

Organic chemistry is the study of the **compounds of carbon**, but does not include carbonates hydrogen carbonates, carbides and the oxides of carbon. Organic molecules are defined as molecules containing carbon atoms.

There are millions of organic compounds; some very simple and others complicated with large molecular masses. The reasons for the large variety of compounds are that carbon atoms:

1. can covalently bond with one another to form straight or branched chains (**catenation**).
2. can covalently bond with other atoms - usually non-metals.
3. can supply four electrons for four different covalent bonds.
4. Can form double, single or triple bonds

**Hydrocarbons** – contain carbon and hydrogen ONLY

### Formulae of Organic Compounds

- Molecular formula – A chemical formula that indicates the element and numbers of each of the atoms in a molecule. Eg:  $C_3H_8$
- Structural formula – A structural formula of a compound shows which atoms are attached to which within the molecule. Eg: 
$$\begin{array}{ccccccc} & H & & H & & H & \\ & | & & | & & | & \\ H & - C & - & C & - & C & - H \\ & | & & | & & | & \\ & H & & H & & H & \end{array}$$
- Condensed structural formula does not show C-C and C-H single bonds. Eg:  $CH_3CH_2CH_3$

| Molecular formula | Structural formula                                                                                                                                                                                                    | Condensed structural formula |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| $C_6H_{12}$       | $\begin{array}{ccccccc} & H & & H & H & H & \\ &   & &   &   &   & \\ H & - C & = C & - C & - C & - C & - H \\ &   &   &   &   &   & \\ & H & H & H & H & H & \end{array}$                                            | $CH_3CHCHCH_2CH_2CH_3$       |
| $C_6H_{14}O$      | $\begin{array}{ccccccc} & & H & & H & & \\ & &   & &   & & \\ & H & H & C & H & H & \\ &   &   &   &   &   & \\ H & - C & - C & - C & - C & - C & - H \\ &   &   &   &   &   & \\ & H & H & H & OH & H & \end{array}$ | $CH_3CH_2CH(CH_3)CH(OH)CH_3$ |

### Functional Groups and Homologous Series

**Homologous Series:** A series of organic compounds that can be described by the same general formula OR in which one member differs from the next with a  $CH_2$  group.

**Functional group:** A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.

#### Properties of homologous series:

1. They have the same general formula (e.g. alkanes  $C_nH_{2n+2}$ ).
2. Each member differs from the next by  $-CH_2-$ . (e.g alkanes  $CH_4$ ,  $C_2H_6$ ,  $C_3H_8$ ...)
3. They have similar chemical properties. (e.g all alkanes burn to form  $CO_2$  and  $H_2O$ )
4. Their physical properties change gradually as their molecular masses increase. The higher the mass the greater the intermolecular (van der Waal) forces. This results in increasing melting and boiling

points, increased viscosity and decreasing vapour pressure. (e.g. methane (CH<sub>4</sub>) is a gas but pentane (C<sub>5</sub>H<sub>12</sub>) is a liquid)

- They can be prepared by the same general methods.

### IUPAC naming of organic compounds

The name has three parts

| Prefix                      | Parent                 | Suffix            |
|-----------------------------|------------------------|-------------------|
| Where and what other groups | Number of carbon atoms | Homologous series |

- Identify the **longest chain containing** the main functional group (homologous series).
- Number carbons** in the chain and give it the parent name.
- Identify functional groups** and side chains.

The prefix for the length of a chain (or side chain) is taken from the following:

**1C-** meth

**2C-** eth

**3C-** prop

**4C-** but

**5C-** pent

**6C-** hex

**7C-** hept

**8C-** oct

| SERIES   | FUNCTIONAL GROUP                                                              | EXAMPLE<br>Structural formula                                                                            | NAME<br>(formula)                              |
|----------|-------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|------------------------------------------------|
| ALKANE   | C-C                                                                           | <pre>       H   H             H — C — C — H                   H   H           </pre>                     | ETHANE<br>C <sub>2</sub> H <sub>6</sub>        |
| ALKENE   | C=C                                                                           | <pre>       H       H                 H — C — C = C — H                       H   H   H           </pre> | PROPENE<br>C <sub>3</sub> H <sub>6</sub>       |
| ALKYNE   | C≡C                                                                           | <pre> H — C ≡ C — H           </pre>                                                                     | ETHYNE<br>C <sub>2</sub> H <sub>2</sub>        |
| ALCOHOL  | C-O-H                                                                         | <pre>       H         H — C — O — H                   H   H           </pre>                             | METHANOL<br>CH <sub>3</sub> OH                 |
| ALDEHYDE | <pre>       O          — C — C — H                           </pre>           | <pre>       H   H             H — C — C — C = O                       H   H   H           </pre>         | PROPANAL<br>C <sub>2</sub> H <sub>5</sub> CHO  |
| KETONE   | <pre>       O          — C — C — C —                                   </pre> | <pre>       H   O   H                 H — C — C — C — H                       H   H   H           </pre> | PROPANONE<br>CH <sub>3</sub> COCH <sub>3</sub> |

| SERIES          | FUNCTIONAL GROUP                                                                                                           | EXAMPLE<br>Structural formula                                                                                                                                                                        | NAME<br>(formula)                               |
|-----------------|----------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| CARBOXYLIC ACID | $\begin{array}{c} \text{O} \\ \parallel \\ -\text{C} \\   \\ \text{O}-\text{H} \end{array}$                                | $\begin{array}{c} \text{H} & & \text{O} \\   & & \parallel \\ \text{H}-\text{C}- & \text{C} & \\   & &   \\ \text{H} & & \text{O}-\text{H} \end{array}$                                              | ETHANOIC ACID<br>$\text{CH}_3\text{COOH}$       |
| HALO-ALKANE     | -Cl....chloro-<br>-Br....bromo-<br>-I.....iodo-                                                                            | $\begin{array}{c} \text{H} & \text{Br} & \text{H} \\   &   &   \\ \text{H}-\text{C}- & \text{C} & -\text{C}-\text{H} \\   &   &   \\ \text{H} & \text{H} & \text{H} \end{array}$                     | 2-BROMOPROPANE<br>$\text{CH}_3\text{CHBrCH}_3$  |
| ESTER           | $\begin{array}{c} \text{O} \\ \parallel \\ \text{C}-\text{C} \\   \quad \backslash \\ \text{O} \quad \text{C} \end{array}$ | $\begin{array}{c} \text{H} & & \text{O} & & \text{H} \\   & & \parallel & &   \\ \text{H}-\text{C}- & \text{C} & -\text{O}- & \text{C}-\text{H} \\   & & &   \\ \text{H} & & & \text{H} \end{array}$ | METHYL ETHANOATE<br>$\text{CH}_3\text{COOCH}_3$ |

NOTE: There are 4 bonds per carbon (ALWAYS).

The position of the side chain or functional group is shown with a number. The choice of number is usually such that the smallest possible numbers are used.

The **-an-** in compounds (e.g. but**an**ol) tells one that the C to C bonds are single bonds only.

Name the following compounds:

|                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. $\begin{array}{c} \text{H} & \text{H} & & \text{H} & \text{H} & \text{H} \\   &   & &   &   &   \\ \text{H}-\text{C}-\text{C}-\text{C}\equiv\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\   &   & &   &   &   \\ \text{H} & \text{H} & & \text{H} & \text{H} & \text{H} \end{array}$ | 2. $\begin{array}{c} & \text{H} & \text{H} & \text{H} & \text{O}-\text{H} \\ &   &   &   &   \\ \text{H}-\text{C}- & \text{C}- & \text{C}- & \text{C}-\text{H} \\   &   &   &   \\ \text{H} & \text{O}-\text{H} & \text{H} & \text{C}-\text{H} \\ &   & &   \\ & \text{H} & & \text{H} \end{array}$ |
| 3. $\begin{array}{c} & & \text{H} & & & \text{O} \\ & &   & & & \parallel \\ \text{H}_3\text{C}-\text{CH}_2-\text{CH}_2- & \text{C} & -\text{CH}_2-\text{CH}_2-\text{C} \\ &   & &   \\ & \text{H}_3\text{C}-\text{CH}_2 & & \text{H} \end{array}$                                        | 4. $\text{H}_3\text{C}-\text{CH}_2-\text{CH}_2-\overset{\text{O}}{\overset{\parallel}{\text{C}}}-\text{O}-\text{CH}_2-\text{CH}_3$                                                                                                                                                                  |
| 5. $\text{CH}_2\text{CHCH}_2\text{CHBrCH}_2\text{CH}_3$                                                                                                                                                                                                                                   | 6. $\text{CH}_3\text{CH}_2\text{COCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$                                                                                                                                                                                                                           |

