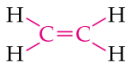
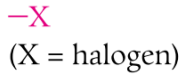
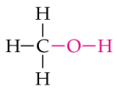
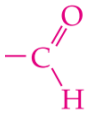
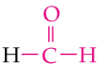
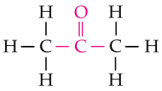
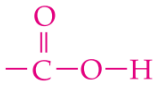
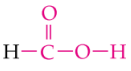
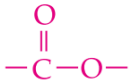
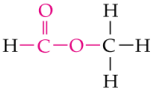
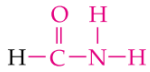
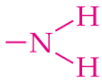
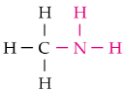
Intensive note (Topic 11: Chemistry of carbon compounds)

Carbon compounds	Functional group	General formula ($R = C_nH_{2n+1}$)	Structural formula of the first member	Boiling point (★ = lowest)	*Solubility in water
Alkanes	---	C_nH_{2n+2}	 **Methane**	★	**Insoluble**
Alkenes		C_nH_{2n}	 **Ethene**	★	**Insoluble**
Haloalkane	 (X = halogen)	RX	 **Halomethane**	★★	**Slightly soluble (1 – 3 C)**
Alcohols		ROH	 **Methanol**	★★★	**Soluble**
Aldehydes		RCHO	 **Methanal**	★★	**Soluble (1 – 3 C)**
Ketones		RCOR’	 **Propanone**	★★	**Soluble (3 – 4 C)**
Carboxylic acid		RCOOH	 **Methanoic acid**	★★★	**Soluble**
Ester		RCOOR’	 **Methyl methanoate**	★★	**Soluble (2 – 3 C)**
Unsubstituted amide		$RCONH_2$	 **Methanamide**	★★★	**Soluble (1 – 3 C)**
Primary amine		RNH_2	 **Methanamine**	★★★	**Soluble**

★: Alkanes and alkenes are essentially non-polar. Molecules are held by weak van der Waals’ forces

★★: Haloalkane, aldehyde, ketone and ester contain polar groups. Strength of van der Waals’ forces between polar molecules are generally stronger than non-polar molecules (e.g. alkanes, alkenes)

★★★: Amide (C=O and -NH_2 can form H bond) > Carboxylic acid (C=O and -OH can form H bond) > Alcohol (Only -OH can form H bond)> Amine (Only -NH_2 can form H bond and N-H is less polar than O-H)

*Water-soluble organic compounds should have short non-polar hydrocarbon chain and groups that can form H bond with water

Examples related to boiling points of carbon compounds

1. Explain why hexanoic acid has a higher boiling point than ethyl butanoate.

   Answer:
   - Molecules of ethyl butanoate are held by weak van der Waals' forces
   - Stronger hydrogen bonds exist between hexanoic acid molecules

2. Explain why butanoic acid has a higher boiling point than butan-1-ol

   Answer:
   - For each butan-1-ol molecule, the −OH group can participate in hydrogen bond formation. For each butanoic acid molecule, both the −C=O and −OH group can participate in hydrogen bond formation.
   - More energy is needed to overcome the extensive hydrogen bonds between butanoic acid molecules than those between butan-1-ol molecules.

3. Explain why hexan-1-ol has a higher boiling point than hexan-1-amine.

   Answer:
   - Nitrogen is less electronegative than oxygen. N–H bond is less polar than O–H bond. Hexan-1-amine molecule is less polar than hexan-1-ol.
   - The hydrogen bonds between hexan-1-amine molecules are weaker than those between hexan-1-ol molecules.

4. Explain why ethanamide has a higher boiling point than ethanoic acid.

   Answer:
   - For each ethanamide molecule, both the −C=O and $-NH_2$ group can participate in hydrogen bond formation. For each ethanoic acid molecule, both the −C=O and −OH group can participate in hydrogen bond formation. Each ethanamide molecule can form 2 hydrogen bonds on average while each ethanoic acid molecule can only form one hydrogen bond on average.
   - More energy is needed to overcome the extensive hydrogen bonds between ethanamide molecules than those between ethanoic acid molecules.

5. Explain why propane-1,2-diol has a higher boiling point than propan-1-ol.

   Answer:
   - Each propan-1-ol molecule can form one hydrogen bond on average while each propane-1,2-diol molecule can form two hydrogen bonds on average.
   - More energy is needed to overcome the extensive hydrogen bonds between propane-1,2-diol molecules than those between propan-1-ol molecules.

