
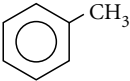


Carbon

- Carbon has an electron configuration of 2, 4. This indicates that carbon atoms have four outer shell or valence electrons. Because of this, each carbon atom forms a total of four covalent bonds
 - o Carbon can bond to many other types of atoms, including hydrogen, oxygen, and nitrogen
 - o Carbon atoms can form single, double, or triple bonds with other carbon atoms
- Carbon's unique bonding properties allow the formation of a variety of structures, including chains and rings of many shapes and sizes

Organic Substances

- **Organic** substances are substances that contain carbon. Often these substances also contain elements such as hydrogen, oxygen and nitrogen
- Organic substances are classified according to its **functional group**, a particular combinations of atoms in each molecule
- These recognisable functional groups help predict/determine the organic substance's:
 - o Name
 - o Physical Properties
 - Melting/boiling points
 - Solubility (in polar and non-polar solvents)
 - Odour
 - o Chemical Properties: Reactions with other elements/molecules
- The functional groups to be studied are:
 - o **Hydrocarbons**
 - Alkanes
 - Alkenes
 - o **Organic Halides**
 - o **Alcohols**
 - o **Aldehydes**
 - o **Ketones**
 - o **Carboxylic Acids**
 - o **Esters**
 - o **Amines**
 - o **Amides**

Family name	General formula	Example
alkanes	$\begin{array}{c} \quad \\ - C - C - \\ \quad \end{array}$	propane $\text{CH}_3 - \text{CH}_2 - \text{CH}_3$
alkenes	$\begin{array}{c} \quad \\ - C = C - \\ \quad \end{array}$	propene (propylene) $\text{CH}_2 = \text{CH} - \text{CH}_3$
alkynes	$- C \equiv C -$	propyne $\text{CH} \equiv \text{C} - \text{CH}_3$
aromatics		methyl benzene (phenyl methane, toluene) 
organic halides	$\text{R} - \text{X}$	chloropropane $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{Cl}$
alcohols	$\text{R} - \text{OH}$	propanol $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{OH}$
ethers	$\text{R} - \text{O} - \text{R}'$	methoxyethane (ethyl methyl ether) $\text{CH}_3 - \text{O} - \text{CH}_2 - \text{CH}_3$
aldehydes	$\begin{array}{c} \text{O} \\ \\ \text{R}[\text{H}] - \text{C} - \text{H} \end{array}$	propanal $\text{CH}_3 - \text{CH}_2 - \overset{\text{O}}{\parallel} \text{C} - \text{H}$
ketones	$\begin{array}{c} \text{O} \\ \\ \text{R} - \text{C} - \text{R}' \end{array}$	propanone (acetone) $\text{CH}_3 - \overset{\text{O}}{\parallel} \text{C} - \text{CH}_3$
carboxylic acids	$\begin{array}{c} \text{O} \\ \\ \text{R}[\text{H}] - \text{C} - \text{OH} \end{array}$	propanoic acid $\text{CH}_3 - \text{CH}_2 - \overset{\text{O}}{\parallel} \text{C} - \text{OH}$
esters	$\begin{array}{c} \text{O} \\ \\ \text{R}[\text{H}] - \text{C} - \text{O} - \text{R}' \end{array}$	methyl ethanoate (methyl acetate) $\text{CH}_3 - \overset{\text{O}}{\parallel} \text{C} - \text{O} - \text{CH}_3$
amines	$\begin{array}{c} \text{R}'[\text{H}] \\ \\ \text{R} - \text{N} - \text{R}''[\text{H}] \end{array}$	propylamine $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \overset{\text{H}}{\underset{ }{\text{N}}} - \text{H}$
amides	$\begin{array}{c} \text{O} \quad \text{R}''[\text{H}] \\ \quad \\ \text{R}[\text{H}] - \text{C} - \text{N} - \text{R}'[\text{H}] \end{array}$	propanamide $\text{CH}_3 - \text{CH}_2 - \overset{\text{O}}{\parallel} \text{C} - \overset{\text{H}}{\underset{ }{\text{N}}} - \text{H}$

Hydrocarbons

- Hydrocarbons are organic substances that only contain hydrogen and carbon
- Hydrocarbons are classified by the kinds of carbon-carbon bonds in their molecules
 - o Aliphatic hydrocarbons are either saturated or unsaturated
 - Saturated hydrocarbons
 - Alkanes are hydrocarbons where all carbons are bonded to other atoms by single bonds, resulting in the maximum number of hydrogen atoms bonded to each carbon atom, hence the classification as saturated
 - Unsaturated hydrocarbons
 - Alkenes are hydrocarbons that contain one or more carbon-carbon double bonds
 - Alkynes are hydrocarbons that contain one or more carbon-carbon triple bonds
 - These two groups are called unsaturated hydrocarbons because they contain fewer than the maximum possible number of hydrogen atoms
 - Because alkenes and alkynes have multiple bonds, they react in characteristic ways
 - In these hydrocarbons, the carbon backbone may form:
 - A straight chain
 - One or more branched chains
 - o A hydrocarbon branch that is attached to the main structure of the molecule is called an alkyl group
 - A cyclic (ring) structure
 - o Non-cyclic:
 - Alkanes have the general formula C_nH_{2n+2}
 - Alkenes (with one double bond only) have the general formula C_nH_{2n}
 - o Cyclic:
 - Alkanes have the general formula C_nH_{2n}
 - Alkenes (with one double bond only) have the general formula C_nH_{2n-2}
 - o Aromatic hydrocarbons
 - The simplest aromatic hydrocarbon is benzene. All other members of this family are derivatives of benzene
 - The formula for benzene is C_6H_6 , and the six carbon atoms form a unique ring structure
 - Unlike cyclohexane, C_6H_{12} , the benzene ring has a planar structure, and is unsaturated
 - The bonds in the benzene ring have properties intermediate between single bonds and double bonds
 - o The common structural diagram for benzene shows a hexagon with an inscribed circle, symbolizing the presence of double bonds in unspecified locations within the six-carbon ring

Nomenclature of Hydrocarbons

The naming conventions described below are those established by the International Union of Pure and Applied Chemistry (IUPAC)

Alkanes

- Straight chain and branched:

1. Identify the longest continuous carbon chain in the alkane. This longest carbon chain is regarded as the parent chain. It is given the stem name associated with the number of carbon atoms in this chain and the suffix for alkanes, **-ane**

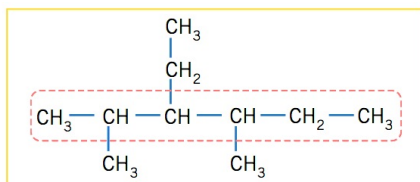
Number of carbon atoms in chain	'Stem' name
1	meth-
2	eth-
3	prop-
4	but-
5	pent-
6	hex-
7	hept-
8	oct-
9	non-
10	dec-

