# National 5 Chemistry

## Unit 2:

### Nature’s Chemistry

### Topic 5

## Hydrocarbon Families

<table>
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<td>1. Cycloalkane Molecules</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>2. Cycloalkane Names</td>
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<td>2. The Bromine Test</td>
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<td>3. Addition Reactions</td>
<td></td>
<td></td>
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<td>4. Cracking</td>
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<td><strong>Consolidation Work</strong></td>
<td>Self-Check Questions 1 - 5</td>
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<td></td>
<td>2. Consolidation B</td>
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<td></td>
<td>3. Consolidation C</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>4. Consolidation D</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### End-of-Topic Assessment

Score: %

Grade:
Fuels and Combustion 1

- An **exothermic** reaction is one in which heat energy is released
- A **fuel** is a substance that releases a large amount of energy when it burns
- When a substance burns it reacts with **oxygen**
- **Combustion** is another word for burning

Coal, oil and natural gas

- Coal, oil and natural gas are **fossil fuels**, formed millions of years ago
- A **fossil fuel** is one that has been formed from the remains of living things
- **Coal** was formed from plant material, including trees
- **Oil** and **natural gas** were formed from tiny **sea** creatures and plants

Fractional distillation

- Oil requires a complex process of **refining** before it can be used
- Crude oil is a mixture of carbon compounds, mainly **hydrocarbons**
- **Hydrocarbons** are compounds containing carbon and hydrogen **only**
- **Fractional distillation** is used to separate crude oil into **fractions**
- A **fraction** is a group of compounds with similar boiling points

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Boiling Range °C</th>
<th>Carbon atoms</th>
<th>End-uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>gas</td>
<td>-160 to 20</td>
<td>1 to 4</td>
<td>fuel gases</td>
</tr>
<tr>
<td>gasoline</td>
<td>20 to 65</td>
<td>5 to 6</td>
<td>petrol</td>
</tr>
<tr>
<td>naphtha</td>
<td>65 to 180</td>
<td>6 to 11</td>
<td>petrochemicals</td>
</tr>
<tr>
<td>kerosene</td>
<td>180 to 250</td>
<td>9 to 15</td>
<td>heating / jet fuel</td>
</tr>
<tr>
<td>gas oils</td>
<td>250 to 350</td>
<td>15 to 25</td>
<td>diesel fuel</td>
</tr>
<tr>
<td>residue</td>
<td>&gt; 350</td>
<td>&gt; 25</td>
<td>bitumen, wax etc</td>
</tr>
</tbody>
</table>

- The fractions vary in **viscosity** (how ‘thick’) and **flammability**

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Molecular Size</th>
<th>Boiling Point</th>
<th>Ease of Evaporation</th>
<th>Flammability</th>
<th>Viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>gas</td>
<td>decreasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
</tr>
<tr>
<td>gasoline</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
</tr>
<tr>
<td>naphtha</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
</tr>
<tr>
<td>kerosene</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
</tr>
<tr>
<td>gas oils</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
</tr>
<tr>
<td>residue</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
<td>increasing</td>
</tr>
</tbody>
</table>
Explanation of Variations

- **Boiling range** and **viscosity** increase as the molecular size increases because the forces of attraction between molecules are also increasing.
- **Evaporation** and **flammability** are also linked to molecular size. The smaller the molecules, the weaker the forces of attraction and easier to change liquid $\rightarrow$ gas.

Fuels and Combustion 2

- Many fuels contain **carbon** and **hydrogen**. When burned completely they produce **carbon dioxide** and **water**.
- The test for **carbon dioxide** is that it turns **lime water milky**
- The test for water is that it freezes at 0 °C and boils at 100 °C
- Water also turns **cobalt chloride paper** from **blue** to **pink**
- **Incomplete** combustion of a carbon fuel can produce carbon (**soot**) and **carbon monoxide**
- **Carbon monoxide** is a poisonous gas

Pollution problems

- Burning fossil fuels produces carbon dioxide a ‘greenhouse gas’ that causes **global warming**
- Sulphur in fuels (mainly coal) produce **sulphur dioxide** which causes **acid rain** (sulphur is removed from oil and gas during refining)
- In petrol engines nitrogen and oxygen react to form poisonous oxides of nitrogen, including **nitrogen dioxide**
- Special exhaust systems can convert pollutant gases into harmless gases
- Using less fuel compared to air in car engines also reduces pollution
- All new cars are fitted with **catalytic convertors**
- These convert the oxides of nitrogen back into nitrogen
- They change unburnt hydrocarbons and carbon monoxide into water and carbon dioxide

Cracking

- Fractional distillation of crude oil gives more long-chained hydrocarbons (mainly alkanes) than are needed by industry
- **Cracking** is a method of producing smaller, more useful molecules by heating large hydrocarbon molecules in the presence of a catalyst
- Cracking alkane molecules produces a **mixture** of alkanes and alkenes
There are not enough hydrogen atoms in an alkane molecule for it to produce only smaller alkanes on cracking

The presence of a catalyst, such as steel wool or aluminium oxide, allows cracking to take place at a lower temperature, making the process cheaper.

**Plastics**

- **Plastics** and other synthetic fibres are examples of polymers - very large molecules formed by joining many small molecules called monomers.
- Monomers are the small molecules that join together to form a large polymer.
- Polymerisation is the process of making a polymer from many monomers.
- Most plastics and synthetic fibres are made from molecules found in crude oil.
- A synthetic fibre is one that is man-made e.g. nylon and terylene.
- A natural fibre is one that is found in nature e.g. wool, silk and cotton.
- Plastics are often used instead of traditional materials like wood, paper etc.
- The particular use is related to the properties of the plastic.
- Most plastics have low density, are good heat and electrical insulators, and are water resistant.

**Plastics and Pollution**

- Very few plastics are biodegradable - they do not rot away.
- Natural materials such as wood, paper and cardboard are biodegradable.
- Plastics can release poisonous carbon monoxide if combustion is incomplete.
- Some plastics can also give off other toxic fumes when they burn or smoulder.
- The gases given off during burning or smouldering can be related to the elements in the plastic:
  - carbon monoxide, \( CO \) when \( C \) present e.g. polystyrene
  - hydrogen chloride, \( HCl \) when \( Cl \) present e.g. PVC
  - hydrogen cyanide, \( HCN \) when \( N \) present e.g. polyurethane

**Thermoplastics and Thermosetting plastics**

- A thermoplastic is one that softens on heating e.g. polythene, perspex etc.
- A thermosetting plastic does not soften on heating e.g. bakelite, formica etc.
- Only thermoplastics can be recycled.
5.1 The ALKANES

Alkane Molecules

The alkanes are a family of hydrocarbons; molecules made from carbon and hydrogen atoms only. The first member of the family is methane, CH₄.

Ca atoms always have four unpaired electrons in their outer shell and so can form four bonds.

The bonds keep as far apart as possible; the hydrogen atoms lie at the corners of a tetrahedral structure. It is much easier to draw flat pictures to show how each of the atoms are joined to each other.

Having as many as four gives carbon atoms the ability to form chains and rings of carbon atoms. They can also join together with single, C — C, double, C = C, or even triple, C ≡ C, bonds.

The Alkane family is made up of chains where all the carbon atoms join together with a single bond.

Alkane Names

The suffix -ane is to tell you it is a member of the alkane family, the first name tells you the number of carbon atoms in each molecule.