Examples related to solubility of carbon compounds

1. Explain why ethane-1,2-diol is soluble in water

   Answer:
   - The –OH groups in it can form hydrogen bonds with water
   - It also has a short non-polar carbon chain.

2. Explain why ethyl ethanoate is a better solvent than water for dissolving benzoic acid (C_6H_5COOH)

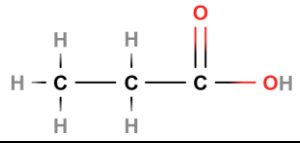
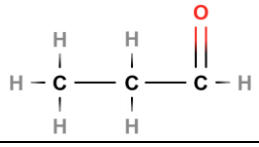
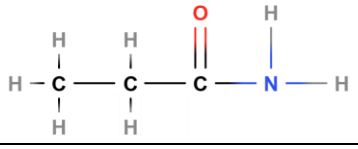
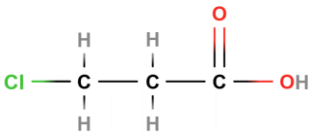
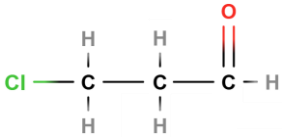
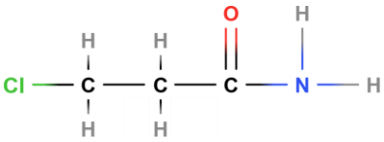
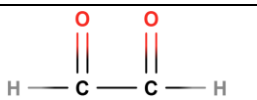
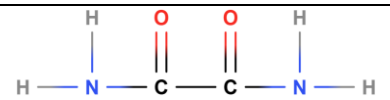
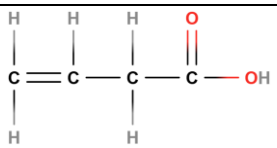
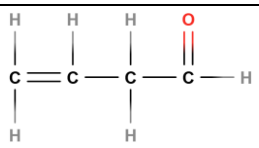
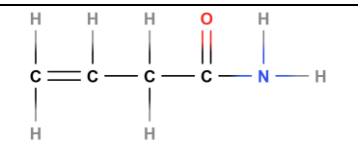
   Answer:
   - Benzoic acid is a non-polar compound which can dissolve in a relatively non-polar organic solvent like ethyl ethanoate. However, water is a very polar solvent.

3. Suggest one reason why lactic acid ($CH_3CH(OH)COOH$) dissolves in ethyl ethanoate but not in hexane.

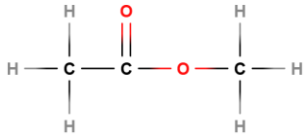
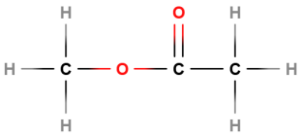
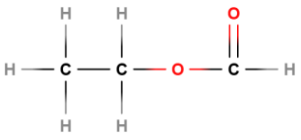
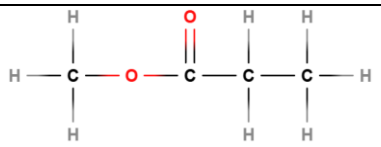
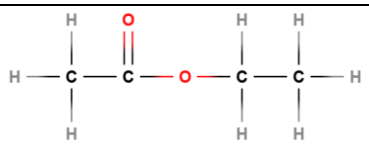
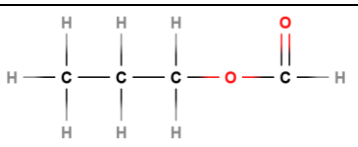
   Answer:
   - Ethyl ethanoate molecules and lactic acid molecules are polar, but hexane molecules are non-polar.

   (OR The intermolecular attraction in ethyl ethanoate and lactic acid is similar while that in hexane is different.)

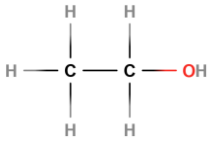
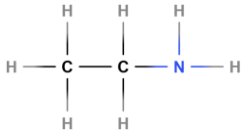
Aldehyde, amide naming

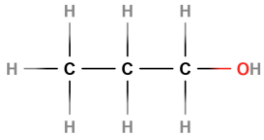
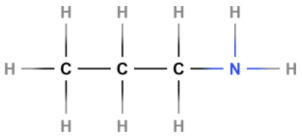
		
Propanoic acid	**Propanal**	**Propanamide**
		
3–chloropropanoic acid	**3-chloropropanal**	3-chloropropanamide
		
Ethanedioic acid	**Ethanedial**	**Ethandiamide**
		
But–3–enoic acid	**But–3–enal**	**But–3–enamide**

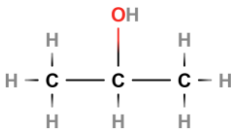
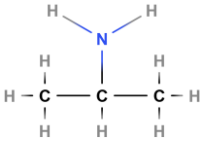
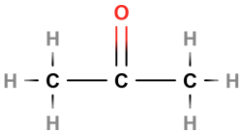
Ester naming