2. Name the side chains that branch off the longest chain. The names of these hydrocarbon side chains (alkyl groups) are derived by adding **-yl** to the appropriate hydrocarbon stem names. Write the names of these side chains in alphabetical order before the name of the parent chain
3. If more than one of a particular side chain appears in the molecule, use the prefixes **di-**, **tri-**, **tetra-**, **penta-** or **hexa-** to indicate the presence of two, three, four, five or six, respectively, identical groups
4. To show the positions of the side chains, number the longest carbon chain consecutively from one end to the other, starting at the end closer to the side chains (to achieve the lowest possible numbers for the side chains). Allocate a number to each side chain and show these numbers before the name of the respective side chains. A hyphen is placed between any word and number, while a comma is placed between two consecutive numbers

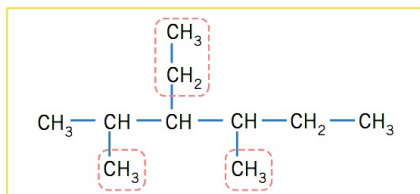
- Cyclic: For cyclic alkanes, or cycloalkanes, the same naming rules are followed except the prefix **cyclo-** is used to show that the parent chain is a ring

Alkenes

1. Identify the longest continuous carbon chain containing the double bond. This is the parent chain. It is given the stem name associated with the number of carbon atoms in this chain and the suffix for alkenes, that is **-ene**
2. Number the parent chain from the end that will give the lowest number to the double bond. The position of the double bond is described by the lowest numbered double bonded carbon
3. Name the side chains in the same way as with alkanes

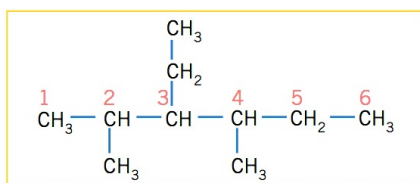


The longest chain has six carbons, i.e. **hex-**, and because the compound is an alkane, the parent chain is called **hexane**.

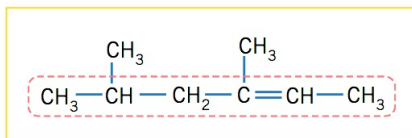


There are three side chains, one ethyl group and two methyl groups.

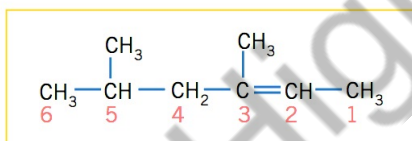
Including the alkyl groups, the name becomes **ethyl dimethylhexane**.



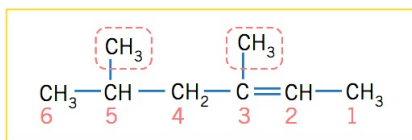
The two methyl groups are on carbons 2 and 4, and the ethyl group on carbon 3. The name becomes **3-ethyl-2,4-dimethylhexane**.



The longest chain has six carbons, that is, **hex-**, and because the compound is an alkene, the parent chain is called **hexene**.



In this example, the chain is numbered from right to left to give double bonded carbons the smallest number. The lowest number for the double bond, that is, 2, is used in the name, and is placed just before suffix **-ene**, to give **hex-2-ene**. Hyphens are used between words and numbers.

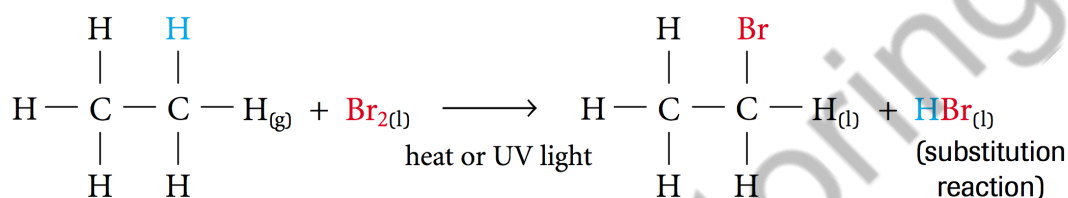


There are two methyl side chains, one on carbon 3 and the other on carbon 5. So the name is **3,5-dimethylhex-2-ene**.

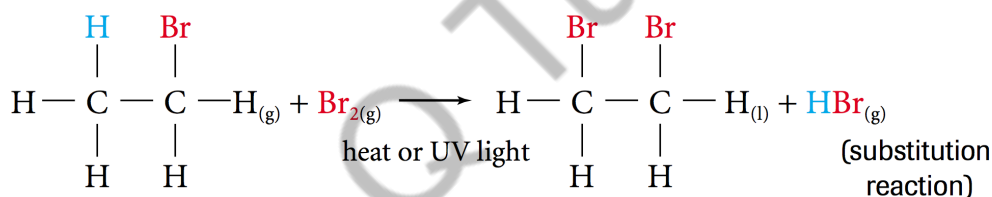
Reactions of Hydrocarbons

Substitution reaction: Occur between alkanes and halogens

- A substitution reaction is one in which an atom in a molecule is replaced by a different atom to form a new molecule
 - o E.g. The reactions of alkanes with halogens
 - The hydrogen atoms of the alkane are replaced, one after the other, by the halogen atoms
 - Organic halides (compounds that contain carbon and halogen atoms and possibly hydrogen atoms) together with a hydrogen halide are formed in these reactions
 - Reactions with F_2 are vigorous, but Cl_2 and Br_2 require heat or ultraviolet light before the reaction will proceed
 - These reactions are generally very slow
- E.g. In the reaction of ethane with bromine, the orange colour of the bromine slowly disappears, and the presence of $HBr_{(g)}$ is indicated by a colour change of moist litmus paper from blue to red



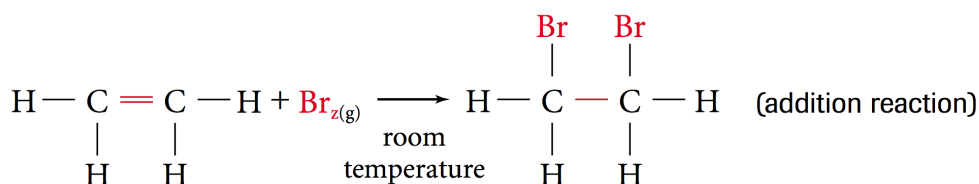
- o As the reaction proceeds, the concentration of bromoethane increases and bromine reacts with it again, leading to the substitution of another of its hydrogen atoms, forming 1,2-dibromoethane



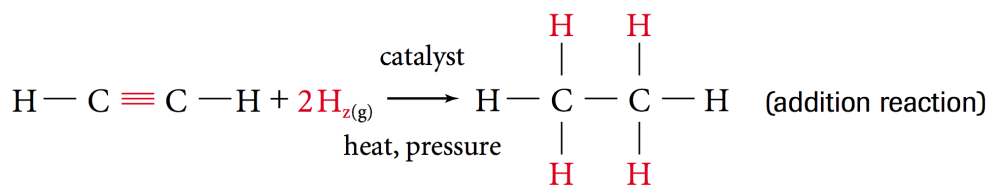
- o Additional bromines may be added, resulting in a mixture of brominated products