Meth- = 1 Carbon atom  Pe - = 5 Carbon atoms
E - = 2 Carbon atoms  Hex- = 6 Carbon atoms
Pr - = 3 Carbon atoms  Hept- = 7 Carbon atoms
B - = 4 Carbon atoms  O - = 8 Carbon atoms

1 2 3 4 5 6 7 8
Monkeys Eat Peanut Butter Perched High High Overhead
### Alkane Structures

<table>
<thead>
<tr>
<th>Number of carbon atoms</th>
<th>Name of alkane</th>
<th>Structural formula</th>
<th>Molecular formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>methane</td>
<td>( \text{H} ) ( \text{H} - \text{C} - \text{H} ) ( \text{H} )</td>
<td>( \text{CH}_4 )</td>
</tr>
<tr>
<td>2</td>
<td>ethane</td>
<td>( \text{H} ) ( \text{H} ) ( \text{H} - \text{C} - \text{C} - \text{H} ) ( \text{H} )</td>
<td>( \text{C}_2\text{H}_6 )</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} ) ( \text{H} ) ( \text{H} )</td>
<td>( \text{C}<em>7\text{H}</em>{16} )</td>
</tr>
<tr>
<td>5</td>
<td>pentane</td>
<td>( \text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} ) ( \text{H} ) ( \text{H} )</td>
<td>( \text{C}<em>6\text{H}</em>{14} )</td>
</tr>
<tr>
<td>6</td>
<td>hexane</td>
<td>( \text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} ) ( \text{H} ) ( \text{H} )</td>
<td>( \text{C}<em>7\text{H}</em>{16} )</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>( \text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} ) ( \text{H} ) ( \text{H} )</td>
<td>( \text{C}<em>8\text{H}</em>{18} )</td>
</tr>
</tbody>
</table>

The alkane are called a *homo* series of molecules. This is because each molecule differs from the previous molecule by the same amount, \(-\text{CH}_2-\), (homo- = same, logous = difference).

The general formula for the alkane family is \( \text{C}_n\text{H}_{2n+2} \). This makes it possible to write a *General Formula* for the alkane family. There are always two plus two hydrogens for any number of carbon atoms.
There are a number of different ways of representing molecules, but great care must be taken in exams where different definitions might prevail.

**Full Structural Formula:** *should* show *every* individual atom and *every* bond.

In an exam, *this is what you should draw* whenever you are asked for a *structural formula.*

![Structural Formulas](image)

**Semi-Structural Formula;**

**Shortened Structural Formula;**

**Extended Molecular Formula;**

In an exam, you can sometimes include one bond to show a branch in a *shortened structural formula.*

For perfection, try and put branches in *brackets* as shown here.

![Examples of Structural Formulas](image)

**Molecular Formula:** *should* show *each type* of atom and *number* only.

<table>
<thead>
<tr>
<th>Name</th>
<th>Structural Formula</th>
<th>Shortened Structural</th>
<th>3-D Model</th>
<th>Molecular Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>methane</td>
<td>( \text{CH}_4 )</td>
<td>( \text{CH}_3 )</td>
<td><img src="image" alt="3D Model" /></td>
<td>( \text{CH}_4 )</td>
</tr>
<tr>
<td>ethane</td>
<td>( \text{CH}_3 \text{CH}_3 )</td>
<td>( \text{CH}_3 \text{CH}_2 )</td>
<td><img src="image" alt="3D Model" /></td>
<td>( \text{CH}_3 \text{CH}_2 \text{CH}_3 )</td>
</tr>
<tr>
<td>propane</td>
<td>( \text{CH}_3 \text{CH}_2 \text{CH}_3 )</td>
<td>( \text{CH}_3 \text{CH}_2 \text{CH}_3 )</td>
<td><img src="image" alt="3D Model" /></td>
<td>( \text{C}<em>4 \text{H}</em>{10} )</td>
</tr>
</tbody>
</table>
In a **straight**-chain hydrocarbon, all the carbon atoms in the molecule are linked one after the other in a **single** continuous chain.

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

Because of **branched**, it is possible to have **different structures** for the same molecular formula. **2-methylpentane**, \( \text{C}_4\text{H}_{10} \), has two **different structures** called **isomers**. Clearly both of them **cannot have exactly** the same name.

**Isomers** are **molecules** with the **same** molecular formula **but have different structures**

**Naming Rules for Alkanes**

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

<table>
<thead>
<tr>
<th>Shortened Structural Formula</th>
<th>Systematic Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{CH}_3\text{CH}_2\text{CHCH}_2\text{CH}_3 )</td>
<td><strong>3-methylpentane</strong></td>
</tr>
<tr>
<td>( \text{CH}_3 )</td>
<td></td>
</tr>
<tr>
<td>( \text{CH}_3\text{CH}_2\text{CHCH}_3 )</td>
<td><strong>2-methylpentane</strong></td>
</tr>
<tr>
<td>( \text{CH}_3 )</td>
<td></td>
</tr>
<tr>
<td>( \text{CH}_3 )</td>
<td><strong>2,3-dimethylbutane</strong></td>
</tr>
<tr>
<td>Systematic name</td>
<td>Full Structural formula</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>3-methylpentane</td>
<td></td>
</tr>
<tr>
<td>3,3-dimethylhexane</td>
<td></td>
</tr>
<tr>
<td>3-ethyl-2-methylpentane</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Systematic name</th>
<th>Shortened Structural formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-methylpentane</td>
<td></td>
</tr>
<tr>
<td>3,3-dimethylhexane</td>
<td></td>
</tr>
<tr>
<td>3-ethyl-2-methylpentane</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Incorrect name</th>
<th>Shortened Structural formula</th>
<th>Correct Systematic name</th>
</tr>
</thead>
</table>
| 3-methylbutane                   | \[
\begin{array}{c}
\text{CH}_3 \\
\text{CH}_3\text{CH}_2\text{CHCH}_3
\end{array}
\] | 2-methylbutane               |
| 2-ethylbutane                    | \[
\begin{array}{c}
\text{CH}_3\text{CHCH}_2\text{CH}_3 \\
\text{CH}_2\text{CH}_3
\end{array}
\] | 3-methylpentane              |
| 3-methyl-5-ethyloctane           | \[
\begin{array}{c}
\text{CH}_3\text{CH}_2\text{CHCH}_2\text{CHCH}_2\text{CH}_2\text{CH}_3 \\
\text{CH}_3 \\
\text{CH}_2\text{CH}_3
\end{array}
\] | 5-ethyl-3-methyloctane         |
Q1.
Name the next five molecules.

<table>
<thead>
<tr>
<th>a)</th>
<th>b)</th>
<th>c)</th>
<th>d)</th>
<th>e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Structure a)</td>
<td>![Structure b)</td>
<td>![Structure c)</td>
<td>![Structure d)</td>
<td>![Structure e)</td>
</tr>
</tbody>
</table>

Q2.
For the next four questions, draw the **full structural formula** for each structure. Then, write the **shortened structural formula**. (Use your jotter - more space needed!)

<table>
<thead>
<tr>
<th>a)</th>
<th>b)</th>
<th>c)</th>
<th>d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Structure a)</td>
<td>![Structure b)</td>
<td>![Structure c)</td>
<td>![Structure d)</td>
</tr>
</tbody>
</table>

Q3.
In the next three questions, the name of each structure is **incorrect**. Draw the structure that each name describes. **Rename** each structure correctly. (Use your jotter!)

<table>
<thead>
<tr>
<th>a)</th>
<th>b)</th>
<th>c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Structure a)</td>
<td>![Structure b)</td>
<td>![Structure c)</td>
</tr>
</tbody>
</table>
5.2 ALKANES - Properties & Uses

Attractions
The alk are a family of hy ca ; molecules made from ca and hy atoms only.

Neither car or hyd atoms have significantly str att for the sh ele so the mol are n-po.

<table>
<thead>
<tr>
<th>alkane</th>
<th>name</th>
<th>formula</th>
<th>mass (amu)</th>
<th>type</th>
<th>BPt (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>methane</td>
<td>water</td>
<td>CH₄</td>
<td>16 amu</td>
<td>non-polar</td>
<td>-164</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H₂O</td>
<td>18 amu</td>
<td>polar</td>
<td>100</td>
</tr>
</tbody>
</table>

The att between alk molecules are significantly we than po mol such as wa. They do, however, get str as the molecules get bi.
Properties

Most properties of the Alk are a result of the weak attractions between the molecules.

