Higher Chemistry

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

Unit 2:

Nature's Chemistry

Student:

Pupil Notes

Part 4

Acids & Esters

Fats & Oils

Terpenes

Proteins
5.4A Alkanoic Acids

This first topic revises the names, formulae and structures of the family of acids called the alkanoic acids

Ethanoic Acid

This activity considers the formation and structure of the alkanoic acid called ethanoic acid.

Ethanoic acid is normally manufactured from ethanol. The oxygen required for the oxidation reaction can come from the air or from an oxidising agent such as copper(II) oxide.

During the first oxidation step, the hydroxyl group is converted into a carbonyl group: ethanol is converted into ethanal

\[
\begin{align*}
\text{H}_3\text{C}-\text{C} & - \text{OH} + [\text{O}] \rightarrow \text{H}_3\text{C}-\text{C} = \text{O} \\
\text{C}_2\text{H}_5\text{OH} & \quad \text{CH}_3\text{CHO}
\end{align*}
\]

During the second oxidation step, an oxygen atom is inserted to convert the carbonyl group into a carboxyl group: ethanal is converted into ethanoic acid.

\[
\begin{align*}
\text{H}_3\text{C}-\text{C} & = \text{O} + [\text{O}] \rightarrow \text{H}_3\text{C}-\text{C} = \text{O} \\
\text{CH}_3\text{CHO} & \quad \text{CH}_3\text{COOH}
\end{align*}
\]

carboxyl group is the functional group of an acid

Alkanoic Acids

This activity considers the alkanoic acids as a homologous series.

<table>
<thead>
<tr>
<th>a)</th>
<th>Chemical properties</th>
<th>Ethanoic acid</th>
<th>Propanoic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Smell &amp; Appearance</td>
<td>'vinegary'</td>
<td>'cheesey'</td>
</tr>
<tr>
<td></td>
<td>colourless liquid</td>
<td>colourless liquid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Universal indicator</td>
<td>soluble</td>
<td>soluble</td>
</tr>
<tr>
<td></td>
<td>pink, pH &lt; 7</td>
<td>pink, pH &lt; 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Magnesium</td>
<td>'fizzes'</td>
<td>'fizzes'</td>
</tr>
<tr>
<td></td>
<td>(hydrogen gas)</td>
<td>(hydrogen gas)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calcium carbonate</td>
<td>'fizzes'</td>
<td>'fizzes'</td>
</tr>
<tr>
<td></td>
<td>(CO₂ gas)</td>
<td>(CO₂ gas)</td>
<td></td>
</tr>
</tbody>
</table>
b) Boiling point trend

![Boiling point graph]

- 100
- 110
- 120
- 130
- 140
- 150
- 160

Boiling point (°C)


c) General formula

The general formula for the alkanoic acids is:-

\[ C_nH_{2n+1}COOH \]

Notice that one of the carbon atoms is not included in the \( C_n \) ‘chain’. This is to enable the carboxyl functional group to be emphasised. **WARNING**! - this means that for each acid \( n \) is one less than you'd expect; methanoic \( n = 0 \), ethanoic \( n = 1 \), etc.

From all this it can be seen that the **alkanoic acids** have:

1. similar chemical properties
2. physical properties that show a steady trend

and
3. a common general formula, so they belong to a **homologous series**


d) 'Normal' Acid Reactions

Alkanoic acids do all the 'normal' acid reactions

- Ethanoic acid reacts with hydrogen chloride to form hydrochloric acid:

  \[ H^+ Cl^- (aq) \]

- Ethanoic acid reacts with hydrogen ions to form ethanoate ion:

  \[ H^+ CH_3COO^- (aq) \]
### Acid + metal → salt + hydrogen

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>magnesium + sulfuric acid</td>
<td>magnesium sulfate + hydrogen</td>
</tr>
<tr>
<td>$\text{Mg}_{(s)} + \text{H}_2\text{SO}_4(aq)$</td>
<td>$\text{MgSO}_4(aq) + \text{H}_2(g)$</td>
</tr>
<tr>
<td>magnesium + ethanoic acid</td>
<td>magnesium ethanoate + hydrogen</td>
</tr>
<tr>
<td>$\text{Mg}_{(s)} + \text{CH}<em>3\text{COOH}</em>{(aq)}$</td>
<td>$\text{Mg(CH}_3\text{COO})_2(aq) + \text{H}_2(g)$</td>
</tr>
</tbody>
</table>

### Acid + metal oxide → salt + water

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>iron (III) oxide + nitric acid</td>
<td>iron(III) nitrate + water</td>
</tr>
<tr>
<td>$\text{Fe}_2\text{O}_3(s) + 6 \text{HNO}_3(aq)$</td>
<td>$2 \text{Fe(NO}_3)_3(aq) + 3 \text{H}_2\text{O}(l)$</td>
</tr>
<tr>
<td>sodium oxide + methanoic acid</td>
<td>sodium methanoate + water</td>
</tr>
<tr>
<td>$\text{Na}<em>2\text{O}(s) + 2 \text{HCOOH}</em>{(aq)}$</td>
<td>$2 \text{NaHCOO}_2(aq) + \text{H}_2\text{O}(l)$</td>
</tr>
</tbody>
</table>

### Acid + alkali → salt + water

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>potassium hydroxide + hydrochloric acid</td>
<td>potassium chloride + water</td>
</tr>
<tr>
<td>$\text{KOH}<em>{(s)} + \text{HCl}</em>{(aq)}$</td>
<td>$\text{KCl}_{(aq)} + \text{H}_2\text{O}(l)$</td>
</tr>
<tr>
<td>lithium hydroxide + ethanoic acid</td>
<td>potassium ethanoate + water</td>
</tr>
<tr>
<td>$\text{LiOH}_{(s)} + \text{CH}<em>3\text{COOH}</em>{(aq)}$</td>
<td>$\text{LiCH}<em>3\text{COO}</em>{(aq)} + \text{H}_2\text{O}(l)$</td>
</tr>
</tbody>
</table>
**Acid + metal carbonate → salt + water + carbon dioxide**

e.g. calcium + hydrochloric acid → calcium + water + carbon dioxide

\[ \text{CaCO}_3 (s) + 2 \text{HCl} \text{(aq)} \rightarrow \text{CaCl}_2 \text{(aq)} + \text{H}_2 \text{O} \text{(l)} + \text{CO}_2 \text{(g)} \]

sodium + methanoic acid → sodium + water + carbon dioxide

\[ \text{Na}_2 \text{CO}_3 (s) + 2 \text{HCOOH} \text{(aq)} \rightarrow 2 \text{NaHCOO} \text{(aq)} + \text{H}_2 \text{O} \text{(l)} + \text{CO}_2 \text{(g)} \]

e) ‘Organic’ Acid Reactions

Alkanoic acids also have reactions that are characteristic of **organic carboxylic acid** reactions

**Condensation:** reaction in which two molecules join together, usually in the presence of a catalyst, with elimination of water or some other simple molecule.

To **join together**, each molecule must **lose** some of the existing atoms attached to the **carbon** atom with the **functional group**.

The **hydroxyl group** on the **alcohol** will have to lose its **hydrogen** atom, −H.

The **carboxyl group** on the **acid** loses its −OH group.

The whole reaction is helped by the fact that an −OH group and an −H atom will then be able to form a **stable molecule**, water (H₂O).

**Reduction:** reaction in which the oxygen:hydrogen ratio decreases

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

In other words, it is possible to **reverse** the oxidation reactions met earlier using a **reducing agent** such as LiAlH₄:

carboxylic acid → aldehyde → primary alcohol

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

Any molecule that contains the **carboxyl group**, —COOH, can be considered as a **carboxylic acid**. The molecule could have a **chain** structure, a **ring** structure or even be **aromatic**, it could be **saturated** (C—C) or **unsaturated** (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**

**full structural formula**

```
H     H     H     H      O
|       |        |      |       ||
H — C — C — C — C — O — H
|       |        |      |       |
H     H     H     H
```

**shortened structural formula**

```
CH₃CH₂CH₂CH₂COOH
```

**functional molecular formula**

```
C₄H₉COOH
```

For naming purposes, the **carbon** of the **carboxyl functional group** is always taken as number 1, and the ‘**longest**’ chain always starts with the **functional group**. **Branches** must then be **numbered** accordingly. For example:

```
H     CH₃   O
|       |        ||
H — C — C  — C — O — H
|       |        |
H     H
```

2-methylpropanoic acid

```
H     CH₃   H     H     O
|       |        |      |       ||
H — C — C — C — C — C — O — H
|       |        |      |       |
H     H     CH₃ H
```

3,4-dimethylpentanoic acid

```
H     CH₃   H     O
|       |        ||
H — C — C — C — C — O — H
|       |        |
H     CH₃ H
```

3,3-dimethylbutanoic acid

```
H     C₂H₅   H     O
|       |        ||
H — C — C — C — C — O — H
|       |        |
H     H     H
```