Addition reactions: Occur between alkenes and halogens/hydrogen/hydrogen halides/water

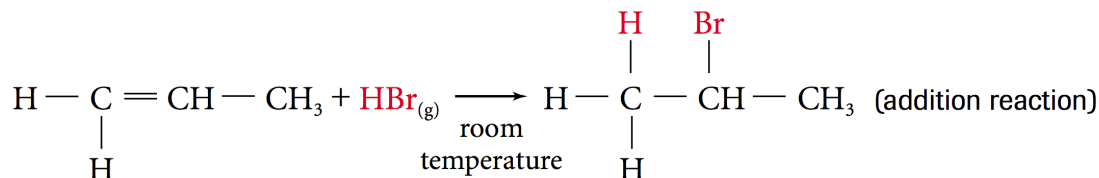
- Alkenes exhibit much greater chemical reactivity than alkanes
 - o E.g. The reaction of these unsaturated hydrocarbons with bromine is fast, and will occur at room temperature
 - o This increased reactivity is attributed to the presence of the double bonds
- This characteristic reaction of alkenes and alkynes is called an addition reaction as atoms are added to the molecule with no loss of hydrogen atoms
- Alkenes can undergo addition reactions not only with halogens, but also with hydrogen, hydrogen halides, and water, given the appropriate conditions
 - o E.g. Halogenation



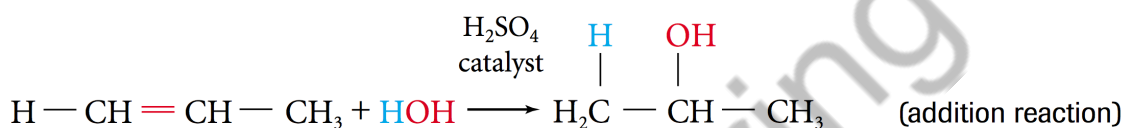
- o E.g. Hydrogenation



- o E.g. Hydrohalogenation

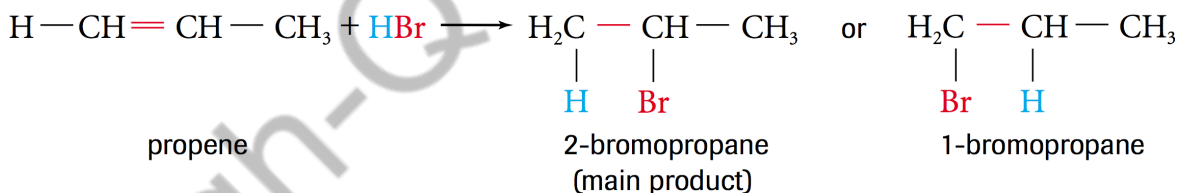


- o E.g. Hydration



- Markovnikov's Rule

- o When molecules such as H₂, consisting of two identical atoms, are added to a double bond, only one possible product is formed (i.e. The addition of identical atoms to either side of the double bond results in identical products. When molecules of non-identical atoms are added, however, two different products are theoretically possible)
- o E.g. When HBr is added to propene, the H may add to C atom 1, or it may add to C atom 2 (i.e. two different products are possible)



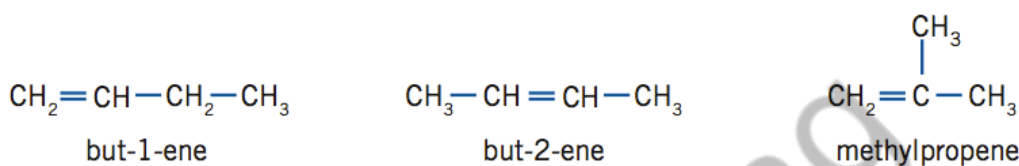
- o Experiments show that, in fact, only one main product is formed. The product can be predicted by a rule known as Markovnikov's rule
 - When a hydrogen halide or water is added to an alkene or alkyne, the hydrogen atom bonds to the carbon atom within the double bond that already has more hydrogen atoms
 - This rule may be remembered simply as "the rich get richer"
 - As illustrated in the reaction of propene above, the first C atom has two attached H atoms, while the second C atom has only one attached H atom. Therefore, the "rich" C1 atom "gets richer" by gaining the additional H atom; the Br atom attaches to the middle C atom
 - Therefore, the main product formed in this reaction is 2-bromopropane

Combustion reactions: Occur when organic molecules are burnt, resulting in the production of carbon dioxide and water

- Hydrocarbons undergo complete combustion to produce only carbon dioxide and water (in excess air)
 - o $\text{C}_a\text{H}_b + x\text{H}_2\text{O} \rightarrow y\text{CO}_2 + z\text{H}_2\text{O}$

Isomerism

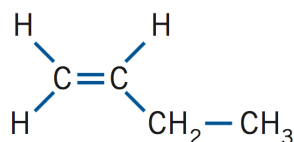
- Isomers are molecules that have the same molecular formula but different structural formula
- There are 2 types of isomers:
 - o Structural isomers:
 - Chain isomerism: These isomers arise because of the possibility of branching in carbon chains
 - E.g. but-1-ene and methyl-propene
 - Position isomerism: These isomers arise because the groups are moved around, although the basic carbon skeleton remains unchanged
 - E.g. but-1-ene and but-2-ene



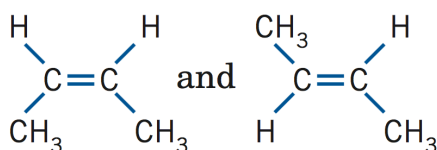
- o Geometric isomers: These isomers arise because different groups attached to carbon atoms joined by a double bond are arranged differently around the double bond
 - The isomer with the two groups on the same side of the double bond, is called the 'cis' isomer
 - The isomer with the two groups on the opposite side of the double bond is called the 'trans' isomer

