Organic Chemistry Revision Sheets
Reactions for AQA A-Level Chemistry

Alkanes Combustion

REACTANTS: Alkane and O_2 (oxygen)
CONDITIONS: Excess of Oxygen (for complete combustion)
PRODUCT(S): Carbon Dioxide and Water
REACTION TYPE: Combustion

REACTION: (example of pentane)

$$\underset{\text{Alkane}}{C_5H_{12}} + \underset{\text{Oxygen}}{8O_2} \longrightarrow \underset{\text{Carbon Dioxide}}{5CO_2} + \underset{\text{Water}}{6H_2O}$$

NOTES:
- When excess oxygen is present complete combustion occurs so carbon dioxide and water are the only products.
- Incomplete combustion of alkanes occurs when oxygen becomes a limiting reagent, leading to the formation of carbon monoxide (CO) and solid carbon particulates (soot).

Alkanes Free Radical Substitution

REACTANTS: Alkanes and Halogen
CONDITIONS: U.V (ultraviolet) light
PRODUCT: Halogenoalkane
REACTION TYPE: Free Radical Substitution

REACTION: (example of methane)

$$\underset{\text{Alkane}}{CH_4} + \underset{\text{Chlorine}}{Cl_2} \xrightarrow{\text{u.v}} \underset{\text{Chloroalkane}}{CH_3Cl} + \underset{\text{Hydrogen Halide}}{HCl}$$

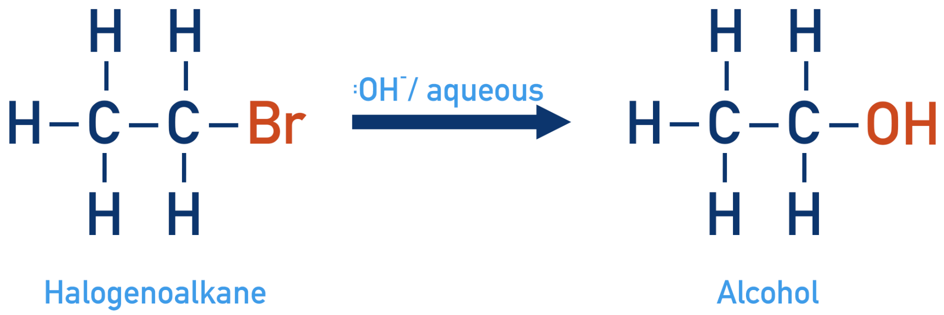
NOTES:

- Chain reaction, occuring in three steps - **initiation**, **propagation** and **termination.** *See mechanism.*
- U.V light is required to homolytically split halogen molecule, forming two radical species.
- Further substitution can occur, forming di, tri and tetra halogenoalkanes.

Halogenoalkanes Substitution (OH^-)

REACTANTS: Halogenoalkane and Sodium Hydroxide, *NaOH* (for OH^- ions)
CONDITIONS: Heat under reflux, Aqueous ('aq' - water present)
PRODUCT(S): Alcohol and Halide Ion (sodium halide salt if sodium hydroxide used)
REACTION TYPE: Nucleophilic Substitution, *Hydrolysis*

REACTION:
(example of bromoethane)



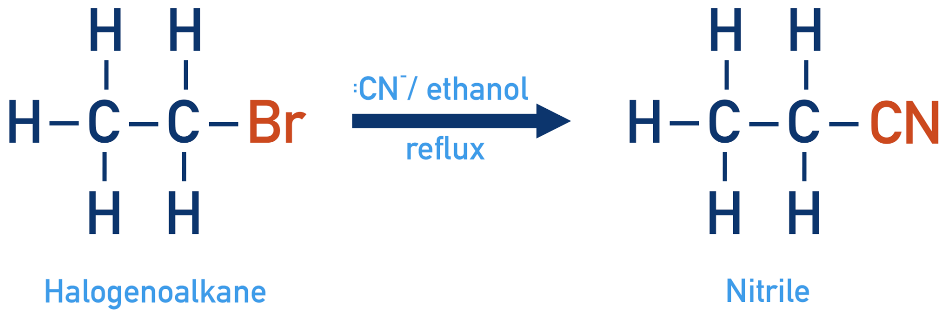
NOTES:

- Rate of reaction is determined by strength of carbon-halogen bond (carbon-flourine bond is strongest giving slowest rate; carbon-iodine bond is weakest, giving fastest rate).
- Rate of hydrolysis can compared using aqueous silver nitrate ($AgNO_3$) within the reaction mixture and timing how long it takes to form precipitate (Cl = **white** ppt, Br = **cream** ppt and I = **yellow** ppt).
- Reaction must be carried out in **aqueous conditions, otherwise an elimination can occur.**

Halogenoalkanes Substitution (CN^-)

REACTANTS: Halogenoalkane and Sodium *or Potassium* Cyanide (NaCN *or KCN*)
CONDITIONS: Heat under reflux, Ethanolic (ethanol as the solvent, **no water present**)
PRODUCT(S): Nitrile and Halide Ion (*forms salt with Na^+ or K^+*)
REACTION TYPE: Nucleophilic Substitution

REACTION:
(example of pentane)



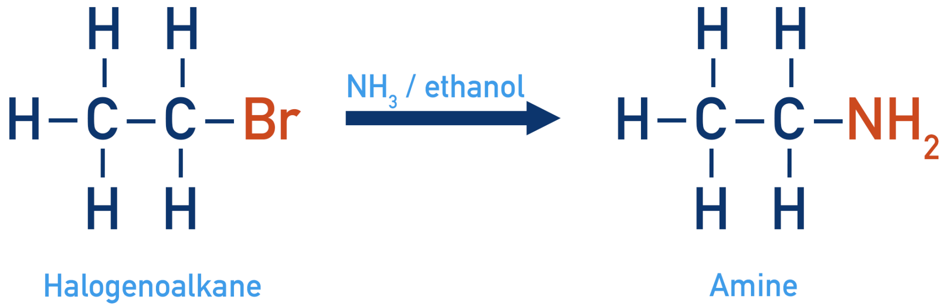
NOTES:

- Rate of reaction is determined by strength of carbon-halogen bond (carbon-flourine bond is strongest, giving slowest rate; carbon-iodine bond is weakest, giving fastest rate).
- Reaction must be carried out in **ethanolic conditions (in ethanol, no water present), otherwise an alcohol is likely to form** rather than the nitrile.
- Reaction is heated under reflux to ensure no volatile substances are lost.