3-methylpentanoic acid
Uses of Acids

This activity is looks at the variety of acids and some of their uses

**ethanoic acid**
Responsible for the pungent smell of vinegar

**butanoic acid**
Responsible for the rancid odour of sour butter

**hexanoic acid**
Responsible for the odour of smelly feet

**lactic acid**
Responsible for the taste of sour milk

**acetylsalicylic acid**
Aspirin: a widely used analgesic

**p-aminosalicylic acid**
Used in the treatment of tuberculosis

**isotretinoin**
Used in the treatment of acne

<table>
<thead>
<tr>
<th>Carbon atoms</th>
<th>Common name</th>
<th>IUPAC name</th>
<th>Chemical formula</th>
<th>Common location or use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Formic acid</td>
<td>Methanoic acid</td>
<td>HCOOH</td>
<td>Insect stings</td>
</tr>
<tr>
<td>2</td>
<td>Acetic acid</td>
<td>Ethanoic acid</td>
<td>CH₃COOH</td>
<td>Vinegar</td>
</tr>
<tr>
<td>3</td>
<td>Propionic acid</td>
<td>Propanoic acid</td>
<td>CH₃CH₂COOH</td>
<td>Preservative for stored grains</td>
</tr>
<tr>
<td>4</td>
<td>Butyric acid</td>
<td>Butanoic acid</td>
<td>CH₃(CH₂)₂COOH</td>
<td>Butter</td>
</tr>
<tr>
<td>5</td>
<td>Valeric acid</td>
<td>Pentanoic acid</td>
<td>CH₃(CH₂)₃COOH</td>
<td>Valerian</td>
</tr>
<tr>
<td>6</td>
<td>Caproic acid</td>
<td>Hexanoic acid</td>
<td>CH₃(CH₂)₄COOH</td>
<td>Goat fat</td>
</tr>
<tr>
<td>7</td>
<td>Enanthal acid</td>
<td>Heptanoic acid</td>
<td>CH₃(CH₂)₅COOH</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Caprylic acid</td>
<td>Octanoic acid</td>
<td>CH₃(CH₂)₆COOH</td>
<td>Coconuts and breast milk</td>
</tr>
<tr>
<td>9</td>
<td>Pelargonic acid</td>
<td>Nonanoic acid</td>
<td>CH₃(CH₂)₇COOH</td>
<td>Pelargonium</td>
</tr>
<tr>
<td>10</td>
<td>Capric acid</td>
<td>Decanoic acid</td>
<td>CH₃(CH₂)₈COOH</td>
<td>Coconut and Palm kernel oil</td>
</tr>
<tr>
<td>11</td>
<td>Undecyl acid</td>
<td>Undecanoic acid</td>
<td>CH₃(CH₂)₉COOH</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Lauric acid</td>
<td>Dodecanoic acid</td>
<td>CH₃(CH₂)₁₀COOH</td>
<td>Coconut oil and hand wash soaps.</td>
</tr>
<tr>
<td>13</td>
<td>Tridecyl acid</td>
<td>Tridecanoic acid</td>
<td>CH₃(CH₂)₁₁COOH</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Myristic acid</td>
<td>Tetradecanoic acid</td>
<td>CH₃(CH₂)₁₂COOH</td>
<td>Nutmeg</td>
</tr>
<tr>
<td>15</td>
<td>Pentadecyl acid</td>
<td>Palmitic acid</td>
<td>CH₃(CH₂)₁₃COOH</td>
<td>Palm oil</td>
</tr>
<tr>
<td>16</td>
<td>Palmitic acid</td>
<td>Hexadecanoic acid</td>
<td>CH₃(CH₂)₁₄COOH</td>
<td>Palm oil</td>
</tr>
<tr>
<td>17</td>
<td>Margaric acid</td>
<td>Heptadecanoic acid</td>
<td>CH₃(CH₂)₁₅COOH</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Stearic acid</td>
<td>Octadecanoic acid</td>
<td>CH₃(CH₂)₁₆COOH</td>
<td>Chocolate, waxes, soaps, and oils</td>
</tr>
<tr>
<td>19</td>
<td>Nonadecyl acid</td>
<td>Nonadecanoic acid</td>
<td>CH₃(CH₂)₁₇COOH</td>
<td>Fats, vegetable oils, pheromone</td>
</tr>
<tr>
<td>20</td>
<td>Arachidic acid</td>
<td>Icosanoic acid</td>
<td>CH₃(CH₂)₁₈COOH</td>
<td>Peanut oil</td>
</tr>
</tbody>
</table>
**Self Check**

**Q1.** Which of the following is a word equation for the manufacture of ethanoic acid?
A copper + ethanol $\rightarrow$ oxygen + ethanoic acid  
B oxygen + ethanol $\rightarrow$ copper + ethanoic acid  
C oxygen + ethanol $\rightarrow$ water + ethanoic acid  
D water + ethanol $\rightarrow$ oxygen + ethanoic acid.

**Q2.** The functional group in an ethanoic acid molecule is called the
A methyl group  
B carboxyl group  
C carbonyl group  
D hydroxyl group.

**Q3.** Which result is obtained when magnesium is put in 0.1 M ethanoic and propanoic acids?
- **ethanoic acid**  
- **propanoic acid**
A bubbles bubbles  
B no bubbles bubbles  
C bubbles no bubbles  
D no bubbles no bubbles.

**Q4.** What is the general formula for an alkanoic acid?
A $C_nH_{2n}COOH$  
B $C_nH_{2n+1}COOH$  
C $C_nH_{2n-1}COOH$  
D $C_nH_{2n+2}COOH$.

**Q5.** Which of the following formulae could represent hexanoic acid?
A $C_6H_{13}COOH$  
B $C_5H_9COOH$  
C $C_5H_{11}COOH$  
D $C_6H_{11}COOH$.

**Q6.** Which of the following structures represents an alkanoic acid?

**Q7.** The systematic name for this molecules is
A 2-methylheptanoic acid.  
B 2-methyloctanoic acid.  
C 6-methylheptanoic acid.  
D 7-methyloctanoic acid.

**Q8.** What is the shortened structural formula for 2-ethylbutanoic acid?

**Q9.** The conversion of butanoic acid to butanal is known as
A condensation  
B oxidation  
C reduction  
D substitution.
# Home Practice 5.4A

## Q1. Name each of the following molecules.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>C₂H₅COOH</td>
</tr>
<tr>
<td>b)</td>
<td>CH₃CH₂CH₂CH₂COOH</td>
</tr>
</tbody>
</table>

## Q2. Draw the full structural formula for each of the following substances.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>methanoic acid</td>
</tr>
<tr>
<td>b)</td>
<td>2-methylbutanoic acid</td>
</tr>
</tbody>
</table>

## Q3. Draw the shortened structural formula for each of the following substances.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>hexanoic acid</td>
</tr>
<tr>
<td>b)</td>
<td>4-methylpentanoic acid</td>
</tr>
</tbody>
</table>

## Q4. All of the substances above are examples of one type of organic compound.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>Name the homologous series to which they belong.</td>
</tr>
<tr>
<td>b)</td>
<td>Name the wider class of organic compound to which they also belong.</td>
</tr>
<tr>
<td>c)</td>
<td>Name the functional group which characterises these compounds.</td>
</tr>
<tr>
<td>d)</td>
<td>Explain of the three acids - butanoic, octanoic, or hexanoic acid - would you expect to have the highest boiling point?</td>
</tr>
</tbody>
</table>

## Q5. Dental anaesthetics are substances used to reduce discomfort during treatment.

Lidocaine is a dental anaesthetic.

Lidocaine causes numbness when applied to the gums. This effect wears off as the lidocaine is hydrolysed.

One of the products of the hydrolysis of lidocaine is compound C.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>Name the functional group circled above.</td>
</tr>
<tr>
<td>b)</td>
<td>Draw a structural formula for the organic compound formed when compound C reacts with NaOH(_{aq})</td>
</tr>
<tr>
<td>c)</td>
<td>Draw a structural formula for both organic compounds that could be formed when compound C is reduced by reacting with NaAlH(_₄).</td>
</tr>
</tbody>
</table>

Total (14)
5.4B ESTERS - Flavour Molecules

This second topic revises the group of substances known as esters and looks at their properties, their uses, and how they are related to alcohols and carboxylic acids.

Properties & Uses

This activity is about the properties and uses of esters, in particular an ester called pentyl ethanoate (amyl acetate)

<table>
<thead>
<tr>
<th>Property</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>clear, colourless liquid</td>
</tr>
<tr>
<td>Smell</td>
<td>sweet, pleasant - 'pear drops'</td>
</tr>
<tr>
<td>Solubility</td>
<td>immiscible in water - separate layers</td>
</tr>
<tr>
<td>pH</td>
<td>neutral, pH = 7, no H⁺ or OH⁻</td>
</tr>
<tr>
<td>Solvent action</td>
<td>dissolves many non-polar &amp; polar substances</td>
</tr>
</tbody>
</table>

The 3 main uses of esters are as:

① **flavourings** - in foodstuffs
② **solvents** - e.g. used in nail varnish
③ **perfumes** - are volatile, so quickly releases vapour

Being volatile often makes them very flammable.

Ester Names

This activity considers the names of esters and how they relate to the alcohol and carboxylic acid from which the ester can be made.

An ester is a substance which is formed by the condensation reaction of an alcohol with a carboxylic acid.

Each ester can thought of as having a ‘parent alcohol’ from which it is formed. The ‘parent alcohol’ provides the ‘christian name’ of the ester. The alcohol name has the ‘—ol’ ending replaced with an ‘—yl’ ending.

<table>
<thead>
<tr>
<th>‘parent alcohol’</th>
<th>ester ‘christian name’</th>
</tr>
</thead>
<tbody>
<tr>
<td>methanol</td>
<td>methyl</td>
</tr>
<tr>
<td>ethanol</td>
<td>ethyl</td>
</tr>
<tr>
<td>propanol</td>
<td>propyl</td>
</tr>
<tr>
<td>butanol</td>
<td>butyl</td>
</tr>
</tbody>
</table>
Each ester also has a ‘parent’ carboxylic acid from which it is formed. The ‘parent acid’ provides the ‘surname’ of the ester. The acid name has the ‘—oic’ ending replaced with an ‘—oate’ ending.

<table>
<thead>
<tr>
<th>‘parent acid’</th>
<th>ester ‘surname’</th>
</tr>
</thead>
<tbody>
<tr>
<td>methanoic</td>
<td>methanoate</td>
</tr>
<tr>
<td>ethanoic</td>
<td>ethanoate</td>
</tr>
<tr>
<td>propanoic</td>
<td>propanoate</td>
</tr>
<tr>
<td>butanoic</td>
<td>butanoate</td>
</tr>
</tbody>
</table>

For example,

pentyl ethanoate

parent alcohol = pentanol

parent acid = ethanoic acid

<table>
<thead>
<tr>
<th>parent alcohol</th>
<th>parent carboxylic acid</th>
<th>ester name</th>
<th>ester flavour</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethanol</td>
<td>methanoic acid</td>
<td>ethyl methanoate</td>
<td>rum</td>
</tr>
<tr>
<td>ethanol</td>
<td>ethanoic acid</td>
<td>ethyl ethanoate</td>
<td>sweet wine</td>
</tr>
<tr>
<td>pentan-1-ol</td>
<td>ethanoic acid</td>
<td>penty ethanoate</td>
<td>pear drop</td>
</tr>
<tr>
<td>ethanol</td>
<td>butanoic acid</td>
<td>ethyl butanoate</td>
<td>pineapple</td>
</tr>
</tbody>
</table>

**Functional Group**

This activity considers the functional group in an ester molecule by looking at how it is formed from the parent alcohol and the parent carboxylic acid.