Melting & Boiling Pts

as seen, the melting and boiling points increase as the size of the molecules increase.

One way of measuring the flammability of a substance is to determine its Flash Point - the lowest temperature at which it can vaporise to form an ignitable mixture in air.

<table>
<thead>
<tr>
<th>Hydrocarbon</th>
<th>Formula</th>
<th>Flash Pt (°C)</th>
<th>Boiling Pt (°C)</th>
<th>Flammability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
<td>CH₃CH₂CH₃</td>
<td>-104</td>
<td>-42</td>
<td>Flammable</td>
</tr>
<tr>
<td>Isobutane</td>
<td>(CH₃)₃CH</td>
<td>-84</td>
<td>-12</td>
<td>Flammable</td>
</tr>
<tr>
<td>Butane</td>
<td>CH₃(CH₂)₂CH₃</td>
<td>-60</td>
<td>-1</td>
<td>Flammable</td>
</tr>
<tr>
<td>Pentane</td>
<td>CH₃(CH₂)₃CH₃</td>
<td>-40</td>
<td>36-38</td>
<td>Flammable</td>
</tr>
<tr>
<td>Hexane</td>
<td>CH₃(CH₂)₄CH₃</td>
<td>-22 to -26</td>
<td>65-69</td>
<td>Flammable</td>
</tr>
<tr>
<td>Heptane</td>
<td>CH₃(CH₂)₅CH₃</td>
<td>-8</td>
<td>92-100</td>
<td>Flammable</td>
</tr>
<tr>
<td>Octane</td>
<td>CH₃(CH₂)₆CH₃</td>
<td>16</td>
<td>125-127</td>
<td>Flammable</td>
</tr>
<tr>
<td>Nonane</td>
<td>CH₃(CH₂)₇CH₃</td>
<td>31</td>
<td>151</td>
<td>Flammable</td>
</tr>
<tr>
<td>Decane</td>
<td>CH₃(CH₂)₈CH₃</td>
<td>46</td>
<td>174</td>
<td>Combustible</td>
</tr>
<tr>
<td>Kerosene</td>
<td>HC mixture</td>
<td>43-82</td>
<td>151-301</td>
<td>Combustible</td>
</tr>
<tr>
<td>Isopar ® H</td>
<td>C₁₁-C₁₂ Isoparaffin</td>
<td>57</td>
<td>182</td>
<td>Combustible</td>
</tr>
<tr>
<td>Undecane</td>
<td>CH₃(CH₂)₉CH₃</td>
<td>60</td>
<td>196</td>
<td>Combustible</td>
</tr>
<tr>
<td>Dodecane</td>
<td>CH₃(CH₂)₁₀CH₃</td>
<td>71</td>
<td>215-217</td>
<td>Combustible</td>
</tr>
<tr>
<td>Tridecane</td>
<td>CH₃(CH₂)₁₁CH₃</td>
<td>79</td>
<td>234</td>
<td>Combustible</td>
</tr>
<tr>
<td>Tetradecane</td>
<td>CH₃(CH₂)₁₂CH₃</td>
<td>100</td>
<td>252</td>
<td>Combustible</td>
</tr>
<tr>
<td>Pentadecane</td>
<td>CH₃(CH₂)₁₃CH₃</td>
<td>132</td>
<td>270</td>
<td>Combustible</td>
</tr>
<tr>
<td>Hexadecane</td>
<td>CH₃(CH₂)₁₄CH₃</td>
<td>135</td>
<td>287</td>
<td>Combustible</td>
</tr>
<tr>
<td>Mineral oil</td>
<td>Paraffin Oil</td>
<td>199</td>
<td>260-360</td>
<td>Combustible</td>
</tr>
</tbody>
</table>

Notice that these hydrocarbons can be ignited at temperatures well below their boiling points - it is only necessary to convert a small proportion into gas to be able to produce a flame.

However, those hydrocarbons which are already gases at room temperature (C₁ to C₄) will be the most flammable.

Flammability

as can be seen, the flammability increases as the size of the molecules decrease.
Non-polar alkane molecules cannot compete with the strength of attractions that exist between water molecules so alkane are insoluble in water.

Most alkane molecules of all sizes, are insoluble (immiscible) in water but will dissolve (are miscible) in similar non-polar liquids.

**Solubility**

Hydrocarbons, including alkanes, were used in many of the early dry-cleaners as they could dissolve many stains. Modern dry-cleaners use less flammable molecules derived from simple hydrocarbons.

**Uses**

Not surprisingly, most of the uses of alkanes are linked to their ability to release large amounts of energy when burnt.

One method of measuring the 'energy content' of a fuel involves determining the energy released (exo) when one mole of the fuel burns in a good supply of oxygen (complete combustion).

This is called the Heat (or Enthalpy) of Combustion and is measured in kilojoules per mole (kJ mol\(^{-1}\)).
Q1.

The table below gives information about some members of the alkane family.

<table>
<thead>
<tr>
<th>Number of carbons</th>
<th>Molecular formula</th>
<th>Name</th>
<th>Condensed structure</th>
<th>Density (g/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CH₄</td>
<td>methane</td>
<td>CH₄</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>C₂H₆</td>
<td>ethane</td>
<td>CH₃CH₃</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C₃H₈</td>
<td>propane</td>
<td>CH₃CH₂CH₃</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>C₄H₁₀</td>
<td>butane</td>
<td>CH₃CH₂CH₂CH₃</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>C₅H₁₂</td>
<td>pentane</td>
<td>CH₃(CH₂)₂CH₃</td>
<td>0.5572</td>
</tr>
<tr>
<td>6</td>
<td>C₆H₁₄</td>
<td>hexane</td>
<td>CH₃(CH₂)₂CH₂CH₃</td>
<td>0.6603</td>
</tr>
<tr>
<td>7</td>
<td>C₇H₁₆</td>
<td>heptane</td>
<td>CH₃(CH₂)₂CH₂CH₂CH₃</td>
<td>0.6837</td>
</tr>
<tr>
<td>8</td>
<td>C₈H₁₈</td>
<td>octane</td>
<td>CH₃(CH₂)₂CH₂CH₂CH₂</td>
<td>0.7026</td>
</tr>
<tr>
<td>9</td>
<td>C₉H₂₀</td>
<td>nonane</td>
<td>CH₃(CH₂)₂CH₂CH₂CH₃</td>
<td>0.7177</td>
</tr>
<tr>
<td>10</td>
<td>C₁₀H₂₂</td>
<td>decane</td>
<td>CH₃(CH₂)₂CH₂CH₂CH₂</td>
<td>0.7299</td>
</tr>
<tr>
<td>11</td>
<td>C₁₁H₂₄</td>
<td>dodecane</td>
<td>CH₃(CH₂)₂CH₂CH₂CH₂</td>
<td>0.7402</td>
</tr>
<tr>
<td>12</td>
<td>C₁₂H₂₆</td>
<td>tridecane</td>
<td>CH₃(CH₂)₂CH₂CH₂CH₂</td>
<td>0.7487</td>
</tr>
<tr>
<td>13</td>
<td>C₁₃H₂₈</td>
<td>tetradecane</td>
<td>CH₃(CH₂)₂CH₂CH₂CH₂</td>
<td>0.7546</td>
</tr>
</tbody>
</table>

a) State the density of pentane. ________________
b) Suggest the name and the condensed structure of the alkane with 14 carbons.
   name ________________
   condensed structure ________________

c) What is the increase in density between pentane and pentadecane? ________________
d) Predict the density of the alkane with 25 carbon atoms. ________________
e) What is the density of water? ________________
f) Predict the size of the first alkane that would sink if mixed with water. ________________
g) Use the graph below to explain why your prediction is unlikely to be correct.

Q2.