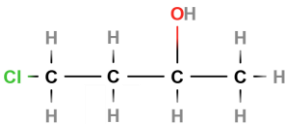
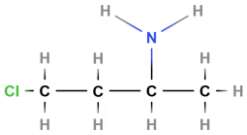
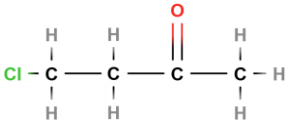
		
Methyl ethanoate	**Methyl ethanoate**	**Ethyl methanoate**
		
Methyl propanoate	**Ethyl ethanoate**	**Propyl methanoate**

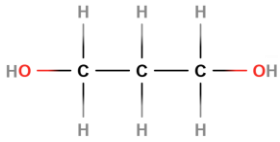
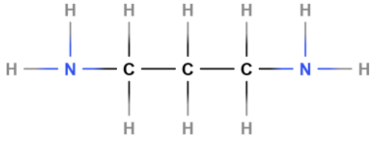
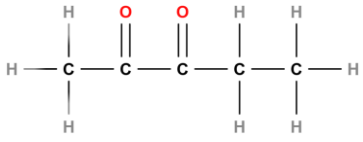
Ketone, amine naming

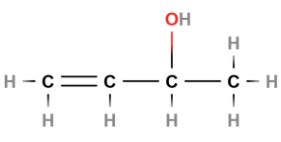
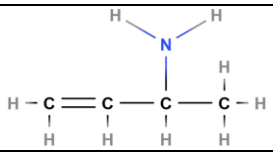
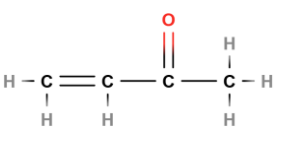
	
Ethanol	**Ethanamine**

	
Propan–1–ol	**Propan–1–amine**

		
Propan–2–ol	**Propan–2–amine**	**Propanone**

		
4–chlorobutan–2–ol	**4–chlorobutan–2–amine**	**4–chlorobutanone**

		
Propane–1,3–diol	**Propane–1,3–diamine**	**Pentane–2,3–dione**

		
But–3–en–2–ol	**But–3–en–2–amine**	**Butenone**

Trivial name of organic compounds

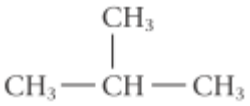
Trivial name	Chloroform	Isopropyl alcohol	Formaldehyde	Acetone	Acetic acid
Systematic name	Trichloromethane	Propan-2-ol	Methanal	Propanone	Ethanoic acid

Isomerism

Isomers are different compounds that have the same molecular formula.
Stereoisomers are isomers in which the atoms are linked in the same order but have different arrangements in space.

Structural isomer 1: Chain isomerism

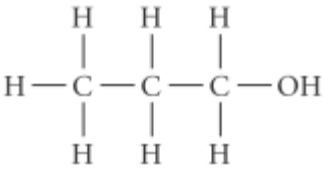
Butane (C_4H_{10})



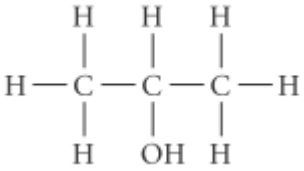
Methylpropane (C_4H_{10})

- Chain isomers differ in their carbon skeletons.
- They have similar chemical properties as they have same functional group.

Structural isomer 2: Position isomerism



Propan-1-ol (C_3H_8O)

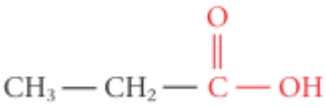


Propan-2-ol (C_3H_8O)

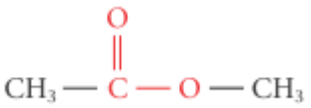
- Position isomers differ in the position of functional group.
- They have similar chemical properties as they have same functional group.