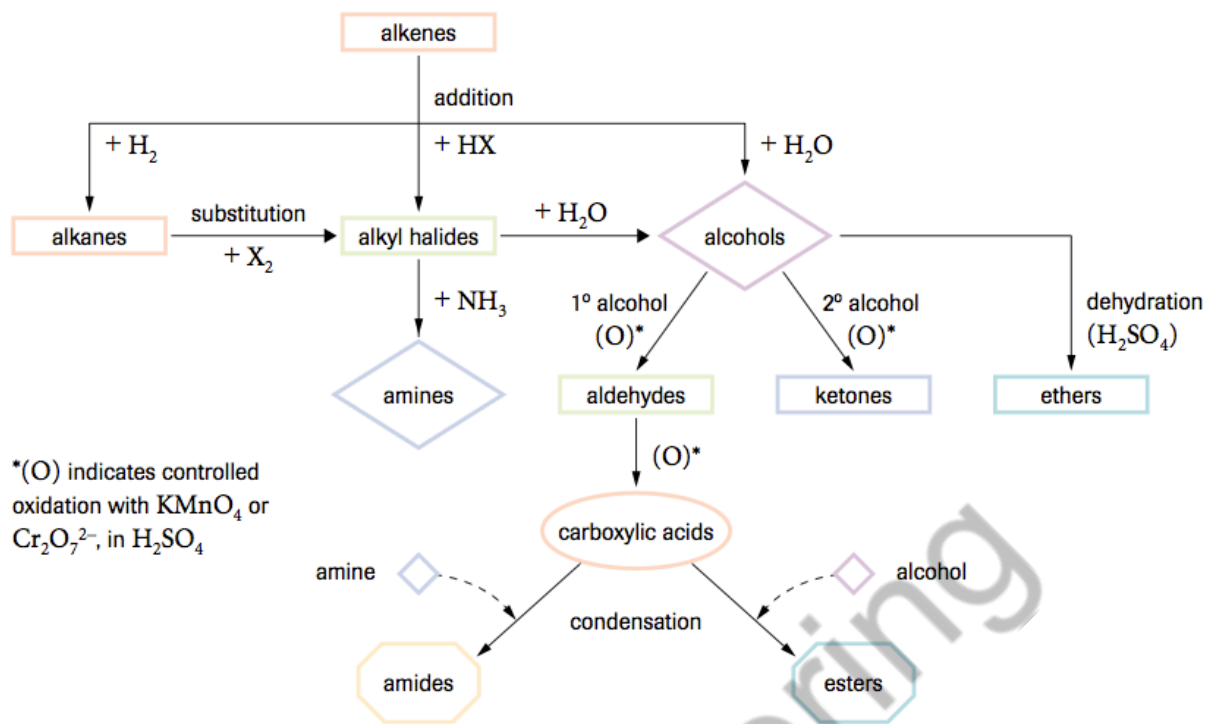


- Geometrical isomerism occurs for alkenes only because the carbon atoms joined by the double bond are unable to rotate about the double bond
 - If there is only a single bond between two carbon atoms, then the carbon atoms can rotate about the bond and therefore geometric isomerism cannot exist
 - An alkene will exhibit geometrical isomerism if each of the carbon atoms joined by the double bond have different groups attached to them
 - E.g. $\text{CH}_2\text{CHCH}_2\text{CH}_3$ cannot exhibit geometric isomerism



- E.g. $\text{CH}_3\text{CHCHCH}_3$ will exhibit geometric isomerism





Organic Halides (R-X)

- Organic halides or haloalkanes contain one or more halogens on any carbon atom of the carbon chain
- Nomenclature: Organic halides are named in a similar fashion to alkyl group side chains
 - o The abbreviated name of the halogen (**fluoro-**, **chloro-**, **bromo-**, **iodo-**) is included in front of the alkane. Write the names of these halogens in alphabetical order before the name of the parent chain
 - o If more than one of a particular halogen appears in the molecule, use the prefixes **di-**, **tri-**, **tetra-**, **penta-** or **hexa-** to indicate the presence of two, three, four, five or six, respectively, identical groups
 - o To show the positions of the halogens, number the longest carbon chain consecutively from one end to the other, starting at the end closer to the halogens (to achieve the lowest possible numbers for the halogens). Allocate a number to each halogen and show these numbers before the name of the respective halogens. A hyphen is placed between any word and number, while a comma is placed between two consecutive numbers
- Preparation:
 - o **Substitution Reaction: Alkane + Halogen \rightarrow Organic Halide + Hydrogen Halide**
 - o **Hydrohalogenation (Addition) Reaction: Alkene + Hydrogen Halide \rightarrow Organic Halide**
 - o **Halogenation (Addition) Reaction: Alkene + Halogen \rightarrow Organic Halide**

Alcohols (R-OH)

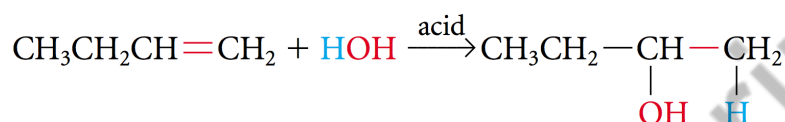
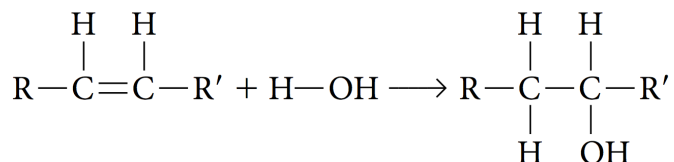
- Alcohols contain the hydroxyl functional group on any carbon atom of the carbon chain

- Nomenclature:

- o Alcohols are named by dropping the final e of the parent alkane name and adding the suffix **-ol**
- o A number is used (if needed) with the suffix to show the position of the alcohol group

- Preparation: Hydration (Addition) Reaction: Alkene + Water → Alcohol

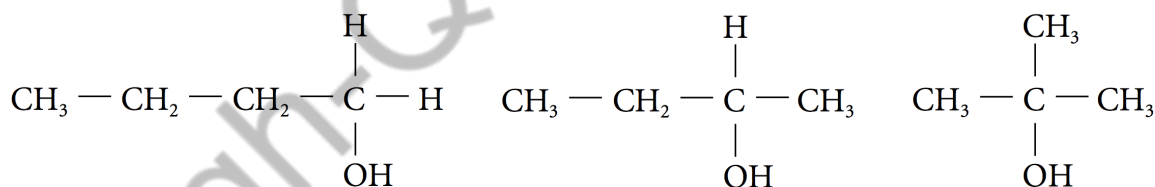
- o The double bonds in alkenes allows them to readily undergo addition reactions. The -OH functional group is incorporated by adding HOH (i.e. H₂O)



- o The reaction follows Markovnikov's rule:
 - The hydrogen attaches to the carbon atom that already has more hydrogen atoms
 - The OH group attaches to the other carbon atom in the double bond

- Classification of Alcohols: 1°, 2°, and 3° Alcohols

- o Alcohols are further classified according to the type of carbon to which the -OH group is attached
- o Since C atoms form four bonds, the C atom bearing the -OH group can be attached to a further 1, 2, or 3 alkyl groups, the resulting alcohols classified as primary, secondary, and tertiary alcohols, respectively (1°, 2°, and 3°)



a 1° alcohol

a 2° alcohol

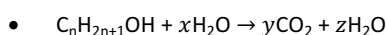
a 3° alcohol

- o This classification is important for predicting the reactions each alcohol will undergo, because the reactions and products are determined by the availability of H atoms or alkyl groups in key positions

- Reactions:

o **Complete Combustion of Alcohols**

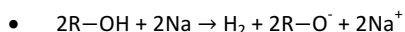
- Like hydrocarbons, alcohols undergo complete combustion to produce only carbon dioxide and water (in excess air)



o **Reactions with Reactive Metals**

- Reactive metals such as sodium and potassium react with water to produce a solution containing the hydroxide ion and liberating hydrogen gas. Alcohols behave in a similar fashion

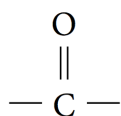
- In addition to hydrogen, the other product of the reaction is alkoxide ion, R-O⁻