The graph below shows the relationship between temperature and the composition of a reaction mixture of 2-methylbutane and pentane in the presence of a catalyst.

a) The reaction mixture contain the most of which isomer? ________________
b) Could you obtain better yields of the isomer 2-methylbutane by running the reaction at higher or lower temperatures? ________________
c) At what temperature could you run the reaction to obtain a mixture that contains about 25% pentane? ________________

d) Describe the relationship between the boiling point of an alkane and the number of carbons in the molecule. ________________
e) Describe the relationship between the boiling point of an alkane and the boiling point of an isoalkane. ________________
f) Explain why there are no isoalkanes for methane, ethane and propane. ________________
5.3 The ALKENES

Alkene Molecules

The alk     are a family of hy   ca    ; molecules made from ca    and hy    atoms only. The first (sm ) member of the family is eth    , C₂H₄.

Ca atoms always have unpaired el in their ou shell and so can form bonds in total.

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

In the a ene family, two of the ca atoms will share two pairs of el . This forms a dou bond.

It is much easier to draw fl pictures to show how each of the atoms are joined to each other.

The Alk family is made up of cha where most of the ca atoms join together with a sin bond, but tw of the ca atoms will have joined with a dou bond.

Alkene Names

The same system is used to name the a enes as was used to name the a anes.

The sur     is -ene to tell you it is a mem of the alkene family, the fi name tells you the nu of ca atoms in each molecule.

\[
\begin{align*}
\text{Pe} - & = 5 \text{ Carbon atoms} \\
\text{E} - & = 2 \text{ Carbon atoms} \\
\text{Hex}- & = 6 \text{ Carbon atoms} \\
\text{Pr} - & = 3 \text{ Carbon atoms} \\
\text{Hept}- & = 7 \text{ Carbon atoms} \\
\text{B} - & = 4 \text{ Carbon atoms} \\
\text{O} - & = 8 \text{ Carbon atoms}
\end{align*}
\]

1 2 3 4 5 6 7 8

Monkeys Eat Peanut Butter Perched High High Overhead
<table>
<thead>
<tr>
<th>Number of carbon atoms</th>
<th>Name of alkene</th>
<th>Structural formula of alkene</th>
<th>Molecular formula of alkene</th>
</tr>
</thead>
</table>
| 2                      | ethene         | \[
\begin{array}{c}
    H \\
    H \\
    \text{C} = \text{C} \\
    H \\
    H
\end{array}
\] | $C_2H_4$ |
| 3                      | ene            | \[
\begin{array}{c}
    H \\
    H \\
    H \\
    \text{C} = \text{C} \\
    H \\
    H \\
    H
\end{array}
\] | $C_3H_6$ |
|                        | ene            | \[
\begin{array}{c}
    H \\
    H \\
    H \\
    \text{C} = \text{C} \\
    H \\
    H \\
    H
\end{array}
\] | $C_4H_8$ |
|                        | ene            | \[
\begin{array}{c}
    H \\
    H \\
    H \\
    \text{C} = \text{C} \\
    H \\
    H \\
    H
\end{array}
\] | $C_5H_{10}$ |
|                        | ene            | \[
\begin{array}{c}
    H \\
    H \\
    H \\
    \text{C} = \text{C} \\
    H \\
    H \\
    H
\end{array}
\] | $C_6H_{12}$ |
|                        | ene            | \[
\begin{array}{c}
    H \\
    H \\
    H \\
    \text{C} = \text{C} \\
    H \\
    H \\
    H
\end{array}
\] | $C_7H_{14}$ |
|                        | ene            | \[
\begin{array}{c}
    H \\
    H \\
    H \\
    \text{C} = \text{C} \\
    H \\
    H \\
    H
\end{array}
\] | $C_8H_{16}$ |

The *alkenes* are called a *homo series* of *molecules*. This is because each molecule differs from the previous molecule by the same amount, $-\text{CH}_2-$, (*homo-* = same, *logous* = difference).

**CnH**

This makes it possible to write a General Formula for the *alkene* family. There are always twice as many hydrogen atoms for any number of carbon atoms.

**CnH2**

This is different from the *alkane* family. Since they have no double bond, there is room for twice extra hydrogen atoms on an *alkane* with the same number of carbon atoms.
There are even more *iso* possible in the *alkene* family. Again there are *str*-chain alkenes and *bra*-chain alkenes.

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

In alkenes, the $C = C$ is given priority and the *chain* is numbered from end nearest double bond. (i.e. the number should be as low as possible.)

**Branched Alkenes**

```
  H H H H
  l   l   |
H - C - C - C = C - H
  l   l   l
H   H
```

**Branched Alkene Structures**

<table>
<thead>
<tr>
<th>Name:</th>
<th>5-methylhept-2-ene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Structural Formula:</td>
<td></td>
</tr>
<tr>
<td>Molecular Formula:</td>
<td></td>
</tr>
<tr>
<td>Name:</td>
<td>2,3-dimethylpent-2-ene</td>
</tr>
<tr>
<td>Full Structural Formula:</td>
<td></td>
</tr>
<tr>
<td>Molecular Formula:</td>
<td></td>
</tr>
</tbody>
</table>
The *alk* are a family of *hy* *ca*; molecules made from *ca* and *hy* atoms *only*.

Neither *car* or *hyd* atoms have significantly *str* *att* for the *sha* *ele* so the *mol* are *non-po*.

<table>
<thead>
<tr>
<th>ethene</th>
<th>name</th>
<th>methanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_2H_4$</td>
<td><em>formula</em></td>
<td>$CH_3OH$</td>
</tr>
<tr>
<td>28 <em>amu</em></td>
<td><em>mass</em></td>
<td>32 <em>amu</em></td>
</tr>
<tr>
<td><em>non-polar</em></td>
<td><em>type</em></td>
<td><em>polar</em></td>
</tr>
<tr>
<td>-104</td>
<td><em>BPt</em> (°C)</td>
<td>65</td>
</tr>
</tbody>
</table>

The *att* between *alk* molecules are significantly *wea* than *pol* *molecules* such as *meth*.

They do, however, get *stro* as *the molecules get big* and are not much different from the equivalent *alk*.

Most *prop* of the *Alk* are a result of the *we* *att* between the *mol*.

In general, there are very *sm* *diff* between the *prop* of the *enes* and the *anes*.

*Melting & Boiling Pts*  
*again, the melting and boiling points increase as the size of the molecules increase.*

*Flammability*  
*again, the flammability increases as the size of the molecules decrease.*

*Solubility*  
*alkene molecules of all sizes, are insoluble (immiscible) in water but will dissolve (are miscible) in similar non-polar liquids.*
Though alkenes release large amounts of energy when burnt, they have much more important uses so are rarely used as fuels.

Alk, particularly eth, are important in the manufacture of other chemicals such as plastics, ethanol, ethanoic acid, esters, halogen derivatives etc.

Uses

Other families, such as alcohols, acids and esters will be met later in this Unit.
Q1.
Name the next five molecules.

a)  \[
    \text{H}_3\text{C} \equiv \text{CH} \equiv \text{CH} \equiv \text{CH}_2 \equiv \text{CH}_3
    \]

b)  \[
    \text{H}_2\text{C} \equiv \text{CH} \equiv \text{CH} \equiv \text{CH}_3
    \]

c)  \[
    \text{H}_3\text{C} \equiv \text{CH} \equiv \text{CH} \equiv \text{C} \equiv \text{CH}_2 \equiv \text{CH}_3
    \]

d)  \[
    \text{H}_2\text{C} \equiv \text{C} \equiv \text{CH}_2 \equiv \text{CH}_2 \equiv \text{CH}_3
    \]

e)  \[
    \text{H}_3\text{C} \equiv \text{CH} \equiv \text{C} \equiv \text{CH} \equiv \text{CH}_2 \equiv \text{CH}_3
    \]

Q2.
For the next four questions, draw the full structural formula for each structure. Then, write the shortened structural formula. (Use your jotter - more space needed!)

a)  \text{pent-2-ene}

b)  \text{2-methylbut-1-ene}

c)  \text{3-methylhept-2-ene}

d)  \text{2,5-dimethylhex-2-ene}

Q3.
In the next three questions, the name of each structure is incorrect. Draw the structure that each name describes. Rename each structure correctly. (Use your jotter!)

a)  \text{hex-4-ene}

b)  \text{3-propylhept-5-ene}

c)  \text{3,3-dimethylprop-2-ene}
5.4 The CYCLOALKANES

Cycloalkane Molecules

The cycloalkanes are a family of hydrocarbons; made from carbon and hydrogen atoms only.