1. hept-3-yne
2. pentan-2,4-diol
3. 4-ethylheptanal
4. ethyl butanoate
5. 4-bromohex-1-ene
6. heptan-3-one

Complete the following table:

| Compound name                 | Structural formula                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Condensed structural formula                                                                              |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| hept-3-yne                    | $  \begin{array}{ccccccc}  & \text{H} & \text{H} & & \text{H} & \text{H} & \text{H} \\  &   &   & &   &   &   \\  \text{H} & - \text{C} & - \text{C} & - \text{C} \equiv \text{C} & - \text{C} & - \text{C} & - \text{C} - \text{H} \\  &   &   & &   &   &   \\  & \text{H} & \text{H} & & \text{H} & \text{H} & \text{H}  \end{array}  $                                                                                                                               | $\text{CH}_3\text{CH}_2\text{CCCH}_2\text{CH}_2\text{CH}_3$                                               |
| 4-bromo-2,4-dimethylhex-1-ene | $  \begin{array}{ccccccc}  & \text{H} & & \text{H} & \text{Br} & \text{H} & \text{H} \\  &   & &   &   &   &   \\  \text{H} & - \text{C} = \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} - \text{H} \\  &   & &   &   &   &   \\  & \text{H} & & \text{H} & \text{H} & \text{H} & \text{H} \\  & & &   & &   &   \\  & & & \text{H} & & \text{H} & \text{H}  \end{array}  $                                                                               | $\text{CH}_2\text{C}(\text{CH}_3)\text{CH}_2\text{CBr}(\text{CH}_3)\text{CH}_2\text{CH}_3$                |
| 3-chloropentan-2-one          | $  \begin{array}{ccccccc}  & \text{H} & \text{O} & \text{Cl} & \text{H} & \text{H} & \\  &   &    &   &   &   & \\  \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} - \text{H} \\  &   & &   &   &   & \\  & \text{H} & & \text{H} & \text{H} & \text{H} &   \end{array}  $                                                                                                                                                                    | $\text{CH}_3\text{COCHClCH}_2\text{CH}_3$                                                                 |
| 5,7-dimethyloctanal           | $  \begin{array}{cccccccc}  & \text{O} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\  &    &   &   &   &   &   &   \\  \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} - \text{H} \\  & &   &   &   &   &   &   \\  & & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\  & & & &   & &   & \\  & & & & \text{H} & & \text{H} &   \end{array}  $                            | $\text{CHOCH}_2\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_3)\text{-CH}_2\text{CH}(\text{CH}_3)\text{CH}_3$ |
| 2-iodohexanoic acid           | $  \begin{array}{ccccccc}  & \text{H} & \text{H} & \text{H} & \text{H} & & \text{O} \\  &   &   &   &   & &    \\  \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} \\  &   &   &   &   & & \backslash \\  & \text{H} & \text{H} & \text{H} & \text{H} & & \text{O} - \text{H}  \end{array}  $                                                                                                                                     | $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CHICOOH}$                                              |
| butyl pentanoate              | $  \begin{array}{ccccccc}  & \text{H} & \text{H} & \text{H} & \text{H} & & \text{O} \\  &   &   &   &   & &    \\  \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{O} \\  &   &   &   &   & & \backslash \\  & \text{H} & \text{H} & \text{H} & \text{H} & & \text{O} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\  & & & & & &   &   &   &   \\  & & & & & & \text{H} & \text{H} & \text{H} & \text{H}  \end{array}  $ | $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{COO-CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$            |