Since all alcohols have the hydroxyl functional group they can all be represented by the simple model shown. The block stands for the rest of the molecule which, in alkanols, would be a hydrocarbon chain.

Since all acids have the carboxoxyl functional group they can all be represented by the simple model shown. The block stands for the rest of the molecule which, in alkanoic acids, would be a hydrocarbon chain.
To *join together*, each molecule must *lose* some of the existing atoms attached to the *carbon* atom with the *functional group*.

The *hydroxyl group* on the *alcohol* will have to lose its *hydrogen* atom, —H.  The *carboxyl group* on the *acid* loses its —OH group.

![Diagram of hydroxyl group](image1)

![Diagram of carboxyl group](image2)

The whole reaction is helped by the fact that an —OH group and an —H atom will then be able to form a *stable molecule*, *water* (H₂O).

The resulting *ester* molecule, formed by *joining* an *alcohol* to an *acid*, owes its *properties* to the group of atoms that now *link* the two molecules together. This can be called the *carboxylate group*, but is more often referred to as the ‘*ester link*’.

![Diagram of ester molecule](image3)

It is important to be able to recognise the *ester link* no matter how it is drawn.

You will also be expected to be able to redraw the *parent acid* and *parent alcohol* molecules, so whichever *carbon chain* is directly attached to the *carbonyl group*, C = O, must have been the *parent acid* and the other chain belonged to the *alcohol*.
## Self Check

### Q1. Esters are substances which
A often have poisonous vapours  
B are very soluble in water  
C often have pleasant tastes and smells  
D are liquids with acidic properties.

### Q2. Which of the following is not a use for pentyl ethanoate?
A colouring in food dyes  
B scent in perfume  
C flavouring in sweets  
D solvent in nail varnish.

### Q3. An ester can be made from
A a carboxylic acid and an alkane  
B an alcohol and a carboxylic acid  
C an alkane and an alcohol  
D a carboxylic acid and an alkene.

### Q4. Which of the following substances is an example of an ester?
A 2-methylbutane  
B methylpropanoic acid  
C methylpropanoate  
D 3-methylbutan-1-ol

### Q5. What is the parent alkanoic acid for pentyl ethanoate?
A heptanoic acid  
B pentanoic acid  
C methanoic acid  
D ethanoic acid

### Q6. What is the parent alkanol for pentyl ethanoate?
A heptanol  
B pentanol  
C methanol  
D ethanol

### Q7. What is the structure of the functional group in an ester molecule?

```
A \[ \overset{O}{} \quad \underset{C}{-O-} \]
B \[ \overset{O}{} \quad \underset{C}{-C-} \]
C \[ \overset{O}{} \quad \underset{-O}{C} \quad \underset{-O}{C} \]
D \[ \overset{O}{} \quad \underset{-C}{O} \quad \underset{-C}{O} \quad \underset{-H}{O} \]
```

### Q8. The functional group in an ester is called the
A carbonate group  
B carboxyl group  
C carbonyl group  
D carboxylate group.

### Q9. An ester has the following structural formula
\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{COOCH}_2\text{CH}_3 \]

The name of this ester is
A propyl propanoate  
B ethyl butanoate  
C butyl ethanoate  
D ethyl propanoate.
Q1. Name the ester formed from each of the following pairs of compounds.

   a) ethanol and butanoic acid
   b) propanoic acid and butanol

Q2. Identify three typical uses for esters from the selection given below.

<table>
<thead>
<tr>
<th>fertilisers</th>
<th>flavourings</th>
</tr>
</thead>
<tbody>
<tr>
<td>pigments</td>
<td>perfumes</td>
</tr>
<tr>
<td>explosives</td>
<td>solvents</td>
</tr>
<tr>
<td>vitamins</td>
<td>neutralisers</td>
</tr>
</tbody>
</table>

Q3. The diagram shows a simplified model of an ester molecule.

   [Diagram]

   a) Name the functional group in this molecule.
   b) Which part of the molecule, P or Q, came from the parent acid?

Q4. Name i) the parent acid and ii) the parent alcohol used to make each of the following esters.

   a) propyl hexanoate
   b) methyl octanoate

Q5. The table below shows the duration of numbness for common anaesthetics.

<table>
<thead>
<tr>
<th>Name of anaesthetic</th>
<th>Structure</th>
<th>Duration of numbness (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>procaine</td>
<td>![Structure of procaine]</td>
<td>7</td>
</tr>
<tr>
<td>lidocaine</td>
<td>![Structure of lidocaine]</td>
<td>96</td>
</tr>
<tr>
<td>mepivacaine</td>
<td>![Structure of mepivacaine]</td>
<td>114</td>
</tr>
<tr>
<td>anaesthetic X</td>
<td>![Structure of anaesthetic X]</td>
<td></td>
</tr>
</tbody>
</table>

   a) Which of the anaesthetics are esters? 1
   b) Which of the anaesthetics have amide links? 1
   c) Estimate the duration of numbness, in minutes, for anaesthetic X. 1

Total (14)
5.4c ESTERS - Condensation & Hydrolysis Reactions

This topic looks in more detail at how esters can be made from their parent compounds and how esters can then be broken down to produce the original alcohol and carboxylic acid molecules.

Formation Reaction

This activity considers the structural formulae of the molecules involved in the formation of an ester by the condensation reaction between methanol and ethanoic acid.

A condensation reaction occurs when two molecules each lose one or more atoms in order to join together. Another small molecule is also formed by the ‘lost’ atoms.

The other small molecule formed is often water, hence the use of the name condensation. However, other reactions that ‘form water’, such as neutralisation or the dehydration of alkanols to form alkenes, are not condensations because they do not result in the joining together of two molecules.

Word equation:

\[ \text{pentanol} + \text{ethanoic acid} \rightleftharpoons \text{pentyl ethanoate} + \text{water} \]

Equation using full structural formulae:

\[
\begin{align*}
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \quad \text{O} & \quad \text{H} \\
\uparrow & \quad \uparrow & \quad \uparrow & \quad \uparrow & \quad \uparrow & \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad
**Water Bath:** A beaker of water is heated until boiling and then the bunsen burner is put out - both alcohols and esters are very volatile / flammable - Safety

**Cold Finger:** To prevent loss of volatile chemicals during heating.

conc $\text{H}_2\text{SO}_4$: 5 drops of conc. $\text{H}_2\text{SO}_4$ were added by the teacher - Safety

By this stage, two layers may have formed. The very polar alcohol and carboxylic acid in one layer and the less polar ester floating above.

Adding water (with hydrogen bonding) will dissolve the alcohol and the acid as they also have hydrogen bonding groups. The ester only has polar:polar (dipole:dipole) intermolecular bonding.

The smell of the ethanoic acid (vinegar) is overpowering, so $\text{Na}_2\text{CO}_3$ solution was used instead - the acid is converted to ethanoate salt and fizzing can be used to tell when enough has been added.

By this stage, two definite layers will exist and the characteristic smell of the ester (top layer) will be obvious.

Alternatively, a separating funnel can be used - the more dense water layer (with unreacted alcohol and acid) can be let out of the bottom and then the less dense ester (top layer) is poured out of the top.

---

**Table of esters and their smells**

<table>
<thead>
<tr>
<th>Esters</th>
<th>methyl 1 carbon</th>
<th>ethyl 2 carbons</th>
<th>propyl 3 carbons</th>
<th>2-methyl propyl-4 carbons</th>
<th>butyl 5 carbons</th>
<th>penty 6 carbons</th>
<th>hexyl 7 carbons</th>
<th>benzyl benzene ring</th>
<th>heptyl 8 carbons</th>
<th>octyl 9 carbons</th>
<th>nonyl</th>
</tr>
</thead>
<tbody>
<tr>
<td>methanoate</td>
<td>ETHREAL</td>
<td>ETHREAL</td>
<td>ETHREAL</td>
<td>&quot;GREEN&quot;</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
</tr>
<tr>
<td>ethanoate</td>
<td>ETHREAL</td>
<td>ETHREAL</td>
<td>ETHREAL</td>
<td>&quot;GREEN&quot;</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
</tr>
<tr>
<td>propanoate</td>
<td>ETHREAL</td>
<td>ETHREAL</td>
<td>ETHREAL</td>
<td>&quot;GREEN&quot;</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
</tr>
<tr>
<td>2-methyl propanoate</td>
<td>ETHREAL</td>
<td>ETHREAL</td>
<td>ETHREAL</td>
<td>&quot;GREEN&quot;</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
</tr>
<tr>
<td>butanoate</td>
<td>ETHREAL</td>
<td>ETHREAL</td>
<td>ETHREAL</td>
<td>&quot;GREEN&quot;</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
<td>JASMINE</td>
</tr>
</tbody>
</table>
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 hydrogen atom replaced by a carbon chain (an alkyl group).

Learn to draw acids and you should find esters easy!

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

The carbon chain (derived from the parent alcohol) is the ‘Christian’ name, —ol changed to —yl.

**Ester Structures & Names**

<table>
<thead>
<tr>
<th>Name:</th>
<th>methylheptanoate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Structural Formula:</strong></td>
<td>H H H H H H O H</td>
</tr>
<tr>
<td></td>
<td>H—C—C—C—C—C—C—O—C—H</td>
</tr>
<tr>
<td></td>
<td>H H H H H H H</td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
<td>CH₃ CH₂ CH₂ CH₂ CH₂ CH₂ COO CH₃</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name:</th>
<th>pentyl propanoate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Structural Formula:</strong></td>
<td>H H H O H</td>
</tr>
<tr>
<td></td>
<td>H—C—C—C—O—C—H</td>
</tr>
<tr>
<td></td>
<td>H H H H H</td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
<td>CH₃ CH₂ CH₂ COO CH₃</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name:</th>
<th>ethyl propanoate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Structural Formula:</strong></td>
<td>H H H H O H</td>
</tr>
<tr>
<td></td>
<td>H—C—C—C—O—C—H</td>
</tr>
<tr>
<td></td>
<td>H H H H H</td>
</tr>
<tr>
<td><strong>Shortened Structural Formula:</strong></td>
<td>CH₃ CH₂ CH₂ COO CH₂ CH₃</td>
</tr>
</tbody>
</table>
The aim of this activity is to consider the hydrolysis of an ester to produce an alcohol and carboxylic acid.