Structural isomer 3: Functional group isomerism

Example 1

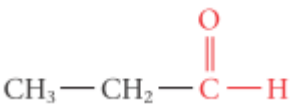


Propanoic acid ($C_3H_6O_2$)

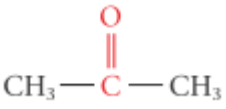


Methyl ethanoate ($C_3H_6O_2$)

Example 2



Propanal (C_3H_6O)

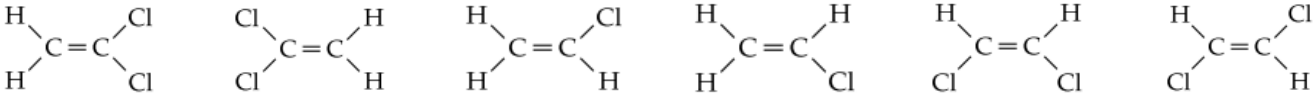


Propanone (C_3H_6O)

- Functional group isomers are structural isomers that have different functional groups.
- They have different chemical properties as they have different functional groups.

Stereoisomer 1: Cis-trans isomerism

- Cis-trans isomers (or geometrical isomers) result from the restricted rotation about the carbon-carbon double bond.
- Cis-trans isomerism occurs if **two different atoms / groups of atoms are attached to each C atom in a C=C bond.**



A **B** **C** **D** **E** **F**

- A and B are identical compounds (Both are 1,1-dichloroethene)
- C and D are identical compounds (Both are chloroethene)
- E and F are cis-trans isomers (E is cis-1,2-dichloroethene, F is trans-1,2-dichloroethene)

Physical properties of cis-trans isomers

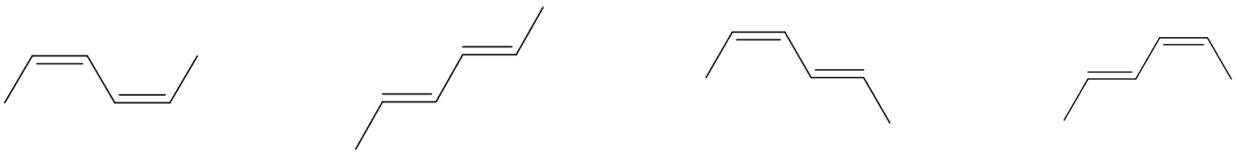
	Boiling point / °C	Melting point / °C	Polarity of molecule	Structure of molecule
cis-1,2-dichloroethene	60.1	–80.0	Polar	Less symmetrical
trans-1,2-dichloroethene	48.7	–49.8	Non-polar	More symmetrical

- Cis-1,2-dichloroethene isomer is polar (as 2 polar C-Cl bonds are on the same sides and their polarities cannot cancel out). The van der Waals' forces between polar cis-1,2-dichloroethene molecules are stronger than those between non-polar trans-1,2-dichloroethene molecules. More energy is needed to separate the cis-1,2-dichloroethene molecules during boiling.

- Trans isomer has a more symmetrical structure. Molecules of trans-1,2-dichloroethene can pack more closely in the solid state. More energy is needed to overcome the van der Waals' forces between them during melting.

Advanced example

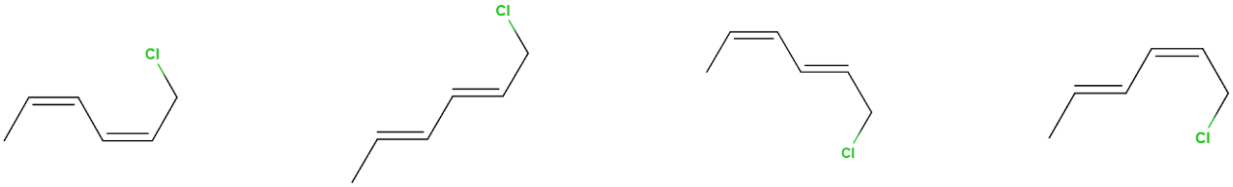
1. How many cis-trans isomer does $CH_3–CH=CH–CH=CH–CH_3$ have?