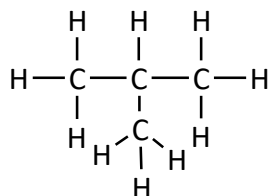
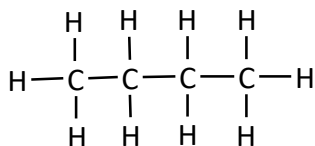
## ISOMERS

**Structural isomer:** Organic molecules with the same molecular formula, but different structural formulae.

There are several types of isomerism - we only deal with STRUCTURAL ISOMERISM which has 3 sub-types:

### CHAIN ISOMERISM

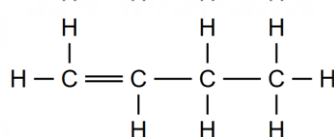
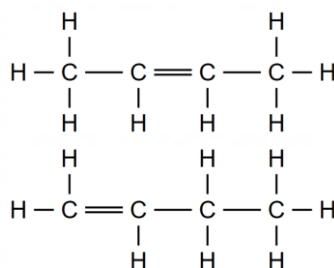
different chains,  
e.g: butane and  
2-methylpropane



### POSITIONAL ISOMERISM

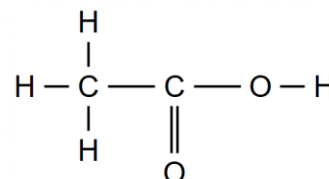
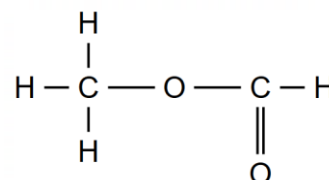
Same molecular formula,  
but different positions of  
the side  
chain, substituents or  
functional groups on the  
parent chain, e.g.

but-2-ene and but-1-ene



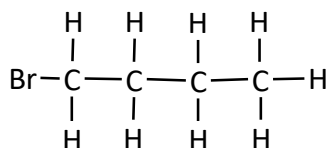
### FUNCTIONAL ISOMERISM

Same molecular formula,  
but different functional  
groups, e.g.  
methyl methanoate and  
ethanoic acid

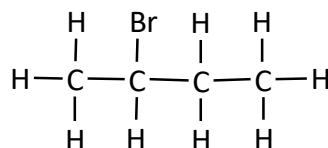


**Note:** Sometimes the isomer is in a different homologous series.  
Isomers will have different physical properties and chemical properties.

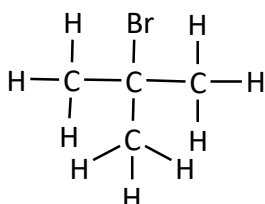
**Exercise:** Draw the structural formula and name all the isomer bromoalkanes with the formula:



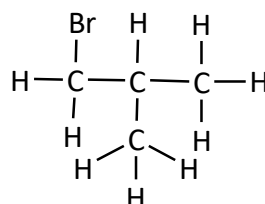
**1-bromobutane**



**2-bromobutane**



**2-bromo-2-methylpropane**

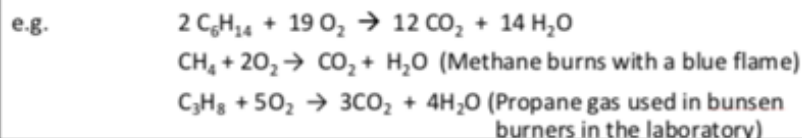


**1-bromo-2-methylpropane**

# REACTIONS OF ALKANES

## OXIDATION (COMBUSTION)

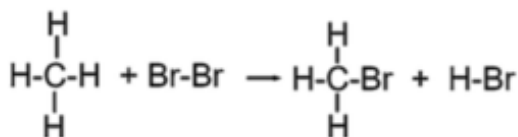
Alkane + oxygen  $\rightarrow$  carbon dioxide + water + energy