Halogenoalkanes Substitution (NH_3)

REACTANTS: Halogenoalkane and Ammonia (NH_3)
CONDITIONS: Heat*, Ethanolic (ethanol as the solvent, **no water present**)
PRODUCT(S): Amine and Ammonium Halide Salt
REACTION TYPE: Nucleophilic Substitution

REACTION: (example of bromoethane)



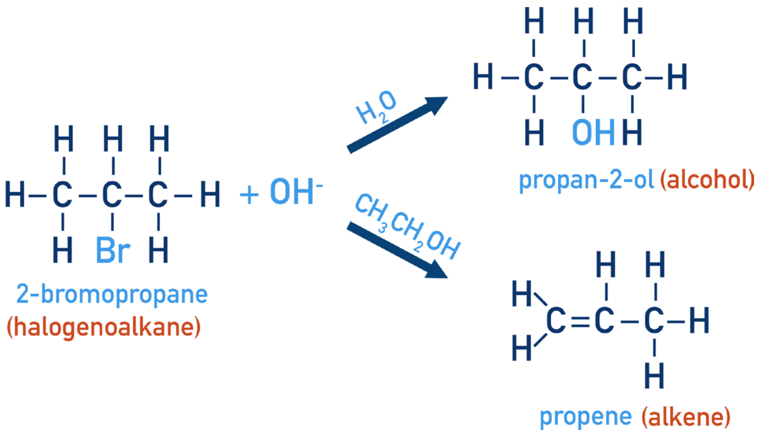
$$H{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}Br \xrightarrow{NH_3\text{ / ethanol}} H{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}NH_2$$

NOTES:
- Reaction must be carried out in **ethanolic conditions (in ethanol, no water present), otherwise an alcohol is likely to form** rather than the amine.
- *A sealed container (to stop ammonia escaping) containing reactants is heated.
- The amine formed in the reaction is a stronger base than ammonia and an ammonium-alkyl $[RNH_3]^+$ salt may be formed. The amine can be obtained by adding sodium hydroxide to the mixture - forcing the alkyl-ammonium ion to 'release' a H^+ ion and become a neutral molecule.
- Rate of reaction is determined by strength of carbon-halogen bond (carbon-flourine bond is strongest, giving slowest rate; carbon-iodine bond is weakest, giving fastest rate).

Halogenoalkanes Substitution <u>and</u> Elimination (OH^-)

REACTANTS: Halogenoalkane and Potassium Hydroxide (for OH^- ions)
CONDITIONS: Heat under reflux, Ethanolic or Aqueous*
PRODUCT(S): Alcohol **and** Alkene (possible mixture of both)
REACTION TYPE: Nucleophilic Substitution **and** Elimination

REACTION(S):
(example of 2-bromo-propane)



NOTES:

- Halogenoalkanes can react with hydroxide (OH^-) ions in both substitution and elimation reactions.
- If **substitution occurs an alcohol is formed,** whereas if **elimination occurs an alkene is formed.**
- The solvent used can help ensure more of one product is formed than the other, although final product mixture can still contain both the alcohol and alkene.
- If a hot **aqueous solvent is used, more alcohol forms.**
- If a hot **ethanolic solvent is used, more alkene forms.**
- Primary alcohols are **more likely to undergo substitution** - tertiary alcohols are **more likely to undergo elimination**. Secondary alcohols can undergo both substitution and elimination.
- *Higher temperatures and a more concentrated solution of hydroxide ions favour elimination.*

Decomposition (Free Radical) Ozone

REACTANTS: Chlorine Radical and Ozone (O_3)
CONDITIONS: Upper Atmosphere, (u.v light to form chlorine radical)
PRODUCT(S): Oxygen
REACTION TYPE: Decomposition (Free Radical)

REACTION: (example of ozone)

$$Cl\bullet + O_3 \longrightarrow ClO\bullet + O_2$$

$$ClO\bullet + O_3 \longrightarrow Cl\bullet + 2O_2$$

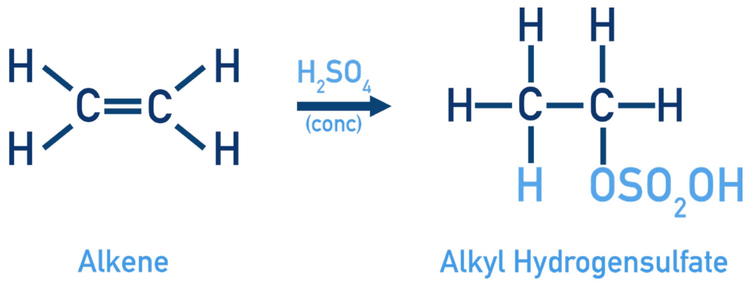
NOTES:

- Chlorine radical is formed by homolytic fission of chlorine molecule in upper atmopshere by u.v light.
- This is a chain reaction as the chlorine radical is reformed and can go on to decompose more ozone molecules.
- Ozone (O_3) prevents u.v radiation from reaching the surface of planet Earth. The use of CFC's (chlorofluourinated carbons) in the 20th century lead to a depletion of ozone in the upper atmosphere; CFCs were banned as a result.

