* are compounds which contain the *carboxyl group* joined to a *hydrocarbon chain* in which all the carbon atoms are joined by *single* bonds.

As usual, there are three ways to represent the formula of, for example, *pentanoic acid*

\[
\text{full structural formula}
\]

\[
\text{shortened structural formula}
\]

\[
\text{functional molecular formula}
\]

For naming purposes, the *car* of the *car *func* group is always taken as number 1, and the ‘longest’ chain always starts with the *func* group. For example:

\[
\text{4-methylpentanoic acid} \quad \text{2-ethylbutanoic acid} \quad \text{2,2-dimethylpropanoic acid}
\]

**Simple Esters**

This activity deals with naming and drawing full and structural formulae for esters.

The ‘best’ way to think about an *ester* is to consider it as an *acid molecule* which has had its *hydrate* atom replaced by a *car* chain (an alkyl group).

Learn to draw acids and you should find esters easy.

\[
\text{ethylopropanoate}
\]

As is often the case, we ‘start’ at the end of the name. Identify the *acid* (look for the *carb* C = O) and give the *est* its *surn* by changing the —*oic* ending to —*oate*.

The *carbon chain* (derived from the parent *alc*) is the ‘chr’ name, —*ol* changed to —*yl*.
<table>
<thead>
<tr>
<th>Name:</th>
<th>Ester Structures &amp; Names</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Full</td>
<td>H H H O H</td>
</tr>
<tr>
<td>Structural</td>
<td>H—C—C—C—C—O—C—H</td>
</tr>
<tr>
<td>Formula:</td>
<td>H H H H</td>
</tr>
<tr>
<td>Shortened</td>
<td>Structural Formula:</td>
</tr>
<tr>
<td>Name:</td>
<td>pentyl propanoate</td>
</tr>
<tr>
<td></td>
<td>CH₃CH₂CH₂COOCH₂CH₂CH₂CH₃</td>
</tr>
<tr>
<td>Full</td>
<td>H H H H H H O H H</td>
</tr>
<tr>
<td>Structural</td>
<td>H—C—C—C—C—C—O—C—H</td>
</tr>
<tr>
<td>Formula:</td>
<td>H H H H H H H H H H H H</td>
</tr>
<tr>
<td>Shortened</td>
<td>Structural Formula:</td>
</tr>
<tr>
<td>Name:</td>
<td>CH₃CH₂CH₂CH₂CH₂CH₂COOCH₃</td>
</tr>
</tbody>
</table>
### Ester Structures & Names

| Name: | \[
\begin{align*}
    \text{Full} & : & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{O} & \quad \text{H} \\
    \text{Structural} & : & \quad \text{H} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{O} & \quad \text{C} & \quad \text{H} \\
    \text{Shortened} & : & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H}
\end{align*}
\] |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name:</td>
<td>pentyl propanoate</td>
</tr>
</tbody>
</table>
| Full | \[
\begin{align*}
    \text{Structural} & : \\
    \text{Formula:} & \quad \text{CH}_3\text{CH}_2\text{CH}_2\text{COOCH}_2\text{CH}_2\text{CH}_2\text{CH}_3
\end{align*}
\] |
| Name: | \[
\begin{align*}
    \text{Full} & : & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{O} & \quad \text{H} \\
    \text{Structural} & : & \quad \text{H} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{O} & \quad \text{C} & \quad \text{H} \\
    \text{Shortened} & : & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H}
\end{align*}
\] |
| Name: | \[
\begin{align*}
    \text{Full} & : & \quad \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{COOCH}_3
\end{align*}
\] |
5.3 Oxidation Reactions

This topic examines how the different types of alcohol are oxidised and the different types of product produced.

Comparing Oxidation

This activity compares the oxidation reactions of the three types of alcohol.

Acidified potassium dichromate is a mild oxidising agent that changes colour when it reacts.

\[
\text{Cr}_2\text{O}_7^{2-} + 14 \text{H}^+ + 6 \text{e}^- \rightarrow 2\text{Cr}^{3+} + 7 \text{H}_2\text{O}
\]

A large number of ions are consumed, hence the need to use an acidified solution or reaction would be too slow.

Three different types of alcohol were added to some dichromate solution and placed in a hot water bath for a few minutes.

<table>
<thead>
<tr>
<th>Name of alcohol</th>
<th>Type of alcohol</th>
<th>Colour change observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>butan-1-ol</td>
<td>primary</td>
<td></td>
</tr>
<tr>
<td>butan-2-ol</td>
<td>secondary</td>
<td></td>
</tr>
<tr>
<td>2-methylpropan-2-ol</td>
<td>tertiary</td>
<td></td>
</tr>
</tbody>
</table>

Both Prim and Sec alcohols can be oxidised but Tertiary alcohols cannot.