## SUBSTITUTION

Alkane  $\rightarrow$  haloalkane

Type of substitution: Halogenation

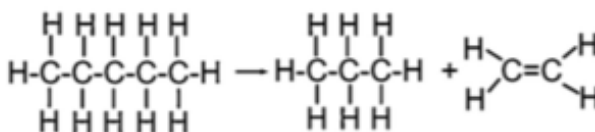


Conditions: heat/sunlight  
 Reactants: alkane +  $\text{X}_2$  ( $\text{X} = \text{F}, \text{Cl}, \text{Br}, \text{I}$ )  
 Products: haloalkane +  $\text{HX}$

## ELIMINATION

Alkane  $\rightarrow$  Alkene + alkane of shorter chain

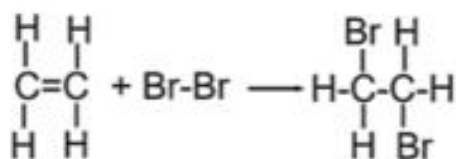
Type of elimination: Thermal cracking



Conditions: heat + high pressure  
 Reactants: alkane  
 Products: alkene + alkane / alkene +  $\text{H}_2$

## ADDITION

Type of addition: halogenation



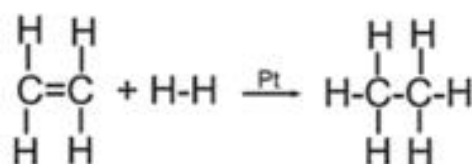
Conditions: unreactive solvent

Reactants: alkene + X<sub>2</sub> (X = F, Cl, Br, I)

Product: haloalkane

## ADDITION

Type of addition: hydrogenation



Conditions: Catalyst, using Pt, Pd or Ni

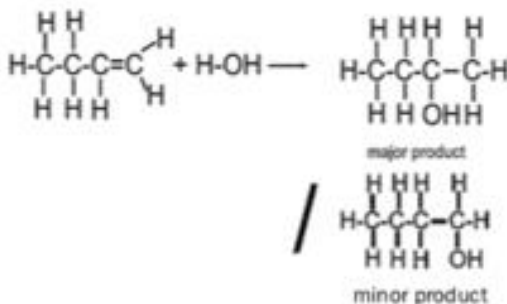
Reactants: alkene + H<sub>2</sub>

Product: alkane

# REACTIONS OF ALKENES

## ADDITION

Type of addition: hydration



Conditions: excess H<sub>2</sub>O, a small amount  
H<sub>2</sub>SO<sub>4</sub> as catalyst

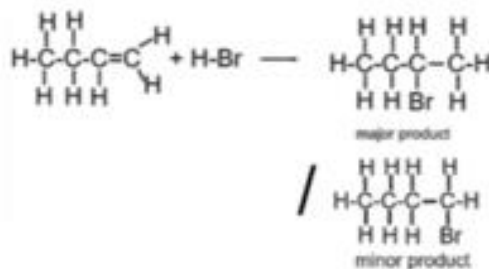
Reactants: alkene + H<sub>2</sub>O

Product: alcohol(s)

Major product: **formed from the stabler carbocation intermediate; Markovnikov's Rule**

## ADDITION

Type of addition: hydro-halogenation



Conditions: No H<sub>2</sub>O; unreactive solvent

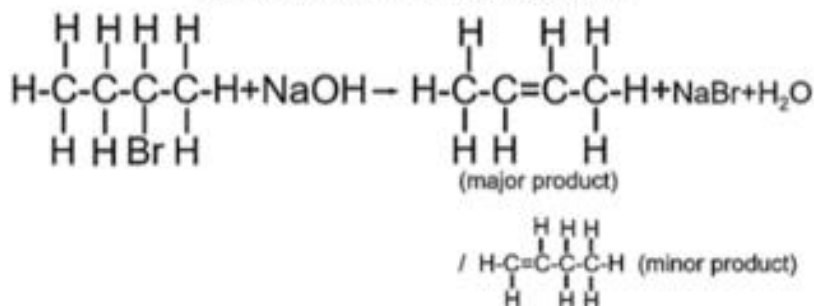
Reactants: alkene + HX

Product: haloalkane(s)

Major product: **H-atom attaches to C already having greater number of H-atoms; Markovnikov's Rule**