The reagent needed for the hydrolysis reaction is dilute $\text{H}_2\text{SO}_4$. Again, it has two functions:

**Catalyst:** it provides $\text{H}^+_{(aq)}$ which help break the ester link but are then reformed.

**Reactant:** it provides the water molecules needed which speeds up the forward reaction and helps push the equilibrium mixture to the right.

\[
\text{pentyl ethanoate} + \text{water} \rightleftharpoons \text{pentanol} + \text{ethanoic acid}
\]

Water Bath: A beaker of water is heated until boiling and then the bunsen burner is put out - both alcohols and esters are very volatile / flammable - Safety

Cold Finger: To prevent loss of volatile chemicals during heating.

\[
\text{dil. } \text{H}_2\text{SO}_4: \text{ to provide water needed for hydrolysis and } \text{H}^+_{(aq)} \text{ to catalyse the reaction.}
\]

At the beginning, two layers will have formed. The very polar water in one layer with the less polar ester floating above.

Gradually, the ester layer will get smaller and the smell of the ethanoic acid (vinegar) may become strong enough to be detected over the smell of the ester - pear drops.

A more reliable way of telling that the hydrolysis has been successful would be to add a few drops of universal indicator - it will turn red.
**Self Check**

Q1. What is the general word equation for the formation of an ester?
A) **ALCOHOL + CARBOXYLIC ACID**
B) **ALCOHOL + CARBOXYLIC ACID**
C) **SULPHURIC ACID + CARBOXYLIC ACID**
D) **ALCOHOL + CARBOXYLIC ACID**

Q2. The formation of an ester is an example of
A) an addition reaction
B) a precipitation reaction
C) an oxidation reaction
D) a condensation reaction

Questions 3 and 4 refer to this diagram showing the preparation of an ester.

Q3. The test-tube with cold water is there to act as a
A) catalyst
B) condenser
C) evaporator
D) purifier

Q4. What substance is added to the reaction mixture to speed up the formation of ester?
A) concentrated nitric acid
B) deionised water
C) dilute hydrochloric acid
D) concentrated sulphuric acid

Q5. Which of the following is not true of the two molecules in a condensation reaction?
A) The two reactant molecules form a larger product molecule.
B) A small molecule is formed from atoms taken from two functional groups.
C) The reactant molecules add together to form a single product.
D) Each reactant molecule must have a reactive functional group.

Q6. Which ester is formed by the reaction of \( CH_3COOH \) with \( CH_3CH_2CH_2OH \)?

Q7. What is the name of the following ester?
A) propyl methanoate
B) methyl ethanoate
C) methyl propanoate
D) ethyl methanoate

Q8. What is the formula of pentyl butanoate?
A) \( CH_3CH_2CH_2COOCH_2CH_3 \)
B) \( CH_3CH_2CH_2COOCH_2CH_3 \)
C) \( CH_3CH_2CH_2COOCH_2CH_3 \)
D) \( CH_3CH_2CH_2COOCH_2CH_3 \)
HOME PRACTICE

Q1. Butyl ethanoate can be hydrolysed using the apparatus shown

   a) What is the purpose of the cold tube?  

   b) Write the word equation for this hydrolysis.  

   c) Write the formula equation using shortened structural formulae.  

   d) What does the term 'hydrolysis' mean?  

   e) How does the hydrolysis equation compare with the equation for the formation of butyl ethanoate?  

Q2. The diagram shows the structural formula of an ester.

   O H H H H H H
   ||  ||  ||  ||  ||  ||  ||
   H-C-O-C-C-C-C-C-C-H
   H H H H H H H H

   a) Why can the hydrolysis of this ester be described as a reversible reaction?  

   b) What sign is used in an equation to show that it is reversible?  

   c) Name the acid produced by the hydrolysis of this ester.  

   d) Draw the shortened structural formula for the alcohol produced.  

Q3. A team of chemists are developing a fragrance for use in a shower gel for men. 

   To give the gel a fruity smell the chemists are considering adding an ester. They synthesise six isomeric esters. Volunteers smell each ester and give it a rating out of one hundred depending on how fruity the smell is.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Fruit-smell rating</th>
<th>Structure</th>
<th>Fruit-smell rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃COO⁻</td>
<td>100</td>
<td>CH₃CH₂CH₂CH₂CH₂CH₂CH₂COO⁻</td>
<td>92</td>
</tr>
<tr>
<td>CH₃CH₂COO⁻</td>
<td>34</td>
<td>CH₃CH₂CH₂CH₂CH₂CH₂CH₂CH₂COO⁻</td>
<td>44</td>
</tr>
<tr>
<td>CH₃CH₂CH₂COO⁻</td>
<td>0</td>
<td>CH₃CH₂CH₂CH₂CH₂CH₂CH₂CH₂CH₂COO⁻</td>
<td>32</td>
</tr>
</tbody>
</table>

   a) Name the ester with the fruit-smell rating of 92.  

   b) Arrange the three esters (A, B and C) in order of decreasing fruit-smell rating.  

Total (12)
5.4D Edible Fats & Oils

This lesson topic introduces edible fats and oils, substances which are both examples of esters and are closely related to each other.

‘Oil' is a much used word in Chemistry and can refer to quite different molecules from different parts of Chemistry.

| mineral oils: | mainly hydrocarbon molecules from crude oil |
| edible oils: | esters based on glycerol made by plants & animals |
| essential oils: | volatile aroma molecules that are characteristic of a particular plant |

**Sources of Fats & Oils**

This activity considers the three main sources of edible fats and oils - animal, vegetable and marine.

Both edible fats and edible oils are esters - formed by *joining* carboxylic acids to *alcohols*. Both fats and oils are greasy to touch, but fats are solid while oils are liquid at room temperature.

They are found in a variety of living things and form an important part of the human diet. They are usually classified according to whether their source is animal, vegetable or marine.

| Types of Edible Fats & Oils (Source) |
|-----------------|-----------------|-----------------|
| Animal          | Vegetable       | Marine          |
| dripping (beef) | fruits (olives) | whale blubber   |
| lard (pork)     | seeds (corn)    | seal blubber    |
| tallow (lamb)   | seeds (peanuts) | sardine oil     |
| fat (goose)     | seeds (soya)    | cod liver oil   |

**Ester Molecules**

This activity looks at the structures of fats and oils as esters of the same alcohol.

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

Both fats and oils are esters - formed by *joining* carboxylic acids to alcohols.

Surprisingly, all fat and oil molecules are formed from the same alcohol. It has 3 carbon atoms each of which has a hydroxyl group (—OH) attached - it is the triol called propan-1,2,3-triol.

It is a clear, colourless but very viscous liquid (very strong hydrogen bonding between molecules) and is better known as glycerol.
Having 3 hydroxyl groups allows 3 acid molecules to join onto glycerol - forming 3 ester links and fats & oils can be described as triple esters or as triglycerides.

When hydrolysed, fats & oils always produce 3 moles of acid molecules to 1 mole of glycerol.

Different fats & oils produce different acids when hydrolysed. These acids are called fatty acids and differences in the structures of these acid molecules account for the different properties of fats and oils.

**Fatty Acids**

This activity looks at the structures of the carboxylic acids, i.e. the fatty acids, obtained by hydrolysing fats and oils

Fatty acids are saturated or unsaturated carboxylic acids, usually with long carbon chains, which are obtained from the hydrolysis of fats and oils.

Stearic acid is a typical saturated fatty acid and is found in animal fat. All along its carbon chain are found C—C single bonds.

Oleic acid is a typical unsaturated fatty acid and is found in olive oil. Somewhere along its carbon chain is found a C = C double bond.

Fatty acids are quite long chained carboxylic acids, typically 18 carbons per molecule. Animal fats tend to have mainly saturated fatty acids while marine oils and vegetable oils usually have some unsaturated fatty acids.

**Glycerides & Their Fatty Acid Content**

This activity considers glycerides and the effect of their parent fatty acids on their properties.

Fats and oils are triple esters based on the alcohol glycerol. They are often called glycerides or even triglycerides.

The 3 acids linked to the central glycerol molecule can be identical or different, saturated or unsaturated. This explains the variety of fats & oils that exist and their different properties.
In animal fats most of the fatty acids are saturated. This makes their carbon chains linear. As a result, the glyceride molecules are able to pack closely together.

This allows for the maximum amount of intermolecular forces and a higher melting point.

Animal fats, therefore, tend to be solids at room temperature.

Vegetable oils and marine oils contain more unsaturated fatty acids in their glyceride molecules.

The presence of the C = C double bond makes the carbon chain non-linear or ‘bent’.

This prevents the glyceride molecules packing so close together, so fewer intermolecular forces can be established, and the melting point is lower.

Vegetable oils and marine oils tend to be liquids at room temperature.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Melting Point</th>
<th>Drops of bromine solution decolourised</th>
</tr>
</thead>
<tbody>
<tr>
<td>lard</td>
<td>‘high’</td>
<td>10</td>
</tr>
<tr>
<td>margarine</td>
<td>medium</td>
<td>15</td>
</tr>
<tr>
<td>corn oil</td>
<td>low</td>
<td>20</td>
</tr>
</tbody>
</table>

The more drops of bromine that can be decolourised, the more C = C double bonds the molecules must contain, the more unsaturated they must be.

Conclusions:

fats are more saturated than oils and have higher melting points

oils are more unsaturated than fats and have lower melting points
This activity deals with the way in which oils can be converted into solids by hardening.

**Hardening** a fat or oil means *hydrogenating* it to increase its melting point.

Foods that are high in *animal fats*, such as *milk* and *butter*, pose *health risks* because of the *saturated fatty acids* they contain.