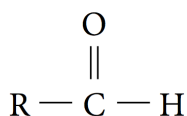
Aldehydes (H-C=O) and Ketones (R-C=O)

- Aldehydes contain the carbonyl functional group on the primary carbon (i.e. terminal end) of the carbon chain
- Ketones contain the carbonyl functional group on a secondary carbon (i.e. one bonded to two other carbon atoms) of the carbon chain

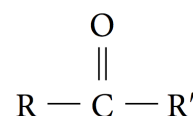
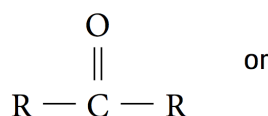
carbonyl group



an aldehyde



two ketones

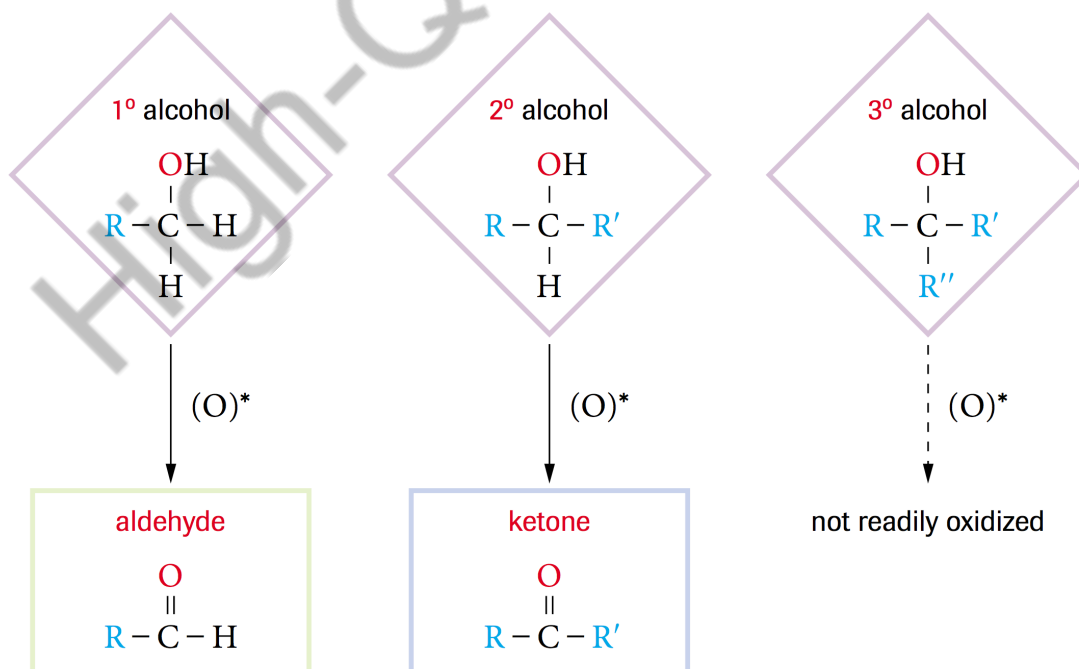


Nomenclature:

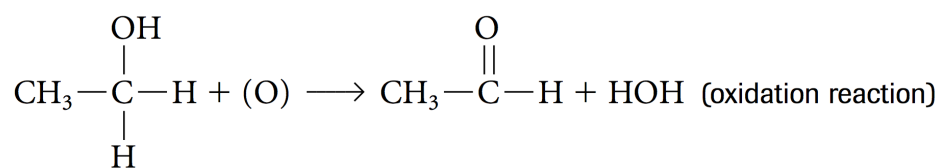
- o Aldehydes:
 - Aldehydes are named by dropping the final e of the parent alkane name and adding the suffix **-al**
 - As the aldehyde group must always occur at the end of a carbon chain, its position is not numbered
- o Ketones:
 - Ketones are named by dropping the final e of the parent alkane name and adding the suffix **-one**
 - A number is used (if needed) with the suffix to show the position of the ketone group

Preparation: Primary Alcohol → Aldehyde, Secondary Alcohol → Ketone

- o When alcohols are burned in oxygen, complete oxidation occurs and carbon dioxide and water are the only products formed
- o However, the conditions of oxidation reactions can be controlled to form other products
 - In these reactions, oxygen atoms are supplied by oxidising agents (e.g. hydrogen peroxide, potassium dichromate and potassium permanganate)
- o In the following equations, (O) will be used to indicate the reactive oxygen atom supplied by an oxidising agent

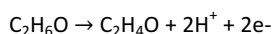
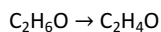


- When a primary alcohol is oxidised, an H atom remains on the C atom, and an aldehyde is produced

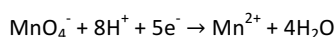


- E.g. The reaction between ethanol and potassium permanganate

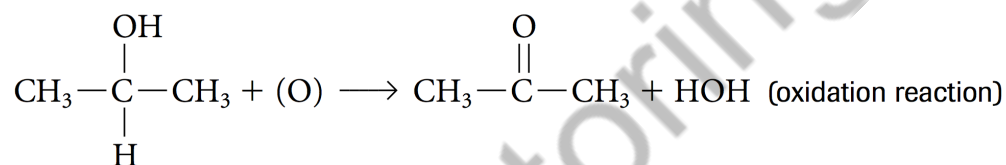
- Reduction reaction:



- Oxidation reaction:

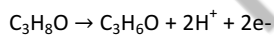
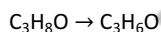


- When a secondary alcohol is oxidised, the carbonyl group formed is necessarily attached to two alkyl groups, forming a ketone

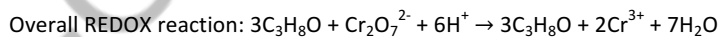
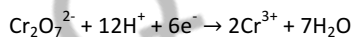


- E.g. The reaction between propan-2-ol and sodium dichromate

- Reduction reaction:



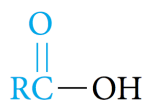
- Oxidation reaction:



- Tertiary alcohols do not undergo this type of oxidation

Carboxylic Acids (R-COOH)

- Carboxylic acids contain the carboxyl (i.e. carbonyl and hydroxyl) functional group on the primary carbon of the carbon chain

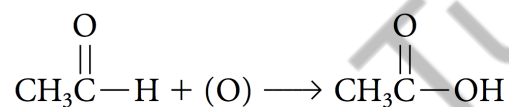
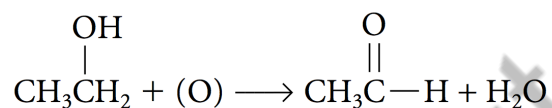


- Nomenclature:

- o Carboxylic acids are named by dropping the final e of the parent alkane name and adding the suffix **-oic acid**
- o As the carboxyl group always occur at the end of a carbon chain, its position is not numbered

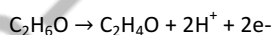
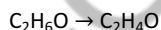
- Preparation: Controlled Oxidation Reactions: Aldehyde → Carboxylic Acid