The first (smallest) member of the family is cyclopropane, \( \text{C}_3\text{H}_6 \).

![Cyclopropane, Cyclobutane, Cyclopentane, Cyclohexane](image)

The cycloalkane family is made up of rings where all of the carbon atoms join together with a single bond. Molecules with single bonds only are described as saturated since they have the maximum number of hydrogens attached.

Cycloalkane Names

The same system is used to name the cycloalkanes as was used to name the alkanes.

The surname is -ane to tell you it is like a member of the alkane family (only single bonds), the first name tells you the number of carbon atoms in each molecule. Cyclo tells you the carbon atoms are in a ring.

- cyclopropr - = 3 C's cyclohex - = 6 C's
- cyclobut - = 4 C's cyclohe - = 7 C's
- cyclopent - = 5 C's cyclooct - = 8 C's

1 2 3 4 5 6 7 8
Monkeys Eat Peanut Butter Perched High High Overhead
Just like alkanes and alkenes the cycloalkanes can also have branches and the same system for naming these branches is used.

The molecule opposite would be named as: methylcyclohexane

1,3-dimethylcyclopentane

**Properties**

Most properties of the cycloalkanes are a result of the weak attractions between the molecules. In general, there are very small differences between the properties of the cycloalkanes and the alkanes.

**Melting & Boiling Pts**

Again, the melting and boiling points increase as the size of the molecules increase.

**Flammability**

Again, the flammability increases as the size of the molecules decrease.

**Solubility**

Cycloalkane molecules of all sizes, are insoluble (immiscible) in water but will dissolve (are miscible) in similar non-polar liquids.

However, though similar, the more rigid structure of the cycloalkanes does allow stronger attractions than alkanes.

As a result they have slightly higher boiling points than expected.

<table>
<thead>
<tr>
<th>No of C atoms</th>
<th>Cycloalkane Boiling Point (°C)</th>
<th>Alkane Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>33</td>
<td>-42</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>-1</td>
</tr>
<tr>
<td>5</td>
<td>49</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
<td>81</td>
<td>69</td>
</tr>
<tr>
<td>7</td>
<td>119</td>
<td>98</td>
</tr>
<tr>
<td>8</td>
<td>149</td>
<td>126</td>
</tr>
</tbody>
</table>
Q1.
Which of the following compounds belongs to the same homologous series as the compound with the molecular formula \( \text{C}_3\text{H}_8 \)?

A. \( \text{C}_3\text{H}_8 \)
B. \( \text{C}_4\text{H}_{10} \)
C. \( \text{C}_5\text{H}_{12} \)
D. \( \text{C}_6\text{H}_{14} \)

Q2.
The properties of hydrocarbons depend on the sizes of their molecules. Compared with a hydrocarbon made up of small molecules, a hydrocarbon with large molecules will

A. be more viscous
B. be more flammable
C. evaporate more readily
D. have a lower boiling point range.

Q3.
Which of the following compounds fits the general formula, \( \text{C}_n\text{H}_{2n} \), and will rapidly decolourise bromine solution?

A. cyclopentane
B. pentane
C. pentene
D. cyclopentene

Q4.
The structures of some hydrocarbons are shown in the grid.

a) Identify the two hydrocarbons with the general formula \( \text{C}_n\text{H}_{2n} \) which do not react quickly with bromine solution. ______________________

b) Identify the hydrocarbon which is the first member of a homologous series. ________________

c) Identify the two isomers of \( \text{CH}_2=\text{C}=-\text{C}=-\text{C}=-\text{H} \)__________________________

Q5.
Which of the following hydrocarbons does not belong to the same homologous series as the others?

A. \( \text{CH}_4 \)
B. \( \text{C}_3\text{H}_8 \)
C. \( \text{C}_4\text{H}_{10} \)
D. \( \text{C}_6\text{H}_{12} \)

Q6.
The table gives information about some members of the cycloalkane family

<table>
<thead>
<tr>
<th>Name</th>
<th>Molecular Formula</th>
<th>Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cyclopropane</td>
<td>( \text{C}_3\text{H}_6 )</td>
<td>-33</td>
</tr>
<tr>
<td>cyclobutane</td>
<td>( \text{C}_4\text{H}_8 )</td>
<td>-12</td>
</tr>
<tr>
<td>cyclopentane</td>
<td>( \text{C}<em>5\text{H}</em>{10} )</td>
<td>49</td>
</tr>
<tr>
<td>cyclohexane</td>
<td>( \text{C}<em>6\text{H}</em>{12} )</td>
<td>81</td>
</tr>
<tr>
<td>cycloheptane</td>
<td>( \text{C}<em>7\text{H}</em>{14} )</td>
<td></td>
</tr>
</tbody>
</table>

a) Predict the boiling point of cycloheptane. ___________ °C

b) What term is used to describe any family of compounds, like the cycloalkanes, which have the same general formula and similar chemical properties? ________________

c) Draw and name a saturated isomer of cyclobutane.

d) Draw and name an unsaturated isomer of cyclobutane.
5.5 Hydrocarbon Reactions

Combustion

This reaction is effectively the same for all 3 hydrocarbon families - Alkane, Alkenes & Cycloalkanes.

\[
\text{carbon} \rightarrow \text{carbon dioxide}: \quad \text{as shown by the lime water turning milky/cloody}
\]

\[
\text{hydrogen} \rightarrow \text{water}: \quad \text{as shown by the blue CoCl₂ paper turning pink}
\]

\[
\text{methane} + \text{ox} \rightarrow \text{carbon dioxide} + \text{water}
\]

\[
\text{butene} + \text{ox} \rightarrow \text{carbon dioxide} + \text{water}
\]

\[
\text{cyclopentane} + \text{ox} \rightarrow \text{carbon dioxide} + \text{water}
\]

\[
\text{hydrocarbon} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}
\]
Hydrocarbon Families

**Bromine Test**

This reaction is often used to help tell the difference between our 3 families - Alk, Alkenes & Cycloalkanes.

The orange colour of bromine disappears when it reacts with an alkene.

<table>
<thead>
<tr>
<th>Family</th>
<th>General Formula</th>
<th>Example</th>
<th>Type of C to C bond</th>
<th>Result with Bromine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alk</td>
<td>$C_nH$</td>
<td><img src="image" alt="Alkane" /></td>
<td>single bonds only (saturated)</td>
<td>bromine stays brown (decolourises slowly)</td>
</tr>
<tr>
<td>Cycloalkane</td>
<td>$C_nH$</td>
<td><img src="image" alt="Cycloalkane" /></td>
<td>single bonds only (saturated)</td>
<td>bromine stays brown (decolourises slowly)</td>
</tr>
<tr>
<td>Alkenes</td>
<td>$C_nH$</td>
<td><img src="image" alt="Alkene" /></td>
<td>one double bond (unsaturated)</td>
<td>bromine decolourises immediately</td>
</tr>
</tbody>
</table>

Alkenes react with bromine because they take part in an addition reaction. Two molecules react together to form just one product.
Hydrocarbon Families

Addition Reactions

These are important reactions that only molecules with C = C bonds (unsaturated) can do. They can be used to make many useful products.