The Oxidation Reaction

This activity explains the changes which occur when different types of alcohol are oxidised.

Prim alcohols can be oxidised in two stages. The oxidising agent is simply the source of oxygen [O].

During the first stage the hydroxyl group C—OH is converted into a carbonyl group, C=O. The molecule produced is called an aldehyde.
The second stage sees the aldhyde converted into an acid.

\[
\begin{array}{c}
\text{R} \text{C} \equiv \text{O} \\
\text{H} & \text{[O]}
\end{array}
\xrightarrow{\text{[O]}}
\begin{array}{c}
\text{R} \text{C} \equiv \text{O} \\
\text{O} \equiv \text{H}
\end{array}
\]

Notice that oxi can involve the loss of hyd as well as the gain of ox (and, of course, oxidation is still the loss of elec).

In Organic Chemistry it is often more convenient to use the following definitions:

**OXIDATION** - an **increase** in the oxygen:hydrogen ratio (O or H)

**REDUCTION** - a **decrease** in the oxygen:hydrogen ratio (O or H)

<table>
<thead>
<tr>
<th>Name</th>
<th>Molecular Formula</th>
<th>Number of O atoms</th>
<th>Number of H atoms</th>
<th>Oxygen: Hydrogen ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethanol</td>
<td>C₂H₆O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ethanal</td>
<td>C₂H₄O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ethanoic acid</td>
<td>C₂H₄O</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sec alcohols can also be oxi, but they can only go through the first stage. Again, the oxidising agent is simply the source of oxy [O].

\[
\begin{array}{c}
\text{R} \text{C} \equiv \text{O} \equiv \text{H} \\
\text{R} & \text{H} & \text{[O]}
\end{array}
\xrightarrow{\text{[O]}}
\begin{array}{c}
\text{R} \text{C} \equiv \text{O} \\
\text{R} + \text{H}_2\text{O}
\end{array}
\]

Again, during the first stage of oxidation the hyd group C—OH is converted into a carb group, C=O. The molecule produced this time is called a ket. The absence of a hyd atom makes it impossible for this molecule to be oxi a second time to form an acid.

Ter alcohols cannot be oxi. The absence of hyd atoms makes oxidation impossible.

\[
\begin{array}{c}
\text{R} \text{C} \equiv \text{O} \equiv \text{H} \\
\text{R} & \text{R} & \text{[O]}
\end{array}
\xrightarrow{\text{[O]}}
\begin{array}{c}
\text{No Reaction}
\end{array}
\]
This activity investigates another method for oxidising primary and secondary alcohols.

When a primary alcohol is passed over heated copper (II) oxide the black oxide turns into red-brown copper metal.

A piece of pH paper held at the mouth of the test-tube turns red - an acid has been formed.

When a secondary alcohol is passed over heated copper (II) oxide the black oxide turns into red-brown copper metal.

A piece of pH paper held at the mouth of the test-tube stays the same because an acid has not been formed.

Summary

H
\[
\begin{align*}
\text{C—C—C—C—OH} & \quad \text{C—C—C—C=O} & \quad \text{C—C—C—C=O} \\
\text{H} & & \\
\end{align*}
\]

a primary alkanol
(—OH at end of chain)
butan-1-ol

an alkanal
(C=O at end of chain)
butanal

an alkanoic acid
(COOH at end of chain)
butanoic acid

H
\[
\begin{align*}
\text{C—C—C—C—OH} & \quad \text{C—C—C—C=O} \\
\text{H} & & \\
\end{align*}
\]

a secondary alkanol
(—OH in middle of chain)
butan-2-ol

a alkanone
(C=O in middle of chain)
butanone

H
\[
\begin{align*}
\text{C—C—C—C—OH} \\
\text{H} \\
\end{align*}
\]

a tertiary alkanol
(—OH at same place as a branch)
2-methylpropan-2-ol
This activity investigates other oxidising agents that can be used to distinguish aldehydes from ketones.

**Acidified potassium dichromate** is a mild oxidising agent that changes color when it reacts.

\[ \text{Cr}_2\text{O}_7^{2-} + 14 \text{H}^+ + 6 \text{e}^- \rightarrow 2\text{Cr}^{3+} + 7 \text{H}_2\text{O} \]

A large number of ions are consumed, hence the need to use an acidified solution or reaction would be too slow.

**Fehling** or **Benedict** are another two mild oxidising agents that change color when they react.

\[ \text{Cu}^{2+} \rightarrow \text{Cu}^+ \]

solution

blue

red-brown

solid

**Tollen** solution is another mild oxidising agent that changes state when it reacts.

\[ \text{Ag}^+ \rightarrow \text{Ag} \]

colourless

silvery

solution

solid

Sometimes the silver attaches to the surface to give a 'silver mirror' effect.