- o Further controlled oxidation of the aldehyde results in the formation of a carboxylic acid
 - The general oxidation pathway in this process is from alcohol to aldehyde to carboxylic acid
 - The functional group in the parent molecule changes from the hydroxyl group to the carbonyl group, then to the carboxyl group
 - To ensure that the carboxylic acid is formed in this reaction rather than the aldehyde, the reaction mixture is normally heated for some time

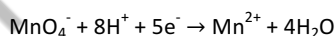


- E.g. The complete reaction between ethanol and potassium permanganate

- o Reduction reaction:

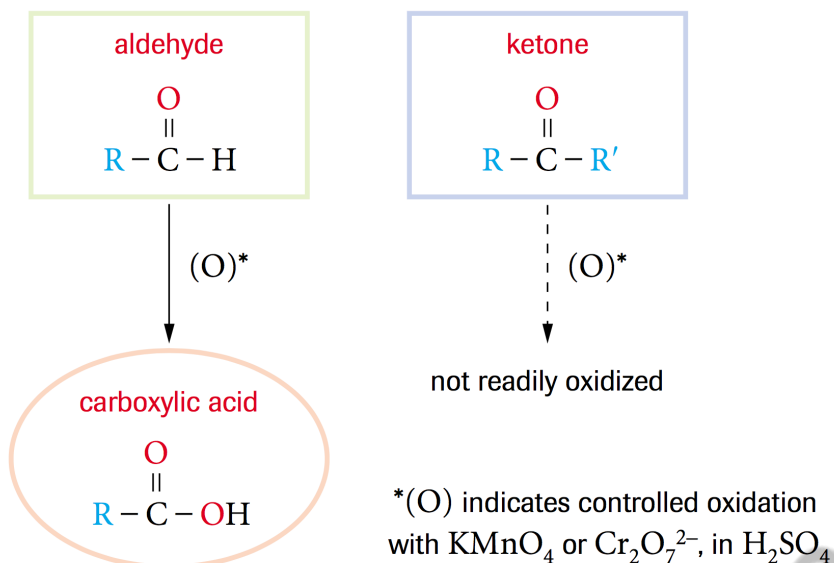


- o Oxidation reaction:



- o Ketones do not undergo this type of oxidation

- In the following equations, (O) will be used to indicate the reactive oxygen atom supplied by an oxidising agent

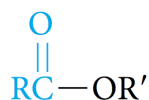


- Reactions: Acid-Base Reactions

- Carboxylic acids are weak acids. Their acidic nature means carboxylic acids and their solutions exhibit chemical properties typical of acid solutions
 - They react with reactive metals to produce hydrogen gas
 - They are neutralised by bases (metal oxides, metal hydroxides, metal carbonates and metal hydrogen carbonates)

Esters (R-COOR')

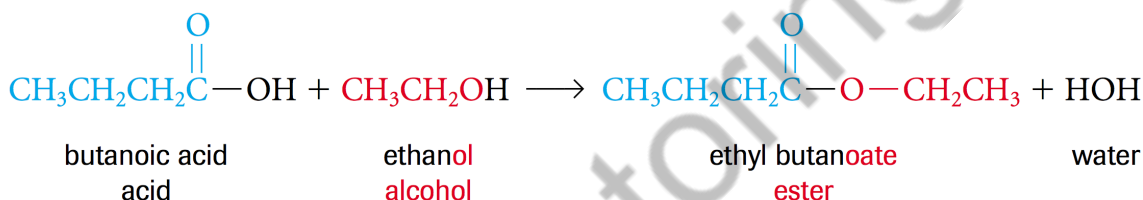
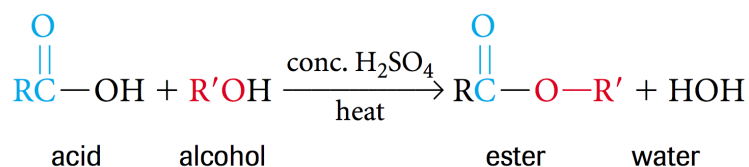
- Esters contain the carboxylate functional group linking two carbon chains



ester

- **Preparation: Esterification/Condensation Reaction: Carboxylic Acid + Alcohol → Ester + Water**

- o The ester formed is an organic salt



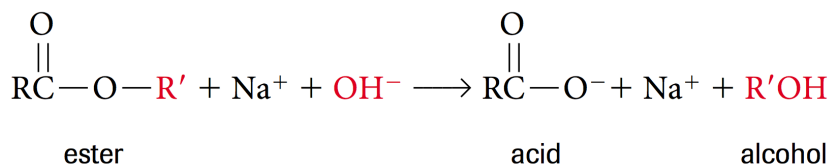
- The carboxylic acid acts as an acid
- The alcohol acts as an organic base
- An acid catalyst, such as sulfuric acid, and heat are generally required

- **Nomenclature:** Esters are named by:

- o Dropping the final e of the parent alkane name (the one derived from the parent carboxylic acid) and adding the suffix **-oate**
- o The alkyl group attached to the single O atom (the one derived from the parent alcohol) is named as a prefix, with a space, to the parent structure

- **Reactions: Hydrolysis of Esters**

- o When esters are treated with an acid or a base, a reversal of esterification occurs (i.e. the ester is split into its acid and alcohol components)
- o The reaction below is carried out in a basic solution, and the products are the sodium salt of the carboxylic acid and the alcohol

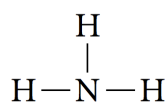


Amines (R-NH₂)

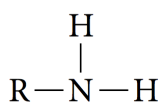
- Amines contain the amine or amino functional group

- **Classification: 1°, 2°, and 3° Amines**

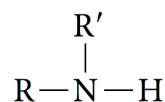
- Amines can be thought of as ammonia (NH₃) with one, two, or all three of its hydrogens substituted by alkyl groups
 - These are classified as primary (1°), secondary (2°), or tertiary (3°) amines, respectively



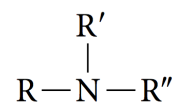
ammonia



primary amine (1°)



secondary amine (2°)



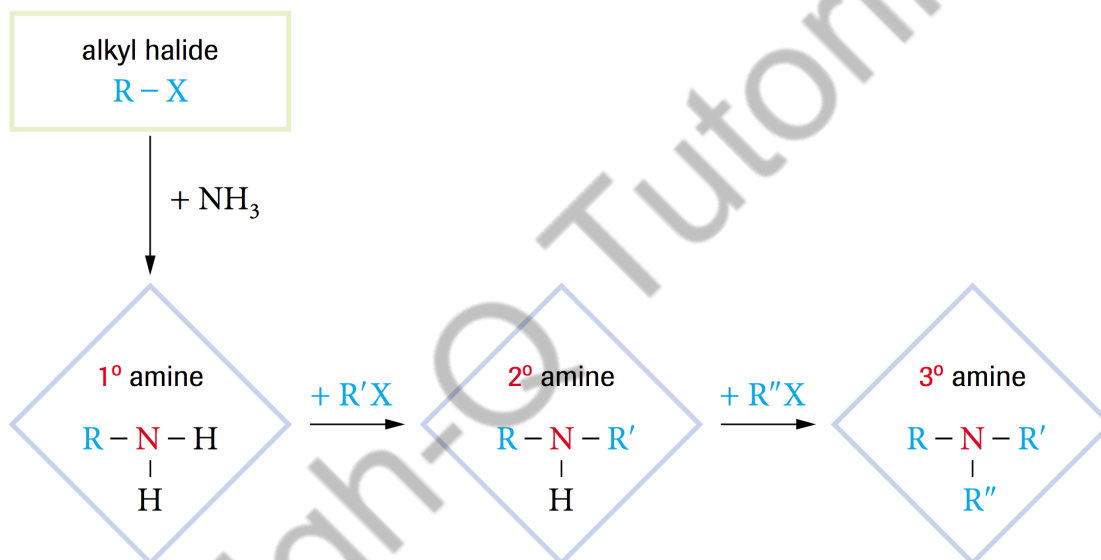
tertiary amine (3°)