This reaction can be done with **hal mol**:

\[(F_2, \quad , \quad , \quad and \quad )\]

or with **hydr hal** molecules:

\[(H—F, H—, H—, H—)\]

In each case the **mol** will break into **two parts** and they will **add on to the C atoms making up the C = C double bond**.

\[\text{Br — Br} \quad \text{or} \quad \text{H — Br}\]

\[
\begin{align*}
\text{Br}_2 & \quad \rightarrow \quad \text{Br} — \text{Br} \\
\text{C}_2\text{H}_4 & \quad + \quad \rightarrow \quad 1,2\text{-dibromoethane}
\end{align*}
\]

\[
\begin{align*}
\text{H} — \text{Br} & \quad \rightarrow \quad \text{Br} — \text{Br} \\
\text{C}_2\text{H}_4 & \quad + \quad \rightarrow \quad \text{bromoethane}
\end{align*}
\]

\[
\begin{align*}
\text{H} — \text{Br} & \quad \rightarrow \quad \text{Br} — \text{Br} \\
\text{C}_2\text{H}_4 & \quad + \quad \rightarrow \quad \text{hydrogen bromide}
\end{align*}
\]
Example 1

Equation using full structural formulae:

\[ \text{CH}_3\text{CH} = \text{CH}_2 + \text{Cl}_2 \rightarrow \text{CH}_3\text{CHClCH}_2\text{Cl} \]

Equation using shortened structural formulae:

\[ \text{CH}_3\text{CH} = \text{CH}_2 + \text{Cl}_2 \rightarrow \text{CH}_3\text{CHClCH}_2\text{Cl} \]

Equation using systematic names:

\[ \text{prop-1-ene} + \text{chlorine} \rightarrow \text{1,2-dichloropropane} \]

Example 2

Equation using full structural formulae:

\[ \text{pent-2-ene} + \text{Br}_2 \rightarrow \text{2,3-dibromopentane} \]

Equation using shortened structural formulae:

\[ \text{pent-2-ene} + \text{Br}_2 \rightarrow \text{2,3-dibromopentane} \]

Equation using systematic names:

\[ \text{pent-2-ene} + \text{bromine} \rightarrow \text{2,3-dibromopentane} \]

The alkenes are described as unsat because they contain a C = C dou bond, whereas the products are sat because they contain only C — C sin bonds, and their names end in -ane to show this.

The Bromine Test is really a test for unsat - the presence of a C = C dou bond.
Example 3

Equation using full structural formulae:

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

\[+ \quad \text{H}-\text{Cl} \quad \rightarrow \]

Equation using shortened structural formulae:

\[+ \quad \rightarrow \]

Equation using systematic names:

\[+ \quad \text{hydrogen} \quad \rightarrow \quad \text{2-chlorobutane} \]

Example 4 - two possible isomeric products

Equation using full structural formulae:

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

\[+ \quad \text{H}-\text{I} \quad \rightarrow \quad \text{or} \]

Equation using shortened structural formulae:

\[+ \quad \rightarrow \quad \text{CH}_3\text{CHI CH}_2\text{CH}_2\text{CH}_3 \quad \text{or} \]

Equation using systematic names:

\[+ \quad \text{hydrogen} \quad \rightarrow \quad \text{2-iodopentane} \quad \text{or} \]

\[\text{iodide} \quad \rightarrow \quad \text{1-iodopentane} \]
Hydration

This reaction uses the water molecule: $H_2O$

Again, the molecule will break into two parts and they will add on to the C atoms making up the C = C double bond.

\[ H \text{–} OH \rightarrow H \text{ and } OH(\text{hydroxyl group}) \]

\[ \text{ethene} \quad + \quad \text{water} \quad \rightarrow \quad \text{ethanol} \]

Example 5

Equation using full structural formulae:

\[ \text{but-2-ene} \quad + \quad \text{H–OH} \quad \rightarrow \quad \text{butan-2-ol} \]

Equation using shortened structural formulae:

\[ \text{CH}_3\text{CH = CHCH}_3 \quad + \quad \text{H–OH} \quad \rightarrow \quad \text{CH}_3\text{CHOHCH}_2\text{CH}_3 \]

Equation using systematic names:

\[ \text{H}_2\text{O} \]
**Hydrogenation**

This reaction uses the *hydrogen molecule*: \( H_2 \)

Again, the *molecule* will break into *two parts* and they will *add on to the C atoms making up the C = C double bond*.

\[
\begin{align*}
H - H & \rightarrow H \quad \text{and} \quad H
\end{align*}
\]

\[
\begin{align*}
\text{Ethene} & \quad + \quad \text{hydrogen} \quad \rightarrow \\
\end{align*}
\]

There is no obvious advantage in turning a *reactive, very useful alkane* into a *less reactive, less useful alkane*.

However, *animal fats*, like *butter*, contain mainly *saturated fats* (C–C *single bonds*) while *vegetable oils* have more *unsaturated fats* (C = C *double bonds*) and are *healthier for us*.

Food scientists use *hydrogenation* to convert some of the *unsaturated fats* in a *liquid oil* into *saturated fats* to produce a more *solid form - margarine* - which is still *healthier* than butter and has the advantage that it can 'spread straight from the fridge'.
**Polymerisation**

*Eth* is an unsat *hydrocarbon*, and the *dou bond*, *C = C*, makes it very reactive. The *dou bond* can break open allowing new atoms or molecules to add on to the carbon atoms. When many many small molecules join together in this way it is called *add poly*.

![Diagram of polymerisation]

Even with a *reac dou bond*, you need *high press* to force the *eth* molecules close together and a *high temp* to help break the *bo open*. A *cat* is also needed to help the reaction go *fas*.

<table>
<thead>
<tr>
<th>Name of Monomer</th>
<th>Structure of Monomer</th>
<th>Structure of Polymer</th>
<th>Repeating Unit</th>
<th>Name of Polymer</th>
</tr>
</thead>
<tbody>
<tr>
<td>chloroethene (vinylchloride)</td>
<td>Cl H Cl H Cl H Cl H Cl H Cl H</td>
<td>Cl H Cl H Cl H Cl H Cl H Cl H</td>
<td>Cl H Cl H Cl H Cl H Cl H Cl H</td>
<td>polychlorethene (PVC)</td>
</tr>
<tr>
<td>propene</td>
<td>C = C</td>
<td>C = C</td>
<td>C = C</td>
<td>C = C</td>
</tr>
<tr>
<td>butene</td>
<td>C = C</td>
<td>C = C</td>
<td>C = C</td>
<td>C = C</td>
</tr>
<tr>
<td>styrene</td>
<td>C = C</td>
<td>C = C</td>
<td>C = C</td>
<td>C = C</td>
</tr>
<tr>
<td>tetrafluoroethene</td>
<td>C = C</td>
<td>C = C</td>
<td>C = C</td>
<td>C = C</td>
</tr>
</tbody>
</table>

KHS Dec 2013/Jan 2014
Cracking allows the oil industry to change less useful, long chained alkanes into a more useful mixture of short chained alkanes and alkenes.

It is not possible for all the smaller molecules produced to be alkanes. There are not enough hydrogen atoms available. At least one of the molecules will need to form a double bond, \( \text{C}=\text{C} \), instead. It is also possible to produce a cycloalkane during cracking.

Modern catalysts allow for more precise cracking of smaller alkanes to produce the equivalent alkenes - particularly useful in producing the monomers needed for the formation of addition polymers. A molecule of hydrogen is also produced.

\[
\begin{align*}
\text{C}_3\text{H}_8 & \rightarrow \text{H}_2 + \text{C}_3\text{H}_6 \\
\text{C}_3\text{H}_6 & \rightarrow \text{H}_2 + \text{C}_3\text{H}_4
\end{align*}
\]
Q1. Which line in the table correctly identifies Process X and Compound Y?