## ELIMINATION

Haloalkane  $\rightarrow$  Alkene  
Type of elimination: Dehydrohalogenation

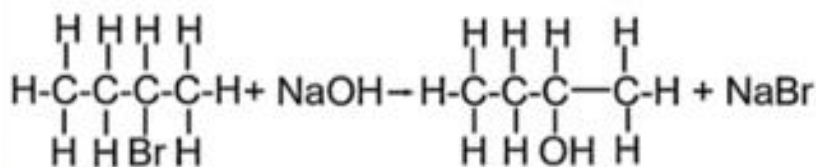


Conditions: Conc. strong base (NaOH, KOH, LiOH) in Ethanol + heat  
 Reactants: Haloalkane + conc. strong base  
 Products: alkene + NaBr + H<sub>2</sub>O  
 Major product: Zaitsev Rule: H-atom is removed from C with least H-atoms; most substituted double bond forms.

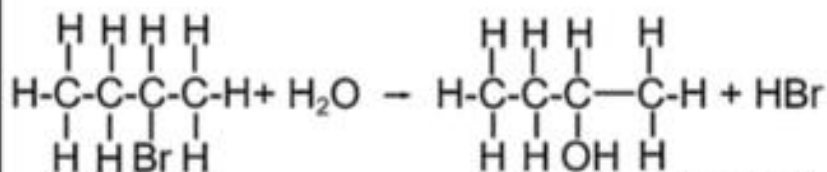
## SUBSTITUTION

Haloalkane  $\rightarrow$  alcohol  
Type of substitution: Hydrolysis

Condition 1: Dil. strong base (NaOH/KOH/LiOH) + mild heat  
 Reactants: Haloalkane + dil. strong base  
 Products: Alcohol + NaBr/KBr/LiBr



Condition 2: Excess H<sub>2</sub>O + mild heat  
 Reactants: Haloalkane + H<sub>2</sub>O  
 Products: Alcohol + HBr



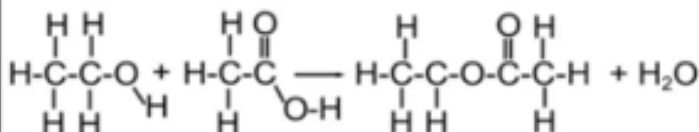
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# REACTIONS OF ALCOHOLS

## ESTERIFICATION (Acid catalysed condensation)

Alcohol + carboxylic acid  $\rightarrow$  ester + water

Type of reaction: Esterification (acid cat condensation)

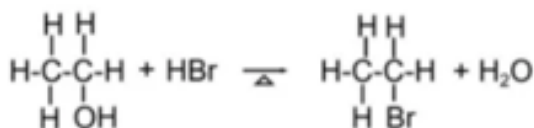


Conditions: heat + acid (as catalyst and dehydrant)  
 Reactants: alcohol  
 Products: ester +  $\text{H}_2\text{O}$

## SUBSTITUTION

Alcohol  $\rightarrow$  haloalkane

Type of substitution: Hydrohalogenation

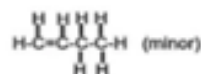
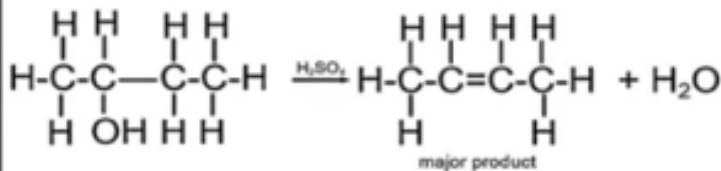


Conditions: heat  
 Reactants: alcohol + HX (acid)  
 Products: haloalkane +  $\text{H}_2\text{O}$

## ELIMINATION

Alcohol  $\rightarrow$  Alkene

Type of elimination: Dehydration



Conditions: heat + dehydrating agent (sulfuric or phosphoric acid)  
 Reactants: alcohol +  $\text{H}_2\text{SO}_4$   
 Products: alkene(s) +  $\text{H}_2\text{O}$   
 Major product: The H-atom removed from the C with least H-atoms

## PHYSICAL PROPERTIES OF ORGANIC COMPOUNDS

- physical properties depend on the strength of intermolecular forces between molecules.