- The alkyl groups in an amine may be identical or different

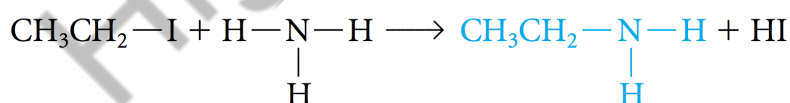
- **Nomenclature:**

- Primary amines are named by dropping the final e of the parent alkane name and adding the suffix **-amine**
- A number is used (if needed) with the suffix to show the position of the amine group

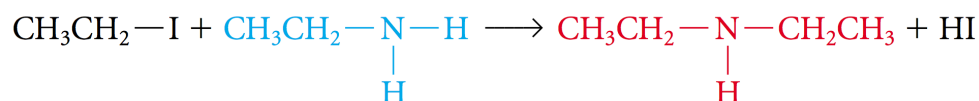
- **Preparation: Alkyl Halide + Ammonia/Amine → Amine**



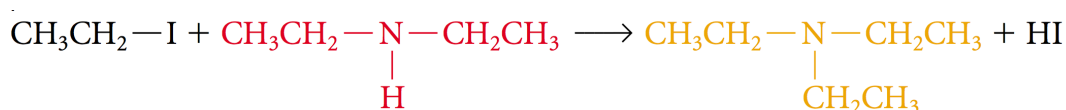
- Primary amines are prepared by the reaction of ammonia with an alkyl halide



- A primary amine can further react with an alkyl halide to produce a secondary amine

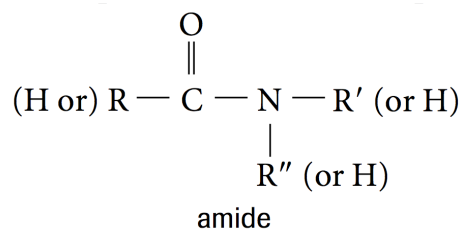


- A secondary amine can further react with an alkyl halide to produce a tertiary amine



Amides (R-CONH₂)

- Amides contain the -CONH₂ functional group

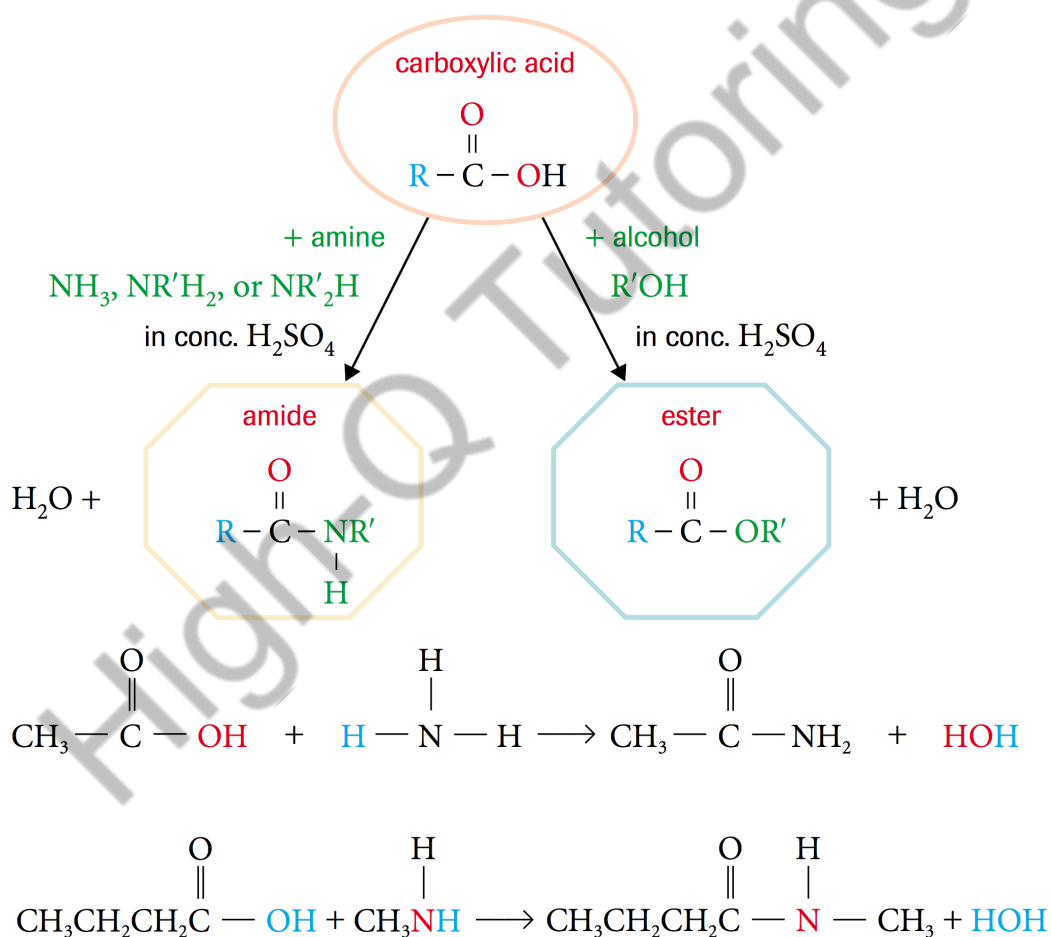


Nomenclature:

- o Primary amides derived by reacting a carboxylic acid with ammonia are named by dropping the final e of the parent alkane name (the one derived from the parent carboxylic acid) and adding the suffix **-amide**

Preparation: Condensation Reaction: Carboxylic Acid + Ammonia/Amine → Amide + Water

- o The amide formed is an organic salt, like an ester



- The carboxylic acid acts as an acid
- Ammonia or the amine acts as an organic base