<table>
<thead>
<tr>
<th>Process X</th>
<th>Compound Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>cracking</td>
</tr>
<tr>
<td>B</td>
<td>cracking</td>
</tr>
<tr>
<td>C</td>
<td>distillation</td>
</tr>
<tr>
<td>D</td>
<td>distillation</td>
</tr>
</tbody>
</table>

A student performed the Bromine Test on 4 unknown hydrocarbons.

a) Complete the table.

b) Suggest a possible name for hydrocarbon C. ______________

c) Suggest a possible structure for hydrocarbon D

Which of the following alkenes will also produce two products when it undergoes an addition reaction with hydrogen bromide?

A Ethene  
B But-1-ene  
C But-2-ene  
D Hex-3-ene

When propene undergoes an addition reaction with hydrogen bromide, two products are formed.

The structure below shows a section of an addition polymer.

Which molecule is used to make this polymer?

A CH₃ C H  
B CH₃ C H  
C CH₃ COOCH₃  
D H C H
N5 Knowledge Met in this Section

Homologous Series

- A homologous series is a group of compounds with:
  - similar chemical properties
  - the same general formula
  - a gradual change in physical properties such as melting and boiling point.
- Examples of homologous series include families of compounds called the **alkanes**, **cycloalkanes** and **alkenes**.

Alkanes

- The **alkanes** are the main family of **hydrocarbons** found in natural gas / oil.

<table>
<thead>
<tr>
<th>Name</th>
<th>Molecular Formula</th>
<th>Shortened Structural Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>methane</td>
<td>CH(_4) (g)</td>
<td>CH(_4)</td>
</tr>
<tr>
<td>ethane</td>
<td>C(_2)H(_6) (g)</td>
<td>CH(_3)CH(_3)</td>
</tr>
<tr>
<td>propane</td>
<td>C(_3)H(_8) (g)</td>
<td>CH(_3)CH(_2)CH(_3)</td>
</tr>
<tr>
<td>butane</td>
<td>C(_4)H(_10) (g)</td>
<td>CH(_3)CH(_2)CH(_2)CH(_3)</td>
</tr>
<tr>
<td>pentane</td>
<td>C(_5)H(_12) (l)</td>
<td>CH(_3)CH(_2)CH(_2)CH(_2)CH(_3)</td>
</tr>
<tr>
<td>hexane</td>
<td>C(_6)H(_14) (l)</td>
<td>CH(_3)CH(_2)CH(_2)CH(_2)CH(_2)CH(_3)</td>
</tr>
<tr>
<td>heptane</td>
<td>C(_7)H(_16) (l)</td>
<td>CH(_3)CH(_2)CH(_2)CH(_2)CH(_2)CH(_2)CH(_3)</td>
</tr>
<tr>
<td>octane</td>
<td>C(_8)H(_18) (l)</td>
<td>CH(_3)CH(_2)CH(_2)CH(_2)CH(_2)CH(_2)CH(_2)CH(_3)</td>
</tr>
</tbody>
</table>

- The **general formula** for the alkanes is C\(_n\)H\(_{2n+2}\)
- The simpler alkanes are mainly used as fuels
- The alkanes burn to give carbon dioxide and water on **complete combustion**
- The alkanes are said to be **saturated** because they contain only **single** C—C bonds
- The alkanes **cannot decolourise** bromine water immediately on mixing
- The alkanes have very **weak attractions** between their molecules and the early (smaller) members of the family
  - have **very low melting & boiling points**
  - are volatile, flammable and non-viscous (runny)
  - are **insoluble** (immiscible) in water
• Alkanes can be **straight chained or branched**.

![Structural formulas for butane and 2-methylpropane]

• Branched alkanes can be **named** systematically according to rules set down by the International Union of Pure and Applied Chemistry (IUPAC).

**butane**  
2-methylpropane

### Alkenes

• The **alkanes** are another family of **hydrocarbons** but contain **double** C = C bonds

<table>
<thead>
<tr>
<th>Name</th>
<th>Molecular Formula</th>
<th>Shortened Structural Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethene</td>
<td>C₂H₄ (g)</td>
<td>CH₂ = CH₂</td>
</tr>
<tr>
<td>propene</td>
<td>C₃H₆ (g)</td>
<td>CH₃CH = CH₂</td>
</tr>
<tr>
<td>hexene</td>
<td>C₆H₁₂ (l)</td>
<td>CH₃CH₂CH₂CH₂CH₂CH = CH₂</td>
</tr>
</tbody>
</table>

• The **general formula** for the **alkenes** is CₙH₂ₙ
• The alkenes burn to give carbon dioxide and water on **complete combustion**
• The alkenes are said to be **unsaturated** because they contain a **double** C = C bond
• The presence of the C = C bond makes alkenes more reactive than alkanes
• The alkenes can undergo many **addition** reactions eg.
  
  * **hydrogenation** \( \text{CH}_2 = \text{CH}_2 + \text{H}_2 \rightarrow \text{CH}_3\text{CH}_3 \)
  * **hydration** \( \text{CH}_2 = \text{CH}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{OH} \)
  * **bromination** \( \text{CH}_2 = \text{CH}_2 + \text{Br}_2 \rightarrow \text{CH}_2\text{BrCH}_2\text{Br} \)

• The alkenes **can decolourise** bromine water immediately on mixing
• **Decolourising bromine water is a test for unsaturation**
• The alkenes have very **weak attractions** between their molecules and the early (smaller) members of the family
  
  ❖ have **very low melting & boiling points**
  ❖ are **volatile, flammable** and **non-viscous** (runny)
  ❖ are **insoluble** (immiscible) in water
Alkenes can be straight chained or branched. The double bond can be found anywhere in the molecule.

\[
\begin{align*}
\text{Alkenes:} & \\
\text{but-1-ene} & \quad \text{but-2-ene} & \quad 2\text{-methylpropene}
\end{align*}
\]

Cycloalkanes

- The cycloalkanes are another family of hydrocarbons that contain single C—C bonds joined in rings.

<table>
<thead>
<tr>
<th>Name</th>
<th>Molecular Formula</th>
<th>Shortened Structural Formula</th>
</tr>
</thead>
</table>
| cyclopropane  | C_3H_6 (g)       | \[
\begin{align*}
\text{H} & \quad \text{C—H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H}
\end{align*}
\] |
| cyclopentane  | C_5H_10 (l)      | \[
\begin{align*}
\text{H} & \quad \text{CH} \\
\text{H} & \quad \text{C—H} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C—H} \\
\text{H} & \quad \text{H}
\end{align*}
\] |

- The general formula for the cycloalkanes is C_nH_{2n}
- The cycloalkanes burn to give CO_2 and H_2O on complete combustion
- The cycloalkanes are saturated because they contain single C—C bonds
- The cycloalkanes cannot decolourise bromine water immediately on mixing
- The cycloalkanes have very weak attractions between their molecules and the early (smaller) members of the family
  - have very low melting & boiling points
  - are volatile, flammable and non-viscous (runny)
  - are insoluble (immiscible) in water
- Cycloalkanes are rings which can also have branches.

- Cycloalkanes can be named systematically according to rules set down by the International Union of Pure and Applied Chemistry (IUPAC).

<table>
<thead>
<tr>
<th>Name</th>
<th>Molecular Formula</th>
<th>Shortened Structural Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>cyclopentane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>methylcyclopentane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,3-dimethylcyclopentane</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Hydrocarbon Families

Isomers

- Isomers are compounds that have the same molecular formula but have different structural formulae.

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

- Isomers will have slightly different properties.

Making Addition Polymers

- Many polymers are made from the small unsaturated (C = C) molecules made by cracking.

- Many monomers made from ethene e.g chloroethene (vinyl chloride \(\rightarrow\) PVC).

- During the polymerisation of ethene, many ethene monomers join to make one large poly(ethene) molecule.
**CONSOLIDATION QUESTIONS**

Q1. Int2
Which of the following could be the molecular formula of a cycloalkane?