Alkenes Addition (H_2SO_4)

REACTANTS: Alkene and Sulfuric Acid (H_2SO_4)
CONDITIONS: Concentrated Sulfuric Acid
PRODUCT(S): Alkyl Hydrogen Sulfate
REACTION TYPE: Electrophilic Addition

REACTION: **(example of ethene)**



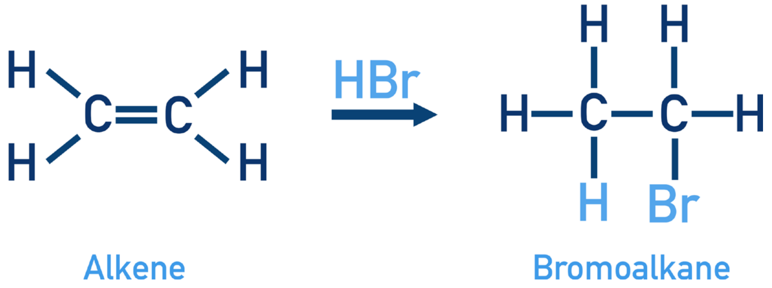
NOTES:

- For unsymetrical alkenes, there will be two possible products from the electrophilic addition.
- Stability of the carbocation intermediate in the mechanism will determine which product will made more readily (**major product**) and which product will be made less readily (**minor product**). *See mechanism.*
- Alkyl hydrogensulfate formed can be heated to form alcohol.

Alkenes Addition (HBr)

REACTANTS: Alkene and Hydrogen Bromide (HBr)
CONDITIONS: Hydrogen Bromide Gas or (concentrated) Hydrobromic Acid
PRODUCT(S): Bromoalkane
REACTION TYPE: Electrophilic Addition

REACTION:
(example of ethene)



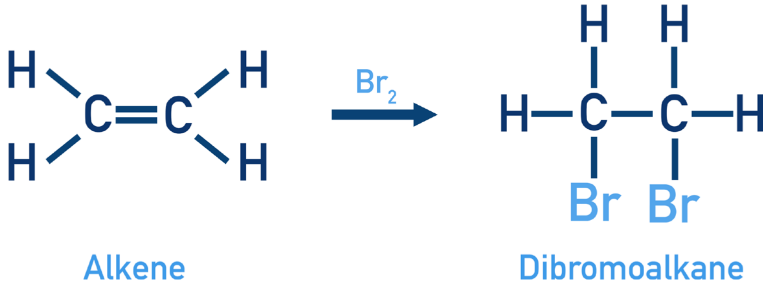
NOTES:

- For unsymetrical alkenes, there will be two possible products from the electrophilic addition.
- Stability of the carbocation intermediate in the mechanism will determine which product will made more readily (**major product**) and which product will be made less readily (**minor product**). *See mechanism.*

Alkenes Addition (Br_2)

REACTANTS: Alkene and Bromine (Br_2)
CONDITIONS: Bromine Liquid (pure Br_2) or Bromine Water ($Br_2(aq)$)
PRODUCT(S): Dibromoalkane
REACTION TYPE: Electrophilic Addition, *Bromination*

REACTION: (example of ethene)



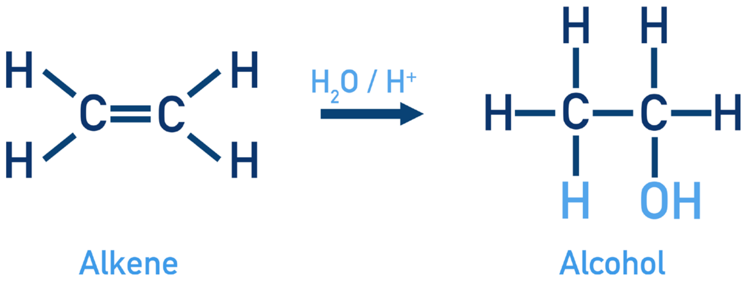
NOTES:

- Double bond in alkene polarises the bromine molecule to form an electrophile ($Br^{\delta+}$) that starts the reaction.
- Reaction can be used to test for the presence of an alkene. A sample is mixed with bromine water, if the bromine water turns colourless (from orange - brown) an alkene is present in the sample.

Alkenes Hydration (to alcohol)

REACTANTS: Alkene and Steam ($H_2O_{(g)}$)
CONDITIONS: Heat and Acid Catalyst (Phosphoric Acid, H_3PO_4)
PRODUCT(S): Alcohol
REACTION TYPE: Electrophilic Addition, *(acid catalysed) Hydration*

REACTION: (example of ethene)



NOTES:

- Acid catalyst is required to form hydroxonium ion (H_3O^+) ion that is able to act as an electrophile to start the reaction.
- For unsymetrical alkenes, there will be two possible products from the electrophilic addition.
- Stability of the carbocation intermediate in the mechanism will determine which product will made more readily (**major product**) and which product will be made less readily (**minor product**).*See mechanism.*

Glucose Fermentation (to ethanol)

REACTANTS: Glucose (aqueous)
CONDITIONS: Yeast, Anaerobic Atmosphere (no oxygen) and Warm Temperature
PRODUCT(S): Ethanol and Carbon Dioxide
REACTION TYPE: Fermentaion (respiration of yeast)

REACTION:

$$C_6H_{12}O_6(aq) \xrightarrow{\text{Yeast}} 2CH_3CH_2OH(aq) + 2CO_2(g)$$

Glucose Ethanol Carbon Dioxide

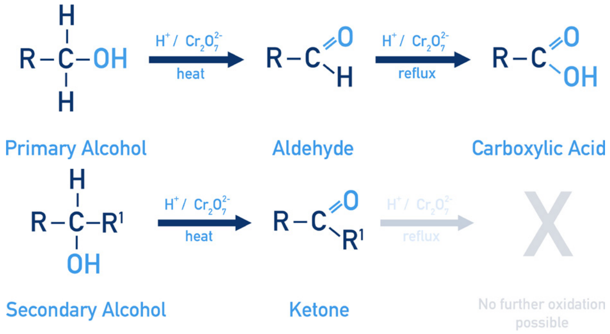
NOTES:

- Yeast is a living organism that carries out anaerobic respiration of glucose to release energy for itself.
- Aneorobic (no oxygen present) conditions are essential to force aneorobic respiration and a warm temperature is required to ensure maximum activity of the enzymes present in yeast.
- Once a certain concentration of ethanol is present, the yeast will be killed and no further ethanol will be produced. To obtain higher concentrations of ethanol, it must be distilled from the mixture.