*Vegetable oils* are considered *healthier* because of the *higher level* of *unsaturated acids* they contain. In many cases, e.g. *frying food*, oils can do the same job that fats such as *lard* and *butter* used to do.

*Vegetable oils* are *runny liquids* and unsuitable for *spreading* on bread. However, if some of the *unsaturated acids* are converted into *saturated acids* by reacting with *hydrogen*, then the *melting point* of the oil will be *increased* and it will be *more solid* at *room temperature*.

This is the same *addition reaction* met earlier in the course that can be used to *convert* an *alkane* into an *alkene* and requires the same *catalyst*, *nickel*.

As more and more of the *unsaturated acids* are *converted*, the *margarine* becomes *more and more solid*. However, it must not be allowed to become *too saturated* or it will be *too solid* and will loose it ability to ‘*spread straight from the fridge’*. Even more importantly, if allowed to become *too saturated* the *health advantages* that *unsaturated margarine* enjoys over *saturated butter* will be lost. For both these reasons only *partial hydrogenation* takes place.

**Health and Diet**

This activity looks at some of the benefits and some of the problems associated with fats and oils.

We all need some fat in our diet. But too much of a particular kind of fat – *saturated fat* – can raise our *cholesterol*, which *increases* the risk of *heart disease*. It's important to cut down on fat and choose foods that contain *unsaturated fat*.

Fats & Oils are *high energy* foods - *twice* as much as *carbohydrate* - and food high in fats & oils would be appropriate for people doing *very active* jobs, but for most people will be *stored* and can lead to *obesity* and the *health problems* associated with *obesity*.

The four *fat-soluble vitamins* namely *vitamin A*, *D*, *E* and *K* are, in fact, require fats and oils in the food to be *absorbed* through the gut. Inadequate fats may results in the *deficiency* of these *vitamins* leading to serious *health problems*. By law, *vitamins* are added to *margarine*.

Eating *unsaturated* fats instead of *saturated* can help lower blood cholesterol. *Unsaturated* fat, such as *omega-3 essential fatty acids*, is found in: *oily fish* such as *salmon* and *sardines*. 

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**Self Check**

**Q1.** Which of the following is not a source of fats and oils for direct consumption?
A animal
B mineral
C vegetable
D marine

**Q2.** Which of the following will provide a fat with a high melting point?
A olives
B lamb
C sunflower seed
D sardines

**Q3.** Fats and oils are both examples of
A carboxylic acids
B hydrocarbons
C alcohols
D esters

**Q4.** The most unsaturated fats or oils are those which decolourise
A bromine solution the most quickly
B the least bromine solution
C bromine solution the most slowly
D the most bromine solution

**Q5.** When comparing a fat and an oil of equal molecular size
A the more saturated one will have the higher melting point
B the more unsaturated one will have the higher melting point
C the less saturated one will have the higher melting point
D the two will have exactly the same melting point

**Q6.** In comparison to oils, fats are generally
A more unsaturated
B equally unsaturated
C more saturated
D equally saturated

**Q7.** Compared with carbohydrates, fats provide
A slightly less energy per gram
B slightly more energy per gram
C more than double the energy per gram
D less than half the energy per gram

**Q8.** Compared with vegetable oils, butter in the human diet can
A provide important vitamins
B cause less heart disease
C keep the arteries clear
D cause less obesity

**Q9.** Fats have higher melting points than oils because comparing fats and oils
A fats have more hydrogen bonds
B fat molecules are more saturated
C fat molecules are more loosely packed
D fats have more cross-links between molecules

**Q10.** Oils are generally
A solid at room temperature and contain a high proportion of unsaturated molecules
B solid at room temperature and contain a high proportion of saturated molecules
C liquid at room temperature and contain a high proportion of unsaturated molecules
D liquid at room temperature and contain a high proportion of saturated molecules
**SELF CHECK**

**Q11.** Which statement is not true of fats?
- A the parent acid molecule has three carboxyl groups.
- B there are three fatty acid chains in the fat molecule.
- C the parent alcohol molecule has three hydroxyl groups.
- D there are three ester links in the fat molecule

**Q12.** Hydrolysis of an oil is likely to produce
- A methanol
- B glycerol
- C ethanoic acid
- D methanoic acid

**Q13.** What is the structural formula of glycerol?

A [Structural formula of glycerol]

B [Structural formula of glycerol]

C [Structural formula of glycerol]

D [Structural formula of glycerol]

**Q14.** What is the ratio of alcohol to acid in the products from a hydrolysed fat?
- A 3 moles acid to 2 moles alcohol
- B 3 moles acid to 1 moles alcohol
- C 1 moles acid to 2 moles alcohol
- D 1 moles acid to 3 moles alcohol

**Q15.** Which of the following is a saturated fatty acid?
- A $C_{18}H_{33}COOH$
- B $C_{18}H_{35}COOH$
- C $C_{17}H_{33}COOH$
- D $C_{17}H_{35}COOH$

**Q16.** The conversion of an oil into a fat involves the removal of
- A single bonds
- B double bonds
- C hydrogen atoms
- D hydroxyl groups

**Q17.** Hardening of a fat or oil is done by
- A hydrolysis.
- B dehydration.
- C catalytic hydrogenation.
- D fractional distillation.

**Q18.** In the manufacture of margarine, why is only partial hydrogenation carried out?
- A to retain as much unsaturation as possible.
- B to avoid destroying natural vitamins.
- C to avoid losing the natural flavours.
- D to keep the molecular size as large as possible.

**Q19.** Which line in the table shows correct functional groups for aldehydes and ketones and fats and oils?

<table>
<thead>
<tr>
<th>Aldehydes and ketones</th>
<th>Fats and oils</th>
</tr>
</thead>
<tbody>
<tr>
<td>A carbonyl</td>
<td>hydroxyl</td>
</tr>
<tr>
<td>B carboxyl</td>
<td>hydroxyl</td>
</tr>
<tr>
<td>C carboxyl</td>
<td>ester link</td>
</tr>
<tr>
<td>D carbonyl</td>
<td>ester link</td>
</tr>
<tr>
<td>HOME PRACTICE</td>
<td>5.4D</td>
</tr>
<tr>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td><strong>Q1.</strong> Olive oil and bacon fat are chemically related.</td>
<td></td>
</tr>
<tr>
<td>a) To which class of organic compound do both belong?</td>
<td>1</td>
</tr>
<tr>
<td>b) Which of these two substances has the lower melting point?</td>
<td>1</td>
</tr>
<tr>
<td>c) Which of them is likely to be more unsaturated?</td>
<td>1</td>
</tr>
<tr>
<td>d) What test could you do to compare the degree of unsaturation in these two substances and what result would you expect?</td>
<td>2</td>
</tr>
<tr>
<td><strong>Q2.</strong> Carbohydrates, fats and oils are all regarded as energy foods.</td>
<td></td>
</tr>
<tr>
<td>a) How would you expect equal masses of olive oil and sugar to compare in energy content?</td>
<td>1</td>
</tr>
<tr>
<td>b) In what way can some fatty foods claim to be healthier than oils in the human diet?</td>
<td>1</td>
</tr>
<tr>
<td>c) In what way can unsaturated fats claim to be healthier than saturated fats in the human diet?</td>
<td>1</td>
</tr>
<tr>
<td>d) Explain what obesity is and how eating fats and oils can cause this.</td>
<td>1</td>
</tr>
<tr>
<td><strong>Q3.</strong> Animal fats and vegetable oils are examples of esters.</td>
<td></td>
</tr>
<tr>
<td>a) How many ester links are present in a single fat molecule?</td>
<td>1</td>
</tr>
<tr>
<td>b) Name the alcohol which is produced by the hydrolysis of any animal fat.</td>
<td>1</td>
</tr>
<tr>
<td>c) Draw the full structural formula for this alcohol.</td>
<td>1</td>
</tr>
<tr>
<td><strong>Q4.</strong> The diagram shows a structural formula of an ester oil.</td>
<td></td>
</tr>
<tr>
<td>a) Write the functional molecular formula of the parent fatty acid.</td>
<td>1</td>
</tr>
<tr>
<td>b) Is this particular fatty acid saturated or unsaturated? Explain your answer.</td>
<td>2</td>
</tr>
<tr>
<td>c) What will be the ratio of acid molecules to alcohol molecules in the products of hydrolysis of this oil?</td>
<td>1</td>
</tr>
<tr>
<td>d) What type of reaction can be used to 'harden' this oil?</td>
<td>1</td>
</tr>
</tbody>
</table>
| e) What effect does hardening have on  
  i) the degree of saturation in the molecule,  
  and ii) the melting point? | 2 |
| **Total** | (19) |
Soaps & Cleansing Action

Soaps are molecules that help water cope with awkward 'greasy' molecules, such as fats & oils, that would be difficult for water alone to wash away.

The names of some soaps, e.g Palmolive, betray the fact that soaps themselves are made from fats and oils - palm oil and olive oil.

Earlier in this section you learnt that water can be used to break an ester apart to reform the parent acid and parent alcohol.

The reaction benefits from the presence of $\text{H}^+_{(aq)}$ ions provided by dilute sulphuric acid $\text{H}_2\text{SO}_4$$_{(\text{l})}$. This is often called acid hydrolysis.

Alkaline hydrolysis, heating the ester with sodium hydroxide solution, will also break apart an ester to reform the parent alcohol.

The acid, however, goes on to react with the alkali so the salt of the acid is formed instead. In this case sodium ethanoate (CH$_3$COO$^-$ Na$^+$) would be made.

Alkaline hydrolysis of a glyceride molecule will yield glycerol and the sodium salts of its fatty acids.

Glyceryl tristearate (found in most animal fats) will produce sodium stearate which was one of the earliest and most common soaps ever made.

Thousands of years ago, probably by accident, people discovered that boiling animal fat with alkali rocks produced a scum that, when cooled and solidified, could be used as a cleansing agent.
Structurally, what makes these molecules capable of acting as a **cleansing agent** is their ‘ionic head’ - COO⁻, and long ‘covalent tail’ - C₁₇H₃₅.