**Tollen** and **Fehling** solutions can only be used to oxidise aldehydes. They do not usually react with primary or secondary alcohols. This makes acidified dichromate the only 'universal oxidising agent'.

The aim of this activity is to introduce some of the oxygen containing compounds that have important roles as flavour molecules and the problems that oxidation can bring.

Though there are many molecules responsible for the valued smell of truffles, two alcohols and two aldehydes are found in the highest concentrations. Alcohols and aldehydes such as these are easily oxidised. When that happens, the truffles lose their characteristic aroma and flavour.

### Food Chemistry 1

Though there are many molecules responsible for the valued smell of truffles, two alcohols and two aldehydes are found in the highest concentrations. Alcohols and aldehydes such as these are easily oxidised. When that happens, the truffles lose their characteristic aroma and flavour.
Most flavour molecules are more complex, but many contain the alcohol, aldehyde or ketone functional groups. They can be, however, vulnerable to oxidation which will almost certainly change the nature of their flavour. While small acids such as meth and ethanoic acid are ‘vinegary’, others such as propanoic and butanoic acid are ‘cheesey’ and ‘sickly’ and can be responsible for the rancid smells of food ‘going off’.

\[
\text{HCH}_3\text{H} \quad \text{Benzaldehyde—almonds}
\]

\[
\text{CH}_2\text{O} \quad \text{Vanillin—vanilla beans}
\]

\[
\text{CH}_3\text{O} \quad \text{Cinnamaldehyde—cinnamon}
\]

\[
\text{CH}_3\text{C} \equiv \text{C} \equiv \text{CH} \quad \text{Citral—lemon grass}
\]

\[
\text{CH}_3\text{C} \equiv \text{CH} \quad \text{2-Octanone—mushroom flavoring}
\]

No oxidation product as this only contains the ketone group.
Free Radicals

The aim of this activity is to introduce free radicals.

Organic chemistry largely involves stable molecules with covalent bonds - a pair of electrons shared between two atoms.

- Ethene
- Ethanol
- Chloromethane

Often, reactions involve the breaking of polar bonds to form temporary, very reactive ions (the activated complex) and electrons tend to remain as a pair of electrons. Ions with 4 pairs of electrons - the stable octet - will not need to react further.

There are many reagents that can react with the methylene ion produced.

One of these is the hydroxide ion which will quickly react to form an alcohol.

Overall the reaction would be:

\[
\text{CH}_3\text{Cl} + \text{NaOH} \rightarrow \text{CH}_3\text{OH} + \text{NaCl}
\]
Whilst \textit{po bo} are generally easier to break, \textit{n-po bo} can also break, though extra \textit{en}, in the form of \textit{li}, is often required. When these bonds \textit{br}, each atom retains its own electron but very uns, very rea free radicals are formed.

\begin{align*}
\text{When } \text{li} \text{ of the correct } \text{en} \\
\text{strikes a } \text{bo}, \text{the } \text{en} \\
can be \text{ab}.
\end{align*}

\[
\text{Cl — Cl} \quad \rightarrow \quad 2 \text{Cl•}
\]

In \textit{chl mol}, \textit{Cl}_2, each \textit{chl at} is surrounded by 4 \textit{ele pa} and they are \textit{st}. When the bond \textit{bre}, each \textit{chl} atom has only 3 \textit{ele pa}. There are still eq num s of pr ( ) and ele ( ) present so these are at not io.

Similarly, the \textit{n-po O — O bo} in \textit{hy pero} can easily break to produce \textit{fr rad} :-

\[
\text{H — O — O — H} \quad \rightarrow \quad \text{H : O• •O : H}
\]

\section*{Free Radical Chain Reaction}

\textit{The aim of this activity is to examine how reactions involving free radicals lead to a chain reaction}.

When a \textit{fr rad} reacts with another \textit{mol}, a \textit{new fr rad} is always produced. This new \textit{fr rad} can then go on and react to pro ano free radical and so the rea con ‘forever’ - a ch rea.

For example, the \textit{sub} reaction between and \textit{alk} and a \textit{hal} has a number of steps which will repeat ‘forever’.