Alcohols Oxidation

REACTANTS: Alcohol (primary or secondary) and Acidified Dichromate ions ($Cr_2O_7^{2-}$ / H^+)
CONDITIONS: Heat*, Acid Catalyst (sulfuric acid (H_2SO_4))
PRODUCT(S): Aldehyde, Ketone or Carboxylic Acid (see below)
REACTION TYPE: Oxidation

REACTIONS: (example of primary and secondary alcohol)

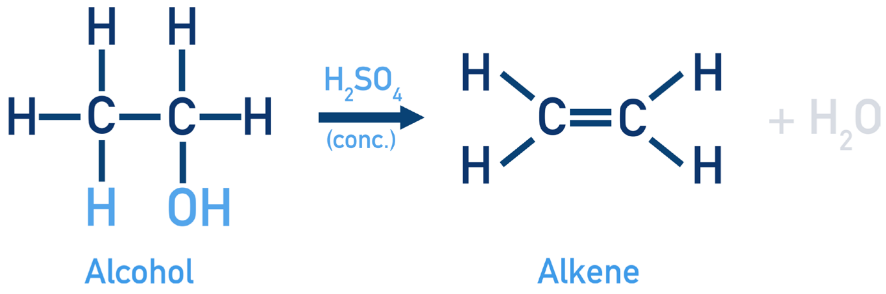


NOTES:
- *Primary alcohols form aldehydes and carboxylic acids when heated with an oxidising agent. To isolate aldehyde, distill aldehyde from reaction mixture as soon as it is formed. To obtain carboxylic acid, heat under reflux to ensure full oxidation of aldehydes already formed.
- Secondary alcohols form ketones and are unable to be further oxidised. Tertiary alcohols are unable to be oxidised at all.
- Oxidising agents can be repesented as [O].

Alcohols Elimination (to alkenes)

REACTANTS: Alcohol
CONDITIONS: Heat, Acid Catalyst (concentrated H_2SO_4 or concentrated H_3PO_4)
PRODUCT(S): Alkene
REACTION TYPE: Elimination, *dehydration*

REACTION: (example of ethene)



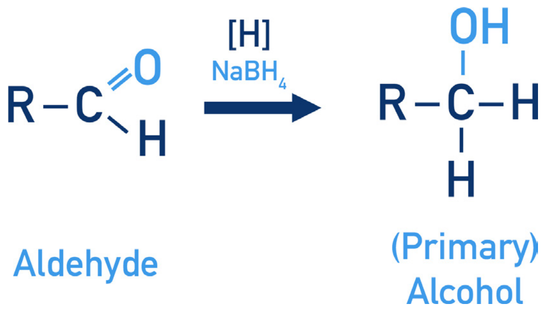
NOTES:

- Acid catalyst provides H^+ ion to start reaction and is reformed at the end when a H^+ ion is released by reacting molecule.
- Water molecule is removed, **dehydration reaction**.

Aldehydes Reduction ($NaBH_4$)

REACTANTS: Aldehyde and $NaBH_4$ (reducing agent)
PRODUCT(S): Primary Alcohol
REACTION TYPE: Reduction

REACTION:



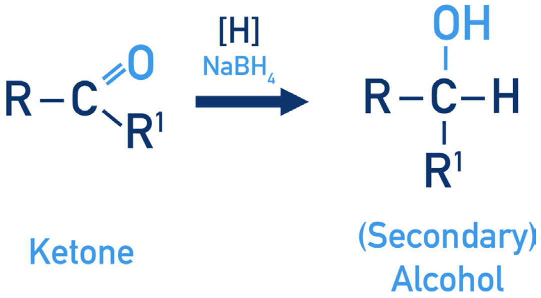
NOTES:

- Aldehydes form **primary alcohols** when reduced.
- $NaBH_4$ is a reducing agent able to provide hydride (:H^-) ions that are needed for the reduction of carbonyls.
- The hydrogens added in reduction reactions are often shown as [H].

Ketones Reduction ($NaBH_4$)

REACTANTS: Ketone and $NaBH_4$ (reducing agent)
PRODUCT(S): Secondary Alcohol
REACTION TYPE: Reduction

REACTION:



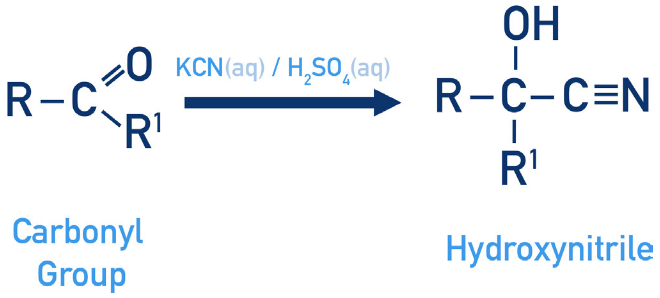
NOTES:

- Ketones form **secondary alcohols** when reduced.
- $NaBH_4$ is a reducing agent able to provide hydride ($:H^-$) ions that are needed for the reduction of carbonyls.
- The hydrogens added in reduction reactions are often shown as [H].

Hydroxynitriles Formation (from carbonyls)

REACTANTS: Carbonyl (aldehyde or ketone) and KCN (in acid)
PRODUCT(S): Hydroxynitrile
REACTION TYPE: Nucleophilic Addition

REACTION:

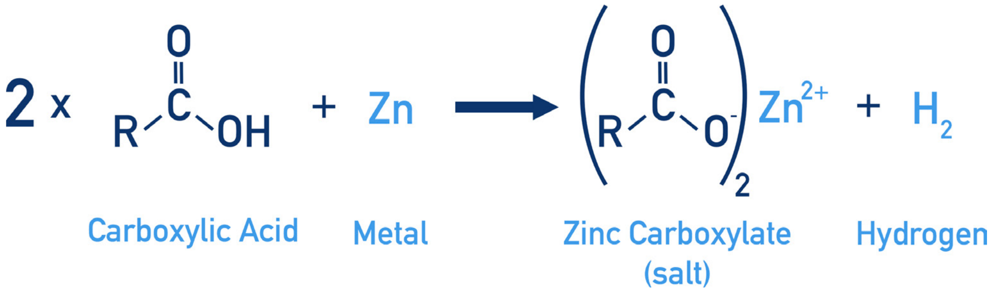


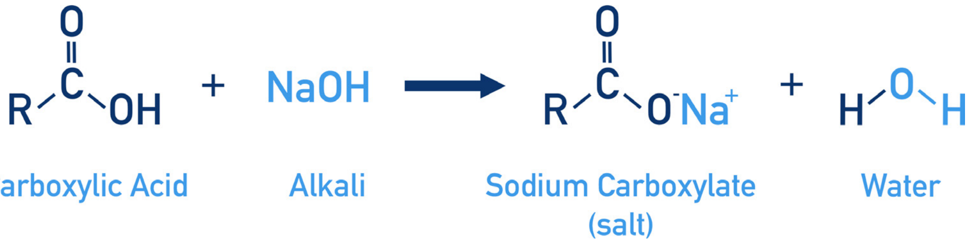
NOTES:

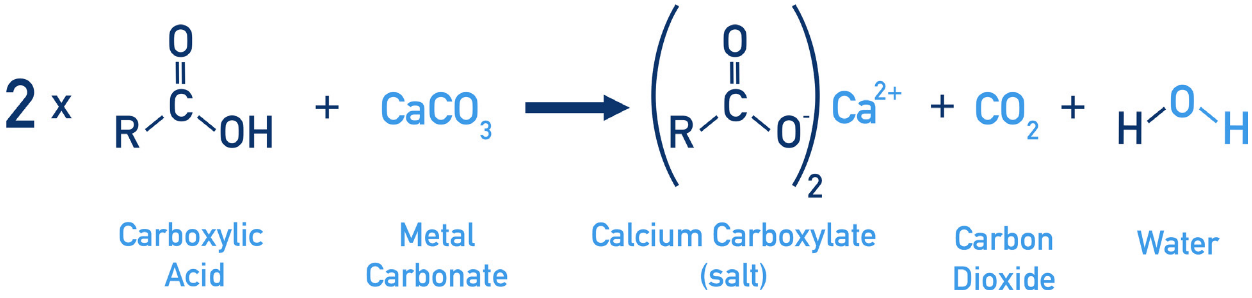
- HCN is sometimes written as the reactant, but HCN is very reactive and dangerous. By using KCN in dilute acid, the same product can be formed as with HCN.
- If a chiral carbon centre is formed in the product, the final product mixture will be **racemic,** containing both enantiomers in a 50:50 ratio. This is because carbonyl groups are planar and there is equal chance of the $:CN^-$ nucleophile attacking the carbonyl group from above or below the plane - producing two possible enantiomers in equal amounts.

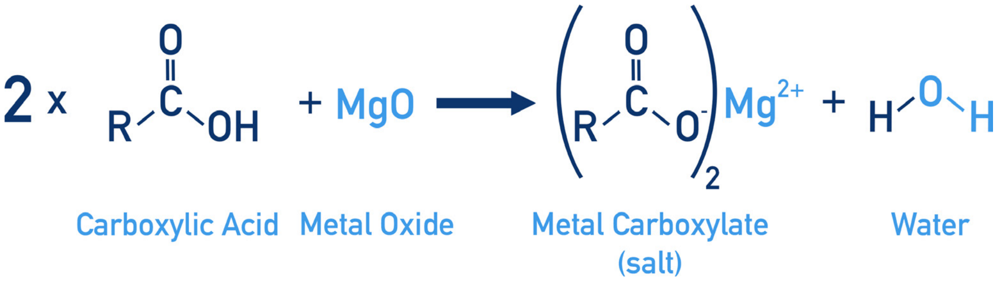
Carboxylic Acids Acid-Base Reactions

Carboxylic acids are able to act as weak acids and react with bases as any weak acid does







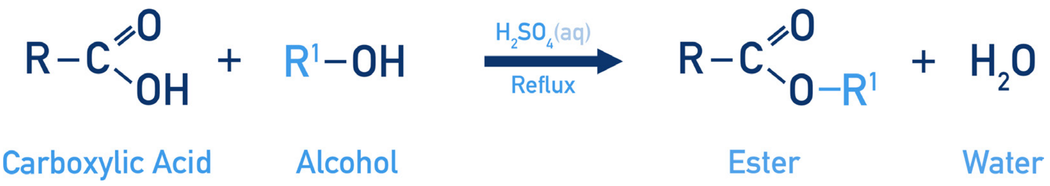


NOTES:
- Salts formed by carboxylic acids are (usually) highly soluble in water and can be a useful source of conjugate bases for making buffer systems.

Esters Esterification (carboxylic acid and alcohol)

REACTANTS: Carboxylic Acid and Alcohol
CONDITIONS: Heat under reflux and (concentrated) Sulfuric Acid (H_2SO_4) catalyst
PRODUCT(S): Ester
REACTION TYPE: Condensation, *Esterification*

REACTION:

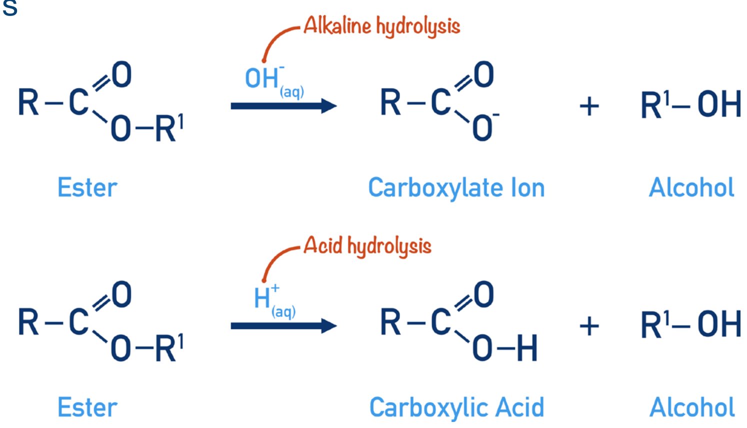


NOTES:
- Reaction is reversible (see hydrolysis of esters), so a (concentrated) acid catalyst is needed to force the position of equilibrium to the formation of ester.