A  C₇H₁₀  
B  C₇H₁₂  
C  C₇H₁₄  
D  C₇H₁₆

Q2. Int2
Compared with pentane, propane

A  is less flammable and contains larger molecules  
B  is less flammable and contains smaller molecules  
C  is more flammable and contains larger molecules  
D  is more flammable and contains smaller molecules.

Q3. Int2
When methane burns in a plentiful supply of air, the products are

A  carbon monoxide and water vapour  
B  carbon and water vapour  
C  carbon dioxide and hydrogen  
D  carbon dioxide and water vapour

Q4. SGC
The monomer in superglue has the structure shown opposite.

a) Draw a section of the polymer, showing three monomer units joined together.

b) What name is given to this type of polymerisation? _____________

c) Bromine reacts with the monomer to produce a saturated compound. Draw the structural formula for this compound.

\[
\begin{align*}
\text{H} & \quad \text{COOCH₃} \\
\text{C} & \quad \text{C} \\
\text{H} & \quad \text{CN}
\end{align*}
\]

\[+ \text{Br–Br} \rightarrow\]

Q5. Int2
The name of the above compound is

A  1, 1–dimethylpropane  
B  2-ethylpropane  
C  2-methylbutane  
D  3-methylbutane

Q6. Int2
Which of the following molecules is an isomer of heptane?

A  

B  

C  

D  

Q7. Int2
Which of the following could be the molecular formula of a cycloalkane?

A  C₇H₁₀  
B  C₇H₁₂  
C  C₇H₁₄  
D  C₇H₁₆

Q8. Int2
Compared with pentane, propane

A  is less flammable and contains larger molecules  
B  is less flammable and contains smaller molecules  
C  is more flammable and contains larger molecules  
D  is more flammable and contains smaller molecules.

Q9. Int2
When methane burns in a plentiful supply of air, the products are

A  carbon monoxide and water vapour  
B  carbon and water vapour  
C  carbon dioxide and hydrogen  
D  carbon dioxide and water vapour

Q10. SGC
The monomer in superglue has the structure shown opposite.

a) Draw a section of the polymer, showing three monomer units joined together.

b) What name is given to this type of polymerisation? _____________

c) Bromine reacts with the monomer to produce a saturated compound. Draw the structural formula for this compound.

\[
\begin{align*}
\text{H} & \quad \text{COOCH₃} \\
\text{C} & \quad \text{C} \\
\text{H} & \quad \text{CN}
\end{align*}
\]

\[+ \text{Br–Br} \rightarrow\]
**Q1.**

Part of the structure of an addition polymer is shown below. It is made using two different monomers.

```
H  H   CH3H   H  H
- C - C - C - C - C - C -
H  H   H   H   H   H
```

Which pair of alkenes could be used as monomers for this polymer?

A) ethene and propene  
B) ethene and butene  
C) propene and butene  
D) ethene and pentene

**Q2.**

The flow diagram shows the manufacture of polythene from hydrocarbons in crude oil.

Which line in the table identifies processes X, Y and Z?

<table>
<thead>
<tr>
<th>Processes</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>distillation</td>
<td>cracking</td>
<td>hydration</td>
</tr>
<tr>
<td>B</td>
<td>cracking</td>
<td>combustion</td>
<td>polymerisation</td>
</tr>
<tr>
<td>C</td>
<td>polymerisation</td>
<td>distillation</td>
<td>hydration</td>
</tr>
<tr>
<td>D</td>
<td>distillation</td>
<td>cracking</td>
<td>polymerisation</td>
</tr>
</tbody>
</table>

**Q3.**

The octane number of petrol is a measure of how efficiently it burns as a fuel. The higher the octane number, the more efficient the fuel.

a) What is a fuel?

b) Predict the octane number for hexane.

c) State a relationship between the structure of the hydrocarbon and their efficiency as fuels.

<table>
<thead>
<tr>
<th>Hydrocarbon</th>
<th>Number of carbon atoms</th>
<th>Octane number</th>
</tr>
</thead>
<tbody>
<tr>
<td>hexane</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>heptane</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>octane</td>
<td>8</td>
<td>-19</td>
</tr>
<tr>
<td>2-methylpentane</td>
<td>6</td>
<td>71</td>
</tr>
<tr>
<td>2-methylhexane</td>
<td>7</td>
<td>44</td>
</tr>
<tr>
<td>2-methylheptane</td>
<td>8</td>
<td>23</td>
</tr>
</tbody>
</table>

**Q4.**

The grid shows the structural formulae of some hydrocarbons.

a) Identify the hydrocarbon which undergoes an addition reaction to form butane.

b) Identify the two isomers.

c) Identify the structural formula which represents propene.

d) Name the hydrocarbon shown in box E.
CONSolidation Questions

Q1.

The shortened structural formula for an organic compound is
\[ \text{CH}_3\text{CH(CH}_3\text{)}\text{CH(OH)}\text{C(CH}_3\text{)}_3 \]
Which of the following is another way of representing this structure?

A

B

C

D


Q2.

The apparatus shown can be used to identify what is produced when a gas is burned.

When gas X was burned, a colourless liquid collected in the cooled test tube but there was no change in the limewater. Gas X could be

A methane
B carbon monoxide
C hydrogen
D ethene

Q3.

The above compound could be formed by adding water to

A

B

C

D


Q4.

Three members of the cycloalkene homologous series are:

The general formula for this homologous series is

A \[ \text{C}_n\text{H}_{2n+2} \]
B \[ \text{C}_n\text{H}_{2n} \]
C \[ \text{C}_n\text{H}_{2n-2} \]
D \[ \text{C}_n\text{H}_{2n-4} \]
**Consolidation Questions**

Q1. Some household cleaners contain the chemical limonene which gives them a lemon smell. The structure of limonene is shown.

Using bromine solution, a student carried out titrations to determine the concentration of limonene in a household cleaner.

---

<table>
<thead>
<tr>
<th>Titration</th>
<th>Initial burette reading (cm³)</th>
<th>Final burette reading (cm³)</th>
<th>Titre (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>17.1</td>
<td>16.6</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>16.3</td>
<td>16.1</td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
<td>16.0</td>
<td>15.9</td>
</tr>
</tbody>
</table>

a) What colour change would be seen in the flask that indicates the end point of the titrations?
________________ to __________________

b) What average volume should be used in calculating the concentration of limonene?

_________ cm³

c) Calculate the number of moles of bromine used.

d) From the structure of limonene, how many moles of bromine would react with 1 mole of limonene?

_______ moles

e) How many moles of limonene were present in the flask?

_______ moles

f) The mass of 1 mole of limonene (C₁₀H₁₆) is 136g.

Calculate the mass of limonene present in 1 litre of the household cleaner.

---

Q2. Chlorofluorocarbons (CFCs) are a family of compounds which are highly effective as refrigerants and aerosol propellants.

However, they are now known to damage the ozone layer. One example of a CFC molecule is shown.

a) What term is used to describe the shape of this molecule?

_________________

Scientists have developed compounds to replace CFCs. The table shows information about the ratio of atoms in CCl₂F₂ and compounds used to replace it.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Number of atoms</th>
<th>Atmospheric life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>Cl</td>
</tr>
<tr>
<td>CCl₂F₂</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Replacement 1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Replacement 2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Replacement 3</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

b) Draw a possible structure for Replacement 2.

F       F
|        |
H — C — C — H
|        |
F       F

c) Compared with CCl₂F₂, the replacement compounds contain less of which element?

_________

d) From the table, what is the advantage of using the replacement molecules as refrigerants and aerosol propellants?

_________________________________________

_________________________________________

This halogen derivative can be be made by reacting H—Cl with an alkene.

H      Cl     H
|        |        |
H — C — C — C — H
|        |
H     H     H

e) State the name of the alkene that would be used.

_________________

f) State the name of this type of reaction.

_________________

g) A second, isomeric, halogen derivative could also have been made.

Draw the structure of this other product.