**Covalent Tail** - most of the **hydrocarbon tail** is far enough away from the **ionic head** that it maintains the **properties** of a typical **covalent** molecule - namely, **weak London Dispersion forces** between neighbouring molecules.

**Ionic Head** - the **ionic heads** can set up **strong attractions** - of similar strength to the **hydrogen bonding** between **water** molecules - allowing the heads to **dissolve in water**.

**Water**, particularly **hot water**, is a very effective **cleansing agent**. The strength of the **hydrogen bonding** between its **polar molecules** is similar to the strength of **attractions** in many **ionic substances**, which allows **water** to **dissolve** them.

Many **covalent substances** are **polar enough** to also dissolve in water. The main problem is with **covalent substances** with very weak **polar attractions** or only **Van der Waals attractions**

When mixed with **water**, these **pure covalent liquids** form **separate layers** as the difference in intermolecular forces is too **great** to allow mixing.

Shaking can form a **temporary emulsion** as small drops of ‘oil’ float in the water.

On standing, the two liquids will **separate** out again.

This makes it very difficult for water to remove **greasy or oily stains** from **clothes, plates** or even **people**.

**Soap molecules** cannot make grease ‘**dissolve**’ in water, but they can prevent the tiny **droplets of grease** from reforming into large **blobs** which would stick to the surface of the **clothes, plates** or **skin of a person**.

Instead they keep the tiny **globules suspended** in the water so that they can be **rinsed** away with the water.

The **negatively charged ionic heads** set up **strong repulsions** which prevent the droplets reforming into large blobs.
**Detergents**

This activity considers the problems caused by 'hard' water and the need for soapless detergents.

To be effective, it is important that the soap molecule is able to **dissolve** and **dissociate** - that the Na⁺ ion detaches to leave a **negatively** charged head.

Compounds containing **Group I** metals (The **Alkali** metals) are always **soluble** but water can also contain **Group II** metals (The **Alkali Earth** metals). Scotland gets its water from 'above ground' - water flows over hard **igneous** rocks to collect in **lochs** and **reservoirs**. There are very few Ca²⁺ and Mg²⁺ ions and the water is described as 'soft'.

In much of England, particularly the **South**, water **percolates** through rocks such as **limestone** and collects below ground from where it is **pumped** to the surface or flows out into rivers and lakes. The water has **higher** levels of Ca²⁺ and Mg²⁺ ions and is described as 'hard'.

This causes a number of problems such as **limescale** build up in **water pipes**, **kettles** and **water heaters**. In addition, normal soaps struggle to work as they form an **insoluble scum** with Ca²⁺ and Mg²⁺ ions.

One solution is to **treat** the water by passing it through 'filters' that absorb the Ca²⁺ and Mg²⁺ ions and replace them with Na⁺ and K⁺ ions which 'softens' the water.

The alternative was to redesign the soap molecule to create a molecule that did not form an **insoluble scum** with Ca²⁺ and Mg²⁺ ions. These 'man made' soaps are usually referred to as detergents.

There are many variations but they all have the '**covalent tail**' with 'polar/ionic head' required.
This activity considers the use of emulsifying agents to form stable emulsions.

Oil and water will mix, but they form an emulsion with droplets suspended. This is unstable and the liquids will separate (as shown in B).

Soap molecules can be very effective at stabilising emulsions (as shown in A), by positioning themselves at the surface of a droplet of oil with covalent tails in the oil and ionic heads in the water. These droplets are referred to as micelles and molecules like soap are described as surfactants. The negative charges on the surface prevent/slow down the separation of the liquids and help form a stable emulsion. Emulsion paints are good examples of stable oil/water mixtures.

There are very few foods that do not contain both oils/fats and water. Therefore emulsifying agents are widely used in the food industry.

Traditional soap molecules can have a negative impact on taste so other, very similar, molecules have been developed.

A convenient way to make an emulsifying agent is to react a glycerol molecule with a single fatty acid (instead of the 'normal' 3 used to make an edible fat or oil).

Though not ionic (like the head of a soap molecule) the hydroxyl groups make the head hydroscopic - 'water loving' - water soluble.

The largely hydrocarbon fatty acid, as well as the ester link, make the tail hydrophobic - 'water hating' - oil soluble.
**Self Check**

**Q1.** Soaps are produced from fats and oils by
A. alkaline hydrolysis  
B. catalytic cracking  
C. acidic condensation  
D. dehydrogenation

**Q2.** Which of the following is a typical soap molecule?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>$\text{CH}_3 - \text{C} - \text{O}^- \text{Na}^+$</td>
<td>$\text{C}<em>17\text{H}</em>{35} - \text{C} - \text{O}^+ \text{Na}^-$</td>
</tr>
<tr>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>$\text{C}<em>17\text{H}</em>{35} - \text{C} - \text{O}^- \text{Na}^+$</td>
<td>$\text{C}<em>17\text{H}</em>{35} - \text{C} - \text{O}^+ \text{Na}^-$</td>
</tr>
</tbody>
</table>

**Q3.** Soap molecules are effective cleansing agents because they have
A. grease-soluble hydrocarbon chains joined to water-soluble ionic ends  
B. water-soluble hydrocarbon chains joined to grease-soluble ionic ends  
C. grease-soluble acidic parts joined to water-soluble alkaline ends  
D. water-soluble acidic parts joined to grease-soluble alkaline ends

**Q4.** Which of following statements about detergents is incorrect?
A. soap detergents can be manufactured from fat  
B. soapless detergents do not form foam in water  
C. the hydrophilic 'head' of a detergent can be anionic or cationic  
D. the hydrophilic 'head' of a detergent can be polar

**Q5.** Soaps are produced by the above reaction. This reaction is an example of
A. condensation  
B. esterification  
C. hydrolysis  
D. oxidation

**Q6.** When a detergent is added to a beaker of oil and water and then the solution is shaken, an emulsion is formed. The emulsion consists of
A. oil and detergent  
B. oil droplets and water  
C. water, oil and oil droplets  
D. water, oil, detergent and oil droplets

**Q7.** Consider the following detergent particle

Which part of this structure makes the detergent particle hydrophilic?
A. $\text{SO}_3\text{Na}^-$  
B. $\text{OSO}_3^-$  
C. $\text{Na}^+$  
D. $\text{OSO}_3\text{Na}^-$

**Q8.** Shaking a soap with grease produces tiny globules which cannot rejoin because
A. they are no longer soluble in water  
B. the grease molecules have hydrolysed  
C. the molecules in them have changed shape  
D. charges on their surfaces make them repel
**HOME PRACTICE 5.4E**

**Q1.** The structure of a soap molecule can be used to explain its cleansing action with grease.

   a) Draw the full structural formula for an example of a soap molecule. 
   b) Which part of this molecule is soluble in grease and which part is soluble in water? 

**Q2.** A fatty acid is a long chain carboxylic acid. Examples of fatty acids are shown in the table below.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Systematic name</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>stearic acid</td>
<td>octadecanoic acid</td>
<td>$\text{CH}_3(\text{CH}<em>2)</em>{15}\text{COOH}$</td>
</tr>
<tr>
<td>oleic acid</td>
<td>octadec-9-enoic acid</td>
<td>$\text{CH}_3(\text{CH}_2)^{14}\text{CH}=$CH(\text{CH}_2)_7\text{COOH}$</td>
</tr>
<tr>
<td>linoleic acid</td>
<td>octadec-9,12-dienoic acid</td>
<td>$\text{CH}_3(\text{CH}_2)_4\text{CH}=$CHCH$_2$CH=CHCH$_2$COOH</td>
</tr>
<tr>
<td>linolenic acid</td>
<td></td>
<td>$\text{CH}_3\text{CH}=$CHCH$_2$CH=CHCH$_2$COOH</td>
</tr>
</tbody>
</table>

   a) What is the systematic name for linolenic acid? 
   b) Stearic acid reacts with sodium hydroxide solution to form sodium stearate. 

   Name the type of reaction taking place when stearic acid reacts with sodium hydroxide. 
   c) Explain fully how sodium stearate acts to keep grease and non-polar substances suspended in water during cleaning.

**Q3.** Small children can find it difficult to swallow tablets or pills so ibuprofen is supplied as an “infant formula” emulsion.

   a) The emulsifier used is polysorbate 80. 
      Its structure is shown below.

   Explain why this molecule acts as an emulsifier. 
   b) The emulsion contains 2 g of ibuprofen in every 100 cm$^3$ of emulsion. The recommended dose for treating a 6 month old baby is 0.050 g. Calculate the volume, in cm$^3$, of “infant formula” needed to treat a 6 month old baby.

**Total (11)**
5.4F Terpenes - Fragrance Molecules

This lesson topic introduces terpenes which are a major component of essential oils.

Essential Oils

This activity considers the role of essential oils.

Essential oils are the concentrated extracts of volatile, non-water-soluble aroma compounds from plants. ‘Essential’ refers to the fact that the oil carries the distinctive essence (scent) of the plant. Essential oils are mixtures of organic compounds, though Terpenes are the key components in most essential oils.

The distinctive character of an essential oil can be attributed to the functional group present in its key molecule. Esters, aldehydes, ketones and alcohols are all found in essential oils but many are terpenes.

As well as their role as fragrance molecules, there are 3 other reasons why essential oils might be used:

- antioxidant activity
- antimicrobial activity
- anticoccidial activity

Coccidia are tiny single-celled parasites that live in the wall of an animal’s intestine.
**Terpenes**

This activity considers the structure of terpenes

**Terpenes** are *unsaturated* compounds formed by joining together *isoprene* units.

**Isoprene** is the common name for 2-methylbuta-1,3-diene

**Isoprene** is produced and *emitted* by many species of trees into the *atmosphere*, where they can be converted by *free radicals* (like the *hydroxyl* (OH) radical) into various species, such as *aldehydes*, *hydroperoxides*, *organic nitrates*, and *epoxides*.

It has been proposed that *isoprene* emission is specifically used by plants to protect against large fluctuations in leaf *temperature*. *Isoprene* also confers *resistance* to reactive oxygen species.

The *isoprene* skeleton can be found in naturally occurring compounds called *terpenes*. They can join 'head to tail' to form *linear terpenes*. An example is *myrcene*, a component of plants, including bay, ylang-ylang and thyme.