Esters Hydrolysis

REACTANTS: Ester
CONDITIONS: Warm, Aqueous (with dilute acid or alkali)
PRODUCT(S): Carboxylic Acid (or carboxylate salt) and Alcohol
REACTION TYPE: Hydrolysis

REACTION(S):



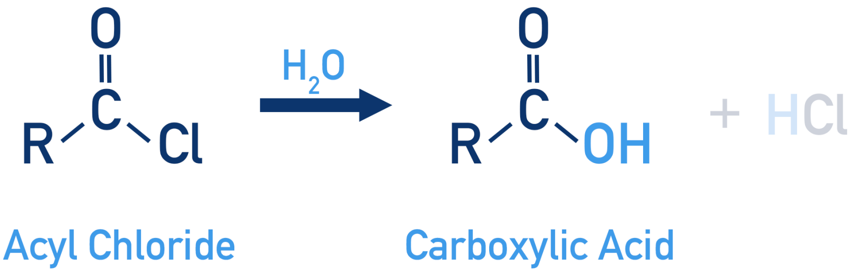
NOTES:

- If alkaline (OH^-) conditions are used, a carboxylate ion is formed and can be isolated by adding a dilute acid.
- Fats and oils are tri-esters and can be broken down into three fatty acid molecules (carboxylic acids) and one alcohol molecule (glycerol) by hydrolysis.
- Biodisel can be made by the reaction of oil (tri-ester) with methanol in the presence of an acid catalyst, forming methyl esters that can be used as a diesel fuel.

Acyl Chlorides Addition-Elimination (H_2O)

REACTANTS: Acyl Chloride and H_2O
PRODUCT(S): Carboxylic Acid and HCl
REACTION TYPE: Nucleophilic Addition-Elimination, *Hydrolysis of acyl chloride*

REACTION:

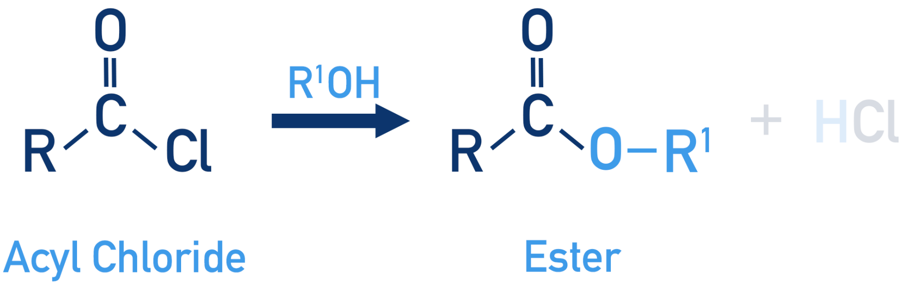


NOTES:
- Acyl chlorides are highly reactive and the reaction is vigorous, with heat given off (exothermic) and fumes of HCl released.

Acyl Chlorides Addition-Elimination (alcohol)

REACTANTS: Acyl Chloride and Alcohol
PRODUCT(S): Ester and HCl
REACTION TYPE: Nucleophilic Addition-Elimination, *Esterification*

REACTION:



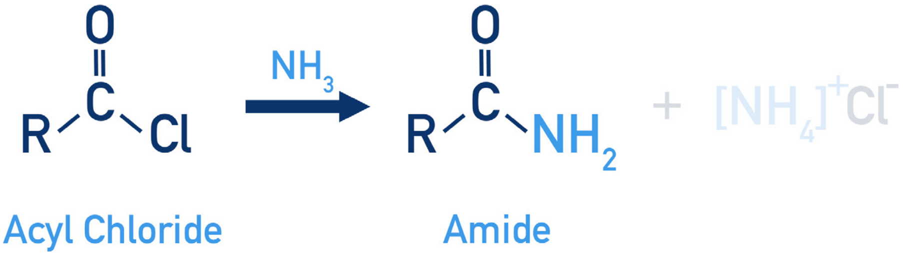
NOTES:

- Ester formed (esterification) has a sweet, fruity smell.

Acyl Chlorides Addition-Elimination (NH_3)

REACTANTS: Acyl Chloride and Ammonia
PRODUCT(S): Amide and HCl
REACTION TYPE: Nucleophilic Addition-Elimination

REACTION:



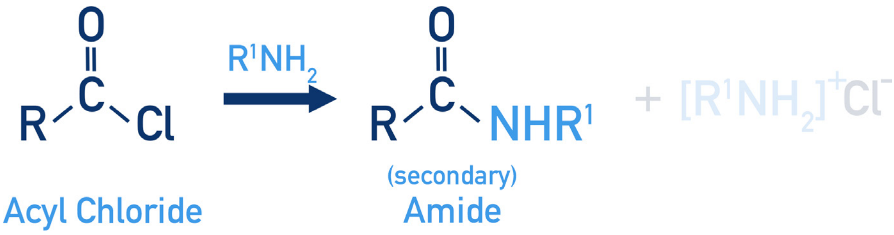
NOTES:

- Ammonia produces a **primary amide** and ammonium chloride salt when reacted with acyl chlorides.
- Primary amines produce a **secondary amide** and an alkyl ammonium chloride salt when reacted with acyl chlorides.
- Secondary amines produce a **tertiary amide** and an alkyl ammonium chloride salt when reacted with acyl chlorides.

Acyl Chlorides Addition-Elimination (amine)

REACTANTS: Acyl Chloride and Amine (primary)
PRODUCT(S): (Secondary) Amide and Alkyl Ammonium Chloride
REACTION TYPE: Nucleophilic Addition-Elimination

REACTION:



NOTES:

- Primary amines produce a **secondary amide** and an alkyl ammonium chloride salt when reacted with acyl chlorides.
- Secondary amines produce a **tertiary amide** and an alkyl ammonium chloride salt when reacted with acyl chlorides.

Acid Anhydrides Addition-Elimination (H_2O)

REACTANTS: Acid Anhydride and H_2O
PRODUCT(S): Carboxylic Acid
REACTION TYPE: Addition-Elimination

REACTION:

NOTES:

- Acid anhydrides behave in a similar way to acyl chlorides in reactions except they are less reactive, making them safer to use.
- Reaction with water is the same as with acyl chlorides, except another carboxylic acid (rather than HCl) is formed.

