Unit 2:

Nature's Chemistry

Pupil Notes
Part 1

Systematic Organic
in
Context
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 2 reactant molecules react to form 2 product molecules.

Equation using systematic names:

\[
\text{methane} + \text{chlorine} \rightarrow \text{chloromethane} + \text{hydrogen chloride}
\]

Equation using full structural formulae:

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

Equation using shortened structural formulae:

\[
\text{CH}_4(g) + \text{Cl}_2(g) \rightarrow \text{CH}_3\text{Cl}_1(g) + \text{HCl}_1(g)
\]
**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:**

\[
\text{propane} \rightarrow \text{propene} + \text{hydrogen}
\]

**Equation using full structural formulae:**

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

**Equation using shortened structural formulae:**

\[
\begin{align*}
\text{CH}_3\text{CH}_2\text{CH}_3(\text{g}) & \rightarrow \text{CH}_3\text{CHCH}_2(\text{g}) + \text{H}_2(\text{g})
\end{align*}
\]

**Dehydration** - a specific elimination reaction in which neighbouring hydrogen atom 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:**

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

**Equation using full structural formulae:**

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

**Equation using shortened structural formulae:**

\[
\begin{align*}
\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} (\text{l}) & \rightarrow \text{CH}_3\text{CHCH}_2(\text{g}) + \text{H}_2\text{O} (\text{l})
\end{align*}
\]

**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 - addition of hydrogen

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

Equation using full structural formulae:
\[
\begin{array}{cc}
\text{H} & \text{H} & \text{H} \\
| & | & | \\
\text{H—C—C = C—H} & + & \text{H—H} \\
| & | & | \\
\text{H}
\end{array}
\rightarrow
\begin{array}{cc}
\text{H} & \text{H} & \text{H} \\
| & | & | \\
\text{H—C—C—C—H} \\
| & | & | \\
\text{H} & \text{H} & \text{H}
\end{array}
\]

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

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 - addition of halogen

Equation using systematic names:
\[
\text{propene} + \text{bromine} \rightarrow 1,2\text{-dibromopropane}
\]

Equation using full structural formulae:
\[
\begin{array}{cc}
\text{H} & \text{H} & \text{H} \\
| & | & | \\
\text{H—C—C = C—H} & + & \text{Br—Br} \\
| & | & | \\
\text{H}
\end{array}
\rightarrow
\begin{array}{cc}
\text{H} & \text{H} & \text{H} \\
| & | & | \\
\text{H—C—C—C—H} \\
| & | & | \\
\text{H} & \text{Br} & \text{Br}
\end{array}
\]

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

The addition 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 bromine, orange \rightarrow colourless
chlorine, green \rightarrow colourless
iodine, brown \rightarrow colourless
Hydrohalogenation - addition of hydrogen halide

Equation using systematic names:

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

Equation using full structural formulae:

\[
\begin{align*}
\text{H} & \quad \text{H} & \quad \text{H} \\
| & | & | \\
\text{H} & - \text{C} & - \text{C} & \longrightarrow & \text{C} & - \text{H} \\
| & | & | & | & | \\
\text{H} & - \text{I} & & & & \\
\text{H}
\end{align*}
\]

Equation using shortened structural formulae:

\[
\begin{align*}
\text{CH}_3 \text{CHCH}_2 \text{(g)} & + \text{HI} \text{(g)} \rightarrow \text{CH}_3 \text{CH}_2 \text{CHI} \text{(l)}
\end{align*}
\]

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 - addition of water

Equation using systematic names:

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

Equation using full structural formulae:

\[
\begin{align*}
\text{H} & \quad \text{H} & \quad \text{H} \\
| & | & | \\
\text{H} & - \text{C} & - \text{C} & \longrightarrow & \text{C} & - \text{H} \\
| & | & | & | & | \\
\text{H} & - \text{OH} & & & & \\
\text{H}
\end{align*}
\]

Equation using shortened structural formulae:

\[
\begin{align*}
\text{CH}_3 \text{CHCH}_2 \text{(g)} & + \text{H}_2\text{O} \text{(l)} \rightarrow \text{CH}_3 \text{CH}_2 \text{CHOH} \text{(l)}
\end{align*}
\]

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:*

\[
\text{propanoic acid} \quad + \quad \text{ethanol} \quad \longrightarrow \quad \text{ethyl propanoate}
\]

*Equation using full structural formulae:*

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

*Equation using shortened structural formulae:*

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

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.

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.

Aldehydes 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 Esters are formed by a Condensation reaction - Proteins and Fats & Oils are also formed by Condensation and broken down by the Hydrolysis reaction.

Soaps are the Salts of Fatty Acids formed when Alkali 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.
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>-C─C─</td>
<td>carbon to carbon</td>
<td>substitution</td>
<td>london dispersion</td>
<td>insoluble</td>
</tr>
<tr>
<td></td>
<td></td>
<td>single</td>
<td></td>
<td>forces</td>
<td></td>
</tr>
<tr>
<td>alkene</td>
<td>-C═C</td>
<td>carbon to carbon</td>
<td>addition</td>
<td>london dispersion</td>
<td>insoluble</td>
</tr>
<tr>
<td></td>
<td></td>
<td>double</td>
<td></td>
<td>forces</td>
<td></td>
</tr>
<tr>
<td>alcohol</td>
<td>-C─O─H</td>
<td>hydroxyl group</td>
<td>oxidation</td>
<td>hydrogen bonding</td>
<td>very soluble</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>condensation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>aldehyde</td>
<td>-C=O</td>
<td>carbonyl group</td>
<td>oxidation</td>
<td>polar-polar</td>
<td>limited solubility</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ketone</td>
<td>-C─O─C</td>
<td>carbonyl group</td>
<td>none</td>
<td>polar-polar</td>
<td>limited solubility</td>
</tr>
<tr>
<td>acid</td>
<td>-C─C=O-H</td>
<td>carboxyl group</td>
<td>condensation</td>
<td>hydrogen bonding</td>
<td>very soluble</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ester</td>
<td>-C─C─O─C─</td>
<td>carboxylate group</td>
<td>hydrolysis</td>
<td>polar-polar</td>
<td>insoluble</td>
</tr>
<tr>
<td>amine</td>
<td>-C─N─H</td>
<td>amino group</td>
<td>condensation</td>
<td>hydrogen bonding</td>
<td>very soluble</td>
</tr>
<tr>
<td>amide</td>
<td>-C─N═C─C─</td>
<td>amide link</td>
<td>hydrolysis</td>
<td>hydrogen bonding</td>
<td>only small amides</td>
</tr>
</tbody>
</table>
As well as determining their **Chemical Reactions, Functional Groups** can also affect the **Physical Properties**. Properties such as

Volutyly

Solubility

Mpts & 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 (carbonyl) 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 ‘oily 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.