Other *terpenes* are *cyclic*, whilst other have been *oxidised* to form *hydroxyl* or *carbonyl* groups:

- **Limonene** (skin of citrus fruits)
- **Menthol** (peppermint)
- **Thujone** (Absinthe)

8 *isoprene* units

40 carbon atoms
This activity considers the technique of gas chromatography as a means of separating and identifying volatile molecules.

As with Paper Chromatography, met in an earlier topic, molecules move in a mobile phase but can also spend some of their time 'trapped' in a stationary phase.

Given the volatile nature of many of the molecules studied in this topic, an inert carrier gas is chosen to be the mobile phase. Thin metal coils are either packed with suitable solid powders (Gas Solid Chromatography (GSC)) or liquids are absorbed onto a polymer coating (Gas Liquid Chromatography (CLC)).

Polar or non-polar materials can be used depending on the molecules being identified.

Different molecules take different times to move through the coil depending on factors such as mass, shape and polarity.

The area under each signal represents the amount present.
This activity examines the chromatograms of natural gas and unleaded petrol and establishes some of the factors that effect retention times.

Whilst methane is the main component (off the scale) in natural gas, there are many other molecules present.

<table>
<thead>
<tr>
<th>molecule</th>
<th>mass</th>
<th>polar</th>
<th>time/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>methane</td>
<td>16</td>
<td>no</td>
<td>1.5</td>
</tr>
<tr>
<td>ethane</td>
<td>30</td>
<td>no</td>
<td>2.0</td>
</tr>
<tr>
<td>propane</td>
<td>44</td>
<td>no</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Since these molecules should have the same polarity we see that:

*as mass increases, the time increases*

Comparing molecules of similar mass like methane with water and ethane with hydrogen sulphide shows the effect of polarity:

*as polarity increases, the time increases*

Propane and carbon dioxide have similar mass and similar polarity. Carbon dioxide is, however, a more compact molecule and moves through the coil more quickly.

Examination of the simplified chromatogram of unleaded petrol confirms that:

*as mass ↗, the time ↗*

Comparing branched isomers with the equivalent chain molecule:

*as no. of branches ↗, the time ✓*

and looking at the positions of branches, 2-methyl to 4-methyl:

branch position ↗, the time ↗
**Self Check**

**Q1.** Myrcene is a simple terpene.

Terpenes contain at least one isoprene unit. Which of the following shows a correctly highlighted isoprene unit?

A

B

C

D

**Q2.** Limonene is one of the terpene molecules responsible for the flavour of lemons.

How many isoprene molecules are used in the production of one limonene molecule?

A 1  
B 2  
C 3  
D 4  

**Q3.** The structure of carophyllene, which can be extracted from clove oil, is

Which of the following would be the best solvent for extracting carophyllene?

A hexane  
B hexanol  
C hexanal  
D hexanone

**Q4.** Which of the following is the most suitable gas to use as a carrier gas in a gas chromatogram?

A oxygen  
B carbon dioxide  
C helium  
D methane

**Q5.** Acetone is an organic molecule with a formula of \( \text{CH}_3\text{COCH}_3 \). A student runs a sample of acetone through a GLC at 50°C. The acetone produces a peak after 4.2 mins. The student then injects a mixture of unknown organic substances into the same column at the same temperature. There are peaks after 3.1, 4.2 and 7.4 mins. From this information, it can be concluded that ...

A the mixture has 3 components, but acetone is not one of them.  
B the mixture has at least 3 components, one of which might be acetone.  
C the mixture has 3 components, one of which must be acetone.  
D the mixture has at least 3 components, one of which must be acetone.
**HOME PRACTICE 5.4F**

**Q1.** Two typical compounds that are present in many perfumes are shown.

![Geraniol and Limonene](image)

a) Why does geraniol evaporate more slowly than limonene?  

The structure of one of the first synthetic scents used in perfume is shown opposite.

b) Name the family of carbonyl compounds to which this synthetic scent belongs.  

c) Copy and complete the structure opposite to show the product formed when this scent is oxidised.  

d) Suggest what effect the oxidation would have on the fragrance of the molecule.  

**Q2.** Study the chromatograph of a mixture of hydrocarbons A and B. Compound A has the shorter retention time.

![Chromatogram](image)

a) What is the retention time of compound A? Compound B?  

b) Which compound is present in a larger amount?  

c) Which compound has the lower boiling point?  

d) You suspect that compound B is octane. What can you do to provide supporting evidence for this hypothesis?  

**Q3.** Traces of a liquid were discovered in a bottle believed to contain perfume belonging to Queen Hatshepsut, ruler of Egypt over 3500 years ago. Perfumes were made by dissolving plant extracts containing pleasant smelling terpenes and esters in an edible oil. A little ethanol and water may also have been added.

Using your knowledge of chemistry, comment on the possible smell(s) when such a bottle is opened after being stored for thousands of years.  

**Total** (11)
5.4G Amines, Amides & Amino Acids

This topic introduces the amine functional groups and, in particular, its ability to form a link with other groups - the amide or peptide link.

Amines & Amides

This activity deals with how to recognise and identify amines and introduces a few of their properties.

Amines are the organic relatives of ammonia, NH₃, and like ammonia, their properties are mainly due to the small, highly electronegative Nitrogen atom.

The simplest amines are called primary amines and will have a carbon chain (alkyl group, R—) in place of one of the hydrogen atoms, R—NH₂

This amine is usually called simply ethylamine, though its more formal name is aminoethane.

You do not need to learn the formal systematic naming of amines.

This is the amino functional group

Replacing two of the hydrogens with carbon chains produces what is called a secondary amine.

Simple naming is used whenever possible, so this molecule is called ethylmethylamine.

Replacing all of the hydrogens with three carbon chains produces what is called a tertiary amine.

Simple naming is used whenever possible, so this molecule is called trimethylamine.

We will concentrate mainly on primary amines and molecules containing the amino group, —NH₂, though you are expected to at least recognise other amines when you meet them.

Properties of Amines

This activity will remind you of some of the properties that ammonia has and which are shared by the amines

Ammonia is a gas with a very pungent smell. Similarly the smaller amines are gases or volatile liquids with very unpleasant smells similar to rotten fish or.......
Last year you were shown that ammonia is an extremely soluble gas - the fountain experiment.

This is due to the fact that ammonia molecules are like water molecules and have very strong hydrogen bonding between them. Small primary amines will also have strong hydrogen bonding and will also be very soluble. Secondary amines are less soluble and tertiary amines even less soluble.

Ammonia was the only alkali gas met during Standard grade. Amines are organic alkalis and will dissolve in water to produce hydroxide ions, OH⁻.

Many ions of Transition metals are coloured but only when hydrated - surrounded by water molecules. Cu²⁺ ions - or more accurately [Cu(H₂O)₄]²⁺ ions - are blue in colour. Ammonia and the smaller amines can replace these water molecules but this will change the colour of these ions:

\[
[Cu(H₂O)₄]^{2+} \rightarrow [Cu(NH₃)₄]^{2+}
\]

BLUE \rightarrow VIOLET

These colour changes are sometimes used as a 'Test' for ammonia/amines

### Reactions of Amines

This activity introduce you to the reactions of ammonia/ amines

1. **Dissolve in water to produce Alkalis-** solutions containing the hydroxide ion.

   \[
   \text{NH}_3 \quad + \quad H^+\text{O}^\text{\_}\text{H} \quad \rightarrow \quad \text{NH}_4^+ \quad + \quad \text{OH}^-\text{ammonium ion}
   \]

   \[
   \text{C}_2\text{H}_5\text{NH}_2 \quad + \quad H^+\text{O}^\text{\_}\text{H} \quad \rightarrow \quad \text{C}_2\text{H}_5\text{NH}_3^+ \quad + \quad \text{OH}^-\text{ethylammonium ion}
   \]

2. **React with acids to produce Salts-**

   \[
   \text{NH}_3 \quad + \quad H^+ \quad Cl^- \quad \rightarrow \quad \text{NH}_4^+ \quad Cl^-\text{ammonium chloride}
   \]

   \[
   \text{C}_2\text{H}_5\text{NH}_2 \quad + \quad H^+ \quad Cl^- \quad \rightarrow \quad \text{C}_2\text{H}_5\text{NHCl}^-\text{ethylammonium chloride}
   \]
React with organic acids to produce Amides:

\[
\begin{align*}
\text{H} & \quad \text{O} & \quad \text{C} & \quad \text{C} & \quad \text{OH} & \quad \text{NH}_3 & \rightarrow & \text{H} & \quad \text{O} \\
& & & & & & & \text{C} & \quad \text{N} & \quad \text{H} & + & \text{H}_2\text{O}
\end{align*}
\]

ammonia  a primary amide

\[
\begin{align*}
\text{H} & \quad \text{O} & \quad \text{C} & \quad \text{C} & \quad \text{OH} & \quad \text{C}_2\text{H}_5\text{NH}_2 & \rightarrow & \text{H} & \quad \text{O} \\
& & & & & & & \text{C} & \quad \text{N} & \quad \text{C}_2\text{H}_5 & + & \text{H}_2\text{O}
\end{align*}
\]

ethylamine  a secondary amide

Amides are not an ‘important’ family and you are not required to learn how to name them.

The reactions above are very similar to esterification - acid groups can react with amine groups in a condensation reaction that allows the two molecules to join together.

This is an important reaction in nature, and you will need to learn to recognise the amide link (the peptide link)

Proteins

This activity will introduce you to some proteins and the roles played by proteins in living organisms

- peas and beans
- meat
- fish
- cheese
- eggs
- hide & skin
- wool & silk

When protein is mentioned, most people will think of foodstuffs that contain protein and make up a very important part of our diet.

When we eat proteins they are digested (broken down) into simpler molecules called amino acids.

These amino acids are then reconstituted as proteins that fulfil a large number of important roles in living organisms.
**Amino Acids**

This activity will introduce you to the structure of amino acids and explains why some are labelled as essential amino acids.

All the proteins in the world are made from about 20 amino acids.

These 20 amino acids have a common structure. (one exception)

A central carbon atom has an acid group (carboxyl), an amino group and a hydrogen atom attached.