Acid Anhydrides Addition-Elimination (alcohol)

REACTANTS: Acid Anhydride and Alcohol
PRODUCT(S): Ester and Carboxylic Acid
REACTION TYPE: Addition-Elimination

REACTION:

NOTES:
- Acid anhydrides behave in a similar way to acyl chlorides in reactions except they are less reactive, making them safer to use.
- Reaction with alcohol is the same as with acyl chlorides, except a carboxylic acid (rather than HCl) is formed as well as the ester.

Acid Anhydrides Addition-Elimination (NH_3)

REACTANTS: Acid Anhydride and Ammonia (NH_3)
PRODUCT(S): (Primary) Amide and Carboxylic Acid*
REACTION TYPE: Addition-Elimination

REACTION:

NOTES:

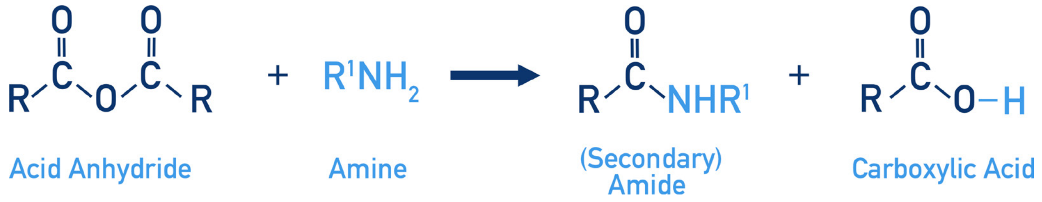
- Acid anhydrides behave in a similar way to acyl chlorides in reactions except they are less reactive, making them safer to use.
- Reaction with ammonia is the same as with acyl chlorides, except a carboxylic acid (rather than HCl) is formed as well as the amide.
- *The carboxylic acid formed will react with any ammonia present to form an ammonium carboxylate salt:

$$RCOOH + NH_3 \rightarrow [RCOO]^- [NH_4]^+$$

Acid Anhydrides Addition-Elimination (amine)

REACTANTS: Acid Anhydride and Amine (RNH_2 *primary* or $RNHR^1$ *secondary*)
PRODUCT(S): (Secondary) Amide and Carboxylic Acid*
REACTION TYPE: Addition-Elimination

REACTION:



NOTES:

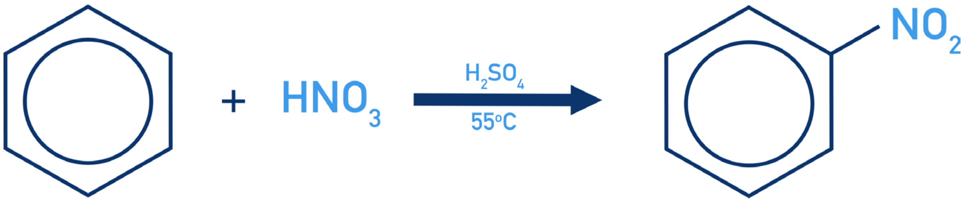
- Acid anhydrides behave in a similar way to acyl chlorides in reactions except they are less reactive, making them safer to use.
- Reaction with amines is the same as with acyl chlorides, except a carboxylic acid (rather than HCl) is formed as well as the amide.
- *The carboxylic acid formed will react with any amine present to form an alkyl ammonium carboxylate salt:

$$\mathbf{RCOOH + RNH_2 \rightarrow [RCOO]^- [RNH_3]^+}$$

Benzene Nitration (adding NO_2)

REACTANTS: Benzene and (concentrated) Nitric Acid (HNO_3)
CONDITIONS: (Concentrated) Sulfuric Acid (H_2SO_4)
PRODUCT(S): Nitrobenzene
REACTION TYPE: Electrophilic Substitution, *Nitration*

REACTION: (example of benzene)



Benzene

Nitrobenzene

NOTES:

- Nitronium ion is formed by the reaction of concentrated nitric acid with concentrated sulfuric acid.

$$HNO_3 + H_2SO_4 \longrightarrow H_2NO_3^+ + HSO_4^-$$

$$H_2NO_3^+ \longrightarrow NO_2^+ + H_2O$$

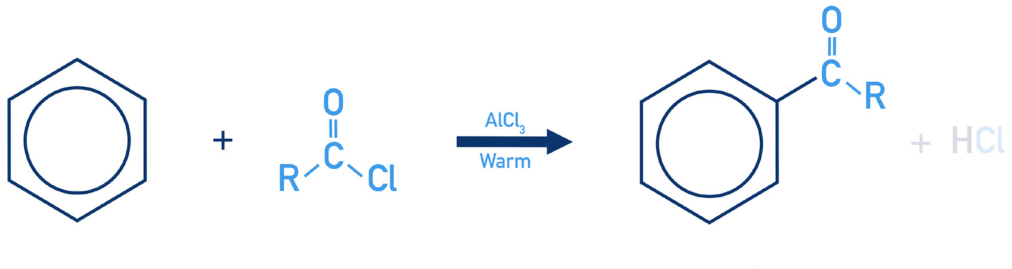
Nitronium Ion

- H^+ ion removed from benzene ring combines with hydrogen sulfate (HSO_4^-) ion to reform catalyst H_2SO_4.

Benzene Acylation (with acyl chlorides)

REACTANTS: Benzene and Acyl Chloride
CONDITIONS: Warm and $AlCl_3$ catalyst
PRODUCT(S): (Aromatic) Ketone
REACTION TYPE: Electrophilic Substitution, *Acylation (Friedel Crafts)*

REACTION: (example of benzene)



Benzene

(Aromatic) Ketone

NOTES:

- Acylium (RCO^+) ion is formed by reacting an acyl chloride with a halogen carrier ($AlCl_3$).

$$RCOCl + AlCl_3 \longrightarrow R\overset{+}{C}O + [AlCl_4]^-$$

Halogen Carrier

Acylium ion

- H^+ ion removed from benzene ring combines with $[AlCl_4]^-$ to reform $AlCl_3$ catalyst and form HCl.

$$H^+ + Cl{-}AlCl_3^- \longrightarrow HCl + AlCl_3$$

Halogen Carrier

Nitriles Reduction (to form primary amine)