Physical Properties of Organic Substances

Hydrocarbons

- Since hydrocarbons contain only C and H atoms, two elements with very similar electronegativities, bonds between C and H are relatively non-polar
 - o Therefore, the main intermolecular interaction in hydrocarbons is dispersion forces
- Since dispersion forces are weak, the molecules are readily separated, and consequently have low melting and boiling points
 - o The strength of these dispersion forces depends on
 - Size of the molecule: The dispersion forces increase in strength for larger molecules
 - This is because these molecules have a larger number of electrons, and so:
 - o There is a greater chance that these electrons will be arranged asymmetrically at any instant (i.e. these molecules are more likely to have a temporary or instantaneous dipole)
 - o The partial charges on the temporary dipoles are likely to be larger
 - Shape of the molecule: Dispersion forces are stronger for molecules with increased surface area of contact between molecules (i.e. linear as compared to branched or spherical shape)
 - This is because these molecules have an increased ability to fit next to each other closely
- Hydrocarbons, being largely non-polar, generally have:
 - o Very low solubility in polar solvents
 - o Relatively high solubility in other non-polar solvents

Organic Halides

- The presence of the halogen atom on a hydrocarbon chain or ring renders the molecule more polar
 - o This is because halogens are more electronegative than C and H atoms, and so C-halogen bonds are more polar than C-H bonds
 - o The increased polarity of alkyl halides increases the strength of the intermolecular forces due to the existence of dipole-dipole forces
 - Thus, alkyl halides have higher boiling points than the corresponding hydrocarbons
 - The increased polarity also makes them more soluble in polar solvents than hydrocarbons of similar size
- When organic halides are formed from halogenation of hydrocarbons, the product obtained is often a mixture of halogenated compounds
 - o These compounds reflect intermediate compounds that can be further halogenated
 - o The molecules that contain more halogen atoms are usually more polar than the less halogenated molecules, and thus have higher melting and boiling points

Alcohols

- Alcohols have melting and boiling points that are higher than those of their parent alkanes due to the presence of hydrogen bonding via the attached hydroxyl group
- Small (i.e. short chain) alcohols are much more soluble in polar solvents than are their parent alkanes due to the presence of mainly hydrogen bonding
 - o However, larger (i.e. long chain) alcohols become less soluble in polar solvents because the non-polar hydrocarbon chain interferes with the hydrogen bonding present between the hydroxyl groups
 - In these long-chain alcohols, the non-polar hydrocarbon chain facilitates the alcohol's solubility in non-polar solvents due to the presence of mainly dispersion forces

Aldehydes and Ketones

- Aldehydes and ketones have lower melting and boiling points than analogous alcohols, but higher than those of their parent alkanes
 - o Aldehydes and ketones are polar, but are unable to interact with one another by hydrogen bonding. Therefore, these molecules attract each other via dipole-dipole attraction forces, hence explaining their melting and boiling points as compared to alcohols and hydrocarbons
- Although aldehyde and ketones cannot interact with each other by hydrogen bonding, they can be involved in hydrogen bonding with compounds such as water, due to lone pair of electrons on the O atom of the carbonyl functional group
 - o Thus, aldehydes and ketones are more soluble in water than are hydrocarbons
 - o Similar to alcohols, the increasing size of the carbon chain in an aldehyde or a ketone leads to a decreasing solubility in polar solvents, and an increasing solubility in non-polar solvents

Carboxylic Acids

- The presence of both carbonyl and hydroxyl groups on the molecules of carboxylic acids facilitates high melting and boiling points as a result of the hydrogen bonding between molecules
- In fact, the melting and boiling points of carboxylic acids is higher than that of similar sized alcohols, due to the presence of two sites of lone electron pairs (i.e. two oxygen atoms) in carboxylic acids as oppose to one in alcohols
- Small carboxylic acids are most soluble in polar solvents, but again an increase in size of the carbon chain leads to a decreasing solubility in polar solvents, and an increasing solubility in non-polar solvents
- Carboxylic acids, like most acids, have a sour odour

Esters

- The presence of the carboxylate group creates a degree of polarity at the corresponding section of an ester molecule
 - o Like aldehydes and ketones, esters mainly interact attract each other via dipole-dipole attraction forces. Thus, esters have similar melting and boiling points to that of similar sized aldehydes and ketones
- Esters have similar solubility behaviours to alcohols, aldehydes and ketones
- The functional group of an ester is similar to the carboxyl group of an acid
 - o What it lacks in comparison to an acid is its -OH group
 - The hydroxyl group is replaced by an OR group
 - o With the loss of the polar -OH group, esters are less polar, and therefore are less soluble in water, and have lower melting and boiling points than their parent acids
- Esters have a strong pleasant fruity odour

Amines

- Amines have higher melting and boiling points than hydrocarbons, aldehydes, ketones and esters of similar size, but lower than similar sized alcohols
 - o This is because amines are also capable of hydrogen bonding. However, a lower electronegativity of N (as compared to O) implies a weaker dipole and consequently a weaker hydrogen bond
- Amines have similar solubility behaviours to alcohols, aldehydes, ketones and amines

Amides

- Amides have higher melting and boiling points than amines, alcohols and carboxylic acids of a similar size
 - o This is because:
 - There is a greater number of suitable lone pairs and hydrogen atoms available for hydrogen bonding in an amide molecule
 - The close proximity of the highly electronegative oxygen atom causes hydrogen atoms from the NH₂ group to develop a larger dipole (δ^+) than would occur due to nitrogen only
 - Amides have similar solubility behaviours to carboxylic acids
- In summary, the order (from lowest to highest) of melting and boiling points of similar sized organic substances, based on the functional groups, is:
- o Hydrocarbons
 - o Organic halides, aldehydes, ketones and esters
 - o Amines
 - o Alcohols
 - o Carboxylic acids
 - o Amides

Empirical Formula

- A molecular formula shows the actual number of each type of an atom in a single molecule of the substance
- An empirical formula by contrast only shows the types of atoms present in a substance and gives their simplest whole number atomic ratio
 - o The empirical formula can be found from a molecular formula by dividing the subscripts of each element in the molecular formula by the lowest common denominator
- The chemical composition of a compound (i.e. its composition by mass or its percentage composition by mass) can be found using various experimental techniques. Empirical data like this then can be used to find the compound's empirical formula
 - o Combustion analysis is an experimental technique used to find the empirical formula of a combustible compound
 - A carefully weighed sample of the compound is burnt in air and the combustion products H_2O and CO_2 are collected and weighed
 - This data is used to determine the mass of carbon and hydrogen in the original sample
 - o $n(\text{C}) = n(\text{CO}_2)$
 - o $n(\text{H}) = 2 \times n(\text{H}_2\text{O})$
- A compound's molecular formula is always a whole number multiple of its empirical formula. The molecular formula can be found by calculating the ratio of the empirical formula mass (M_{ef}) to the molecular formula mass (M). i.e. $\frac{M}{M_{ef}}$
 - o An experimental technique used to find the molar mass of an unknown compound involves vaporising a weighed sample in a sealed flask of known volume
 - The temperature and pressure of the resulting vapour are measured and used along with the vapour volume and mass to experimentally find the molar mass of the compound
 - $PV = nRT$ is first used to calculate the number of moles of the compound
 - $M = \frac{m}{n}$ is then used to calculate the molar mass