The final group attached to the carbon is different for each amino acid and is usually represented by —R.

When we digest proteins we break them down into amino acids which we then use to build new proteins. Most amino acids (12) can be made from carbohydrates and other amino acids so it is not crucial that we eat foods containing these amino acids.

The remaining amino acids (8), however, cannot be made and therefore must be part of our food intake. These are classified as essential amino acids (though we need all 20 to remain healthy).

Proteins can be broken down in the lab by heating them for several hours with dilute acid.

This reaction is called hydrolysis,  
hydro = water  
lysis = splitting apart

To prevent the water evaporating away before the reaction has finished we can use apparatus like these.

Having hydrolysed a protein, we will often attempt to identify the amino acids that made up the protein using paper chromatography. They all have the amine group and carboxyl group but differences in the polarity of their side-groups will effect their retention in the stationary phase.
Making Peptides

This activity looks at how amino acids can link together to form peptides.

Most proteins contain more than 40 amino acids joined together. Firstly, however, the amino acids tend to join together in twos or threes to make peptides.

The carboxylic group from one amino acid links with the amino group of another amino acid.

Water is also produced and this is a condensation reaction.

Tripeptides are made by joining three amino acids together. Peptides are ‘named’ using the accepted abbreviations of the amino acids they contain.

For example, the peptide made from Glycine, Alanine and Phenylalanine would be labelled GlyAlaPhe and would look like this:

By convention, the amino acids are always drawn with their amino groups to the left, in the order they appear in the peptide name - a different peptide would be formed if we’d lined the 3 amino acids up facing the ‘wrong way’.

Polypeptides can contain up to about 40 amino acids; more than 40 and we tend to call it a protein, though the distinction between a polypeptide and a protein is an arbitrary one.
This activity looks at how proteins are made

**Proteins** are **condensation polymers** which can contain **several thousand** amino acids. A massive **variety** of **proteins** can be made by arranging up to **26 amino acids** in varying **numbers** and varying **orders**.

**Proteins** comprise a large part of an animal's **diet**. During **digestion** the **animal** and **vegetable** **proteins** are **hydrolysed** into their component **amino acids**. Some **amino acids** can be **synthesised** in the body, but others (**the essential amino acids**) have to be present in the diet.

**Proteins** required for the body's **specific** needs are built up from **amino acids** in the body cells according to information supplied by DNA in the cell **nuclei**.

This activity looks at the hydrolysis of proteins to recreate the original amino acids used to form them.

You will only ever see a **fragment** of a **protein chain** but it will be enough to allow you to recognise the “**repeating pattern**” and identify how many **different amino acids** are being used to make this protein.

In this case there are **three** amino acids in the “**repeating pattern**”.

The recognisable **peptide link** is used to show where one amino acid ends and the next one begins.

The **original amino acids** can then be drawn - remembering to replace the —H atoms and —OH groups lost when they joined together. In other words, the original **carboxyl** and **amino groups** are reformed.

**serine**

**cysteine**

**tyrosine**
**Structure of Proteins**

This activity looks at how different structures for proteins depend on their constituent amino acids and affect their role.

The primary structure of all proteins is long chains of amino acids. However, all along these chains are polar groups such as $-\text{N}^\delta -\text{H}^\delta+$ and $-\text{C} = \text{O}^\delta$ as well as polar and non-polar groups ($-\text{R}$) on each amino acid. A lot of attractions (and repulsions) are set up within and between chains, plus some reactions that lead to permanent bonds.

As a result of these extra bonds, secondary structures will be formed.

*Chains* can become linked together by strong hydrogen bonds between the chains.

Many chains can link in this way to form a sheet.

Often the chains will twist around to form strong hydrogen bonds within the chain. The length of 4 amino acids is usually enough to allow this to happen.

As a result of this twisting a helix chain will form.

More permanent bonds can also be formed. For example, two cysteine side groups can be oxidised and lose hydrogen atoms to form a ‘disulphide bridge’.

The folding of chains and helixes is what gives proteins their individual shapes.

Proteins which remain more elongated are referred to as FIBROUS proteins. These make up most animal tissue such as muscles. Other examples include Keratin found in horns, hoof and hair, and Collagen found in tendons.
Even more complicated structures called **GLOBULAR** proteins can result when a number of **peptide chains** join together. These **Globular** proteins are involved in the **maintenance and regulation of life processes**.

Examples include **hormones** e.g insulin, and **enzymes**.

**Shape**, and their ability to form various types of bonds to bind to other substances, are crucial to a protein’s role.

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**Enzyme Shape**

This activity looks at the importance of molecular shape to the way an enzyme functions

**Enzymes** are **organic catalysts** and all contain **protein**.

**Enzymes** are so **specific** because they have a precise structure (**shape**) which exactly matches the structure of the **substrate** - the molecule(s) which is/are reacting.

**Enzymes** will have an **active site** where reaction takes place. Within the **active site** chemical groups (some of the side chains on the **amino acids**) will form **bonds** with the **substrate** molecule.

The **bonds** which bind the **substrate** to the **active site** have to be **weak** so that the products can easily leave the **active site** after the reaction. The bonds are usually **hydrogen bonds** or **interactions** between **ionic** groups.

While attached to the **active site**, bonds within the **substrate** molecule(s) will be **weakened** making it **easier** for the **substrate** to react - lowering the **activation energy** of the reaction as a **catalyst** should.

Sometimes, being attached to the **active site** will change the **shape** of the substrate bringing atoms or groups that need to react into **closer contact**. This helps overcome awkward ‘**collision geometry**’.

When talking about **enzymes** we often use the phrase ‘**lock and key**’ to cover the importance of correct **shape** and the fact that each enzyme is likely to only work with one **specific** substrate.

The example on the left is a good illustration of how an enzyme works.
Denaturing

This activity looks at the factors which can change the shape of an enzyme and prevent it functioning.

Many of the groups found on the side chains of amino acids (see page 43) are ionisable and will be affected by a change in pH.

Groups such as —COOH and —NH₂ are polar but can become ionic as the pH changes.

This can change the active site so that the substrate molecule will be unable to bond with the enzyme.

Changing the nature of some of these groups can also change the shape of the enzyme, as folding of the peptide chain may no longer happen at the same points.

If the active site is destroyed the enzyme is said to be DENATURED.

The structure of an enzyme is often held together by weak polar—polar bonds and hydrogen bonds. These can easily be broken by raising the temperature, which causes them to vibrate more vigorously. So enzymes are sensitive to small changes in temperature or pH.

Cooking Meat

This activity looks at some of the reasons why we cook meat and some of the chemical changes that take place.

Whilst killing bacteria and other microorganisms to make meat safe to eat is a major reason for cooking meat, most of the reasons are to do with increasing the acceptability of the food.

Texture -  tough meat can be softened - collagen is a protein that forms the connective material in meat. Too much makes meat tough. At temperatures above 60 °C, the spiral protein unwinds (denatures) and turns into soft gelatine.

Flavour -  browning improves appearance, flavour and aroma - At temperatures above 140°C reactions between —NH₂ groups and carbohydrates produce polymers (brown) as well as volatile flavour and aroma molecules. Maillard Reactions.

Other less desirable changes can happen during the cooking of meat - other protein molecules begin to change (denature) at about 40 °C and cause the meat to harden, for example. Chefs often brown meat with a blow torch and then cook at low temperatures.

maltol - a flavour molecule
**SELF CHECK**

**Q1.** When a protein is denatured
- **A** its overall shape is distorted
- **B** its amide links are hydrolysed
- **C** it is broken into separate peptide fragments
- **D** it decomposes into amino acids

**Q2.** Which of the following compounds can be classified as proteins?
- **A** fats
- **B** oils
- **C** enzymes
- **D** amino acids

**Q3.** Which of the following is an amine?
- **A**
- **B**
- **C**
- **D**

**Q4.** The arrangement of amino acids in a peptide is $Z$-$X$-$W$-$V$-$Y$ where the letters $V$, $W$, $X$, $Y$ and $Z$ represent amino acids.

On partial hydrolysis of the peptide, which of the following sets of dipeptides is possible?
- **A** $V$-$Y$, $Z$-$X$, $W$-$Y$, $X$-$W$
- **B** $Z$-$X$, $V$-$Y$, $W$-$V$, $X$-$W$
- **C** $Z$-$X$, $X$-$V$, $W$-$V$, $V$-$Y$
- **D** $X$-$W$, $X$-$Z$, $Z$-$W$, $Y$-$V$

**Q5.** Which of the following arrangements of atoms shows a peptide link?

- **A**
- **B**
- **C**
- **D**

**Q6.** A tripeptide $X$ has the structure

Partial hydrolysis of $X$ yields a mixture of dipeptides.

Which of the following dipeptides could be produced on hydrolysing $X$?

- **A**
- **B**
- **C**
- **D**
Q1. Chemists have developed cheeses specifically for use in cheeseburgers. When ordinary cheddar cheese is grilled the shapes of the protein molecules change and the proteins and fats separate leaving a chewy solid and an oily liquid.

a) What name is given to the change in protein structure which occurs when ordinary cheddar is grilled?

To make cheese for burgers, grated cheddar cheese, soluble milk proteins and some water are mixed and heated to no more than 82 °C. As the cheese begins to melt an emulsifying agent is added and the mixture is stirred.

b) Why would a water bath be used to heat the mixture?

c) A section of the structure of a soluble milk protein is shown.

Draw a structural formula for any one of the amino acids formed when this section of protein is hydrolysed.

d) The emulsifier used is trisodium citrate, a salt formed when citric acid is neutralised using sodium hydroxide. Copy and complete the equation below showing a structural formula for the trisodium citrate formed.

Q2. Phenylalanine and alanine are both amino acids.

Phenylalanine is an essential amino acid.

a) What is meant by an essential amino acid?

b) Which compound is present in a larger amount?

c) How many hydrogen atoms are present in a molecule of phenylalanine?

d) Phenylalanine and alanine can react to form the dipeptide shown.

Copy and circle the peptide link in this molecule.

e) Draw a structural formula for the other dipeptide that could be formed.

Total (9)