\textbf{Initiation:} needed to produce a free radical to start each chain.

\[
\text{Cl• •Cl:} \quad + \text{ photon (hv)} \quad \rightarrow \quad +
\]

\textbf{Propagation:} the steps that will see a free radical react but a new free radical produced to keep the chain reaction going.

\[
\text{H — C — H} \quad + \text{ Cl•} \quad \rightarrow \quad +
\]

methane \quad chlorine atom \quad methyl radical \quad hydrogen chloride
**Second propagation step**

\[
\begin{align*}
\text{H} & \quad \text{H} \quad \text{Cl} \quad + \quad \text{Cl}^- \\
\text{H} & \quad \text{C} \quad \text{H} \\
\end{align*}
\]

methyl radical  \hspace{1cm} \text{chlorine molecule} \hspace{1cm} \text{chloromethane} \hspace{1cm} \text{chlorine atom}

**Termination:** the steps that will see a chain eventually stopped

\[
\begin{align*}
\text{H} \quad \text{H} \quad \text{Cl}^- \\
\text{H} \quad \text{C} \quad \text{H} \\
\end{align*}
\]

Detailed descriptions of the steps involved in a reaction - showing the movement of electrons as bonds break and form - is called a Reaction Mechanism.

Overall the reaction is simply:

\[
\text{CH}_4 + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl}
\]

This is another example of a Substitution reaction and is the characteristic reaction of saturated hydrocarbons such as alkanes. The reaction with bromine vapour or bromine water is often used as the test for saturation. Both saturated and unsaturated molecules can decompose bromine, but at very different rates,

\[
\begin{align*}
\text{C}_2\text{H}_6 + \text{Br}_2 & \rightarrow \text{C}_2\text{H}_5\text{Br} + \text{HBr} \\
\text{C}_2\text{H}_4 + \text{Br}_2 & \rightarrow \text{C}_2\text{H}_4\text{Br}_2
\end{align*}
\]

sl, sub, add, in light, fa, add, even in dark
Free Radical Oxidation

The aim of this activity is to examine how free radical oxidation leads to problems with food shelf-life as well as natural ageing in organisms.

The radicals of most concern in biological systems are derived from oxygen and are known collectively as reactive oxygen species or RAS. The main 3 are opposite:

- Superoxide $O_2^-$
- Peroxide $O_2^{2-}$
- Hydroxyl $\text{OH}^-$

Whilst some radicals are formed by external processes, many are formed as necessary intermediates in a variety of normal biochemical reactions.

However, when generated in excess or not appropriately controlled (by natural antioxidants), radicals can wreak havoc on a broad range of macromolecules such as lipids (fats & oils), phospholipids (cell membranes) and proteins including parts of DNA and RNA.
Macromolecules such as lip (derived from fatty acids), pro and nuc acids (DNA) are particularly vulnerable to damage through a process known as lipid peroxidation.

The reaction between ox based rad and the C = C dou bond can often progress from:

\[-\text{OH} \quad \text{hyd}\]
\[\text{to} \quad -\text{C} = \text{O} \quad \text{carb}\]
\[\text{to} \quad -\text{COOH} \quad \text{carb}\]

and the carbon ch will often br at the site of the original C = C bond.

## Antioxidants

The aim of this activity is to examine some antioxidants and the types of food in which they can be found.

If fats oxi, they can produce “off” od and fla (stale, rancid odours). Many of the molecules produced are ald, ket or carb acids.

Many vit also oxidise and lose their activity.

If food pigm oxidise, they can change col completely. For example, red meat turns gray when the myoglobin pigm oxi. In this case, the product is not unsafe; it just looks less appealing.

Antioxidants can be classified as one of two types:

‘traditional’ red agents or free rad scav

Wine makers, for example, use SO₂ and/or sulph (SO₂ → SO₃²⁻ in water) to slow down or prevent oxidation. Sausages and other processed meats similarly use sulph or nitr as pres.

Similarly, Vit C (ascorbic acid) is a natural anti found in many foods.
Many of our *anti* **oxidants** are also *free radical scavengers* which can react with free radicals but form stable molecules and prevent chain reactions.

By moving the single electron around the molecule, it is possible to form a stable radical and stop the chain reaction. In addition, this molecule can go on and 'mop up' a second radical making them even more effective.

### Free Radical Scavengers

The aim of this activity is to examine some other applications of Free Radical Scavengers.

It is not just food that we need to protect from oxidation, particularly free radical oxidation brought about by exposure to UV radiation present in sunlight.

**Sun Blocks:** whilst they contain white pigments such as titanium oxide, which try and block the UV light, they also contain free radical scavengers to help minimise the damage caused by free radicals - such as aging of the skin.

**Cosmetics:** for similar reasons, many cosmetics now include free radical scavengers among their ingredients.

**Plastics:** many plastics contain groups that are vulnerable to free radical oxidation so free radical scavengers are added to prolong their use.

However, other plastics deliberately incorporate UV-absorbing groups to accelerate the breakdown of the plastic and make it more biodegradable.