### PHYSICAL PROPERTIES:

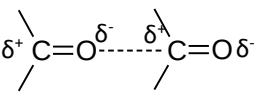
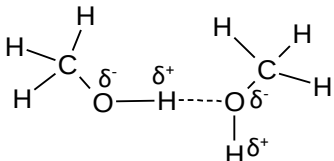
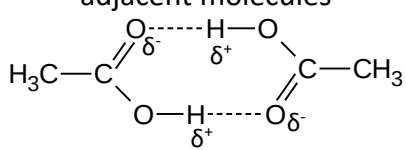
**vapour pressure** - the pressure exerted by a vapour at equilibrium with its liquid in a closed system.  
The stronger the intermolecular forces, the lower the vapour pressure.

**boiling point** - the temperature at which the vapour pressure of a substance equals atmospheric pressure. The stronger the intermolecular forces, the higher the boiling point.

**melting point** - the temperature at which the solid and liquid phases of a substance are at equilibrium. The stronger the intermolecular forces, the higher the melting point.

| RELEVANT INTERMOLECULAR FORCES | Van der Waals Forces                                                 |                                                                                       | Hydrogen bonds<br>10 – 40 kJ.mol <sup>-1</sup><br>Molecules with hydroxyl group (-O-H) |
|--------------------------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
|                                | Dispersion/London<br>0,05 – 40 kJ.mol <sup>-1</sup><br>All molecules | Dipole-Dipole<br>5 – 25 kJ.mol <sup>-1</sup><br>Molecules with polar functional group |                                                                                        |

### PHYSICAL PROPERTIES and FUNCTIONAL GROUPS

|                             |                                                                                                                                                                                                                                        |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ALKANE<br>ALKENE<br>ALKYNE  | non-polar molecules - London forces only                                                                                                                                                                                               |
| HALO-ALKANE                 | contain halogens (Cl, Br, I) which vary in electronegativity – C-X bonds may be polar, so some dipole-dipole forces may be present                                                                                                     |
| ALDEHYDE<br>KETONE<br>ESTER | contain the carbonyl (C=O) group which is polar due to the strongly electronegative oxygen, dipole-dipole forces present<br>                       |
| ALCOHOL                     | contain hydroxyl functional group (OH) so hydrogen bonding present<br>                                                                             |
| CARBOXYLIC ACID             | Carboxyl (COOH) functional group allows H-bonding, but stronger H-bond than alcohols - two sites available for H-bonding on adjacent molecules<br> |

Strength of intermolecular forces:

carboxylic acid > alcohol > aldehyde/ketone > ester > haloalkane > alkane/alkene/alkyne

- **hydrocarbons** have weak IMF, thus enter the gas phase easily and vapour pressure is HIGH. They change state readily and have LOW melting and boiling points
- **polar** compounds have stronger IMF, and thus require more energy to change phase, so melting and boiling points that are higher than the hydrocarbons and vapour pressure is lower.
- **alcohols** and carboxylic acids have the strongest IMF, and thus have low vapour pressure at a specific temperature. Much energy is needed for them to change phase, so melting and boiling points are high.

eg.

|                              | IMF             | Boiling Point (°C) |
|------------------------------|-----------------|--------------------|
| Butane (M <sub>r</sub> 58)   | London only     | 0                  |
| Propanal (M <sub>r</sub> 58) | Dipole - Dipole | 49                 |
| Propanol (M <sub>r</sub> 60) | H-bonding       | 97                 |

### PHYSICAL PROPERTIES and CHAIN LENGTH

- longer carbon chains produce stronger intermolecular forces. (larger surface area over which vdW forces can act.
- in a homologous series, **melting and boiling points increase as chain length increases**, and the vapour pressure decreases.

### PHYSICAL PROPERTIES and BRANCHED CHAINS

- as chains become more branched, the molecule become less 'linear' in shape and less areas on the molecule are in in close enough close proximity for vdW forces to have an influence.
- increased branching results in weaker intermolecular forces and lower melting and boiling points.