REACTANTS: Nitrile and Reducing Agent - $LiAlH_4$, or Hydrogen gas ($H_2(g)$)
CONDITIONS: Dry ether* (if using $LiAlH_4$), Nickel catalyst (if using $H_2(g)$)
PRODUCT(S): Amine
REACTION TYPE: Reduction, *Hydrogenation*

REACTION:

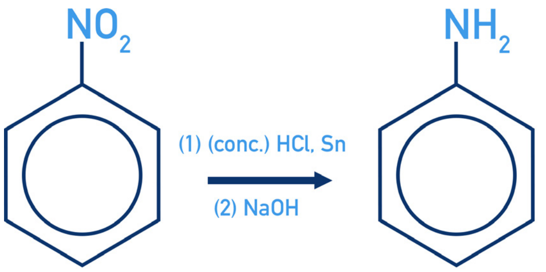
$$\underset{\text{Nitrile}}{R-C\equiv N} \xrightarrow[\text{or } H_2(g)\ /\ Ni]{LiAlH_4} \underset{\text{Amine}}{R-CH_2-NH_2}$$

NOTES:
- If $H_2(g)$ and a nickel catalyst is used, the reaction is an example of catalytic hydrogenation.
- *Dry ether must be used with $LiAlH_4$ ($LiAlH_4$ reacts violently with water). To obtain the amine as a final product, dilute acid must be added to the inital product from reduction.

Nitroarenes Reduction (to form aromatic amines)

REACTANTS: Nitroarene and (concentrated) Hydrochloric Acid (HCl), *followed by NaOH*
CONDITIONS: Tin catalyst
PRODUCT(S): Aromatic Amine
REACTION TYPE: Reduction

REACTION:
(example of nitrobenzene)



Nitroarene

Phenylamine

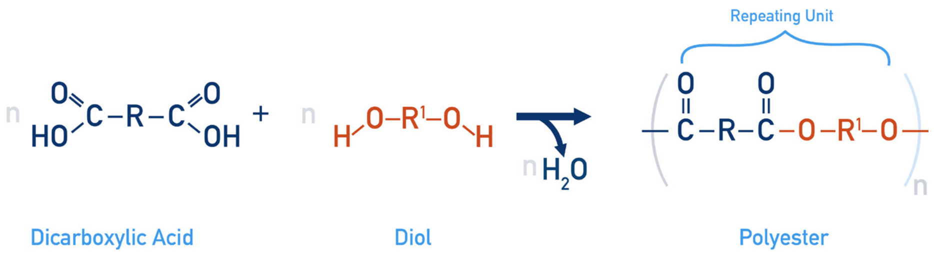
NOTES:

- When reacted with concentrated HCl, the nitroarene will form an ammonium ion -NH_3^+. The aromatic amine can be obtained by adding dilute sodium hydroxide (to form -NH_2).

Polymers Condensation (from dicarboxylic acids and diols)

REACTANTS: Dicarboxylic Acid and Diol
PRODUCT(S): Polyester
REACTION TYPE: Condensation Polymerisation

REACTION:

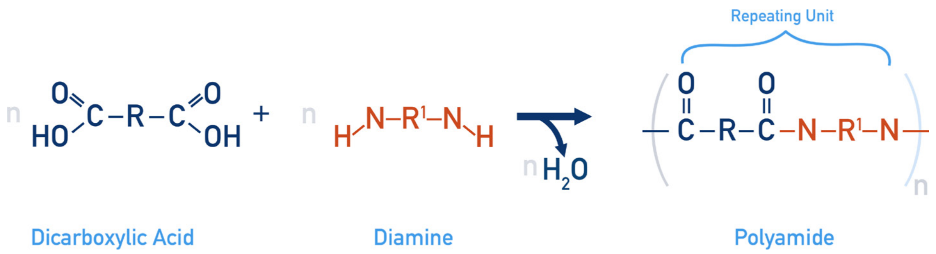


NOTES:
- Polymer formed is a polyester due to ester link between one dicarboxylic acid group and one diol group.
- Condensation polymerisation as water is released when polymer is formed.
- Polyesters are broken apart into dicarboxylic acids and diols by hydrolysis reactions (addition of water) which means they are biodegradable (unlike addition polymers).

Polymers Condensation (from dicarboxylic acids and diamines)

REACTANTS: Dicarboxylic Acid and Diamine
PRODUCT(S): Polyamide
REACTION TYPE: Condensation Polymerisation

REACTION:



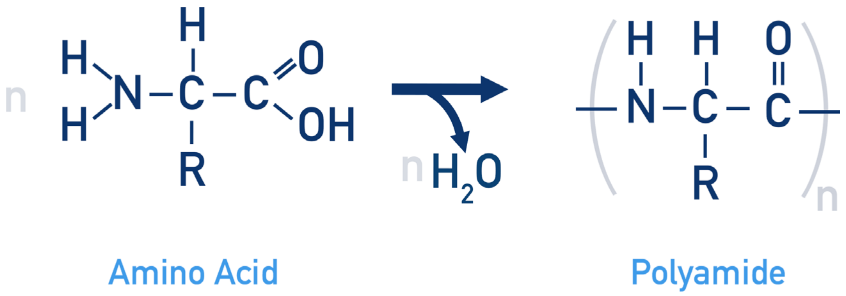
NOTES:

- Polymer formed is a polyamide due to the amide group in the repeating unit (formed when one dicarboxylic acid reacts with a diamine).
- Condensation polymerisation as water is released when polymer is formed.
- Polyesters are broken apart into dicarboxylic acids and diamines by hydrolysis reactions (addition of water), which means they are biodegradable (unlike addition polymers).

Amino Acids Condensation Polymerisation (form proteins)

REACTANTS: Amino Acids
PRODUCT(S): Polyamide (polypeptide)
REACTION TYPE: Condensation Polymerisation

REACTION:



NOTES:

- Polymer formed is a polyamide, often referred to as a polypeptide in biology.
- Polyamide chains formed by amino acids are used in nature to make up proteins.
- DNA is a 'code' used by organisms to give the correct amino acid sequence for a particular protein. A section of DNA that codes for a given protein is called a gene.