A. Cis-Cis **B. Trans-Trans** **C. Cis-Trans** **D. Trans-cis**

Note that C and D are identical, $CH_3–CH=CH–CH=CH–CH_3$ has 3 cis-trans isomers

2. How many cis-trans isomer does $CH_3–CH=CH–CH=CH–CH_2Cl$ have?

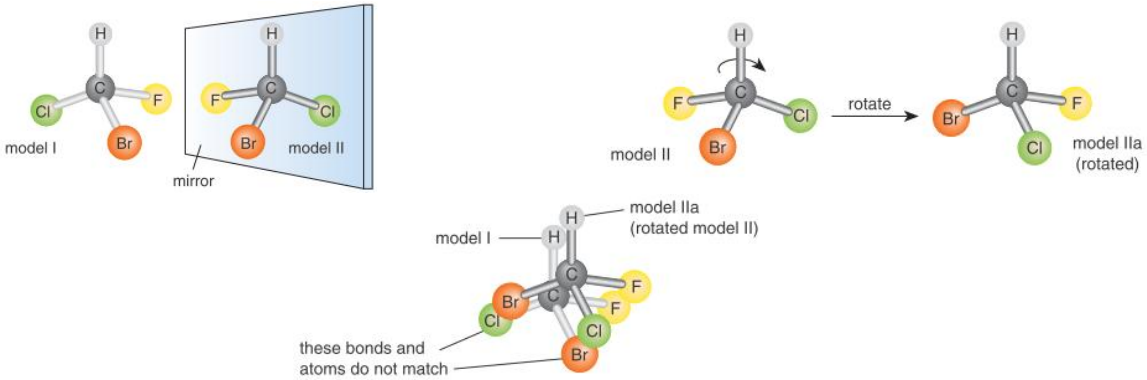


A. Cis-Cis **B. Trans-Trans** **C. Cis-Trans** **D. Trans-cis**

Note that C and D are NOT identical, $CH_3–CH=CH–CH=CH–CH_2Cl$ has 4 cis-trans isomers

Stereoisomer 2: Enantiomerism

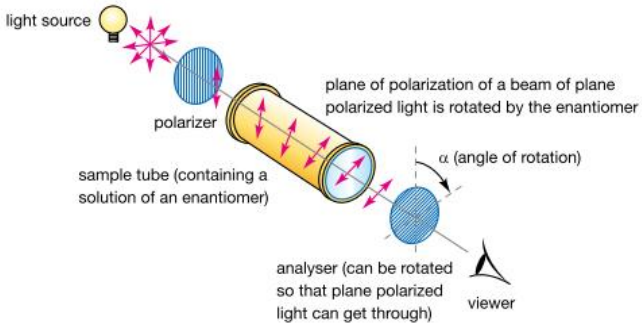
- Chiral carbon: A carbon bonded to 4 different atoms or groups of atoms
- A chiral molecule and its mirror image are called a pair of enantiomers (or optical isomer). They are non-superimposable



Properties of enantiomers

- They have same boiling points, melting points and densities.

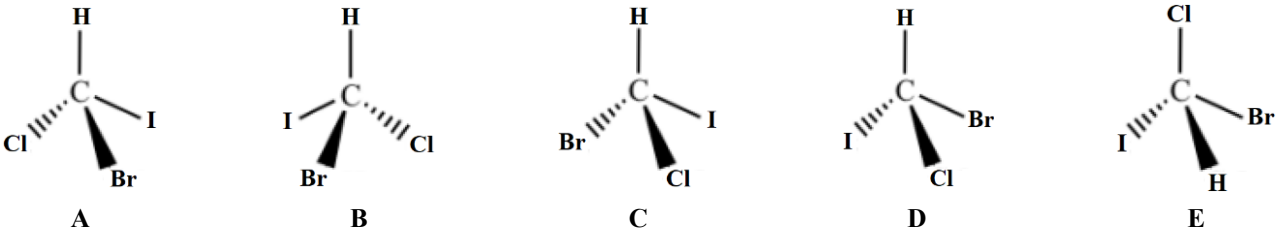
  (As the intermolecular forces are identical for a pair of enantiomers)
- Enantiomers are optically active. They can rotate the plane of plane polarised light. (Instrument: Polarimeter)



- However, they have different optical activity.

  (Two enantiomers can rotate the plane of plane-polarised light by the same extent but in opposite direction)

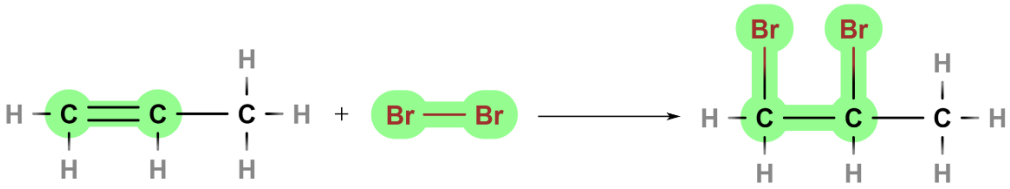
Advanced example



- **A** and **B** are enantiomers [**A** and **B** are chiral, and they are mirror images]
- **A** and **C** are enantiomers [Interchange Cl and Br in **C** (total 1 interchange), **A** can be obtained]
- **A** and **D** are identical compounds [Interchange Cl and Br, then Cl and I in **D** (total 2 interchanges), **A** can be obtained]
- **A** and **E** are enantiomers [Interchange Cl and H, then Cl and I, then I and Br in **E** (total 3 interchanges), **A** can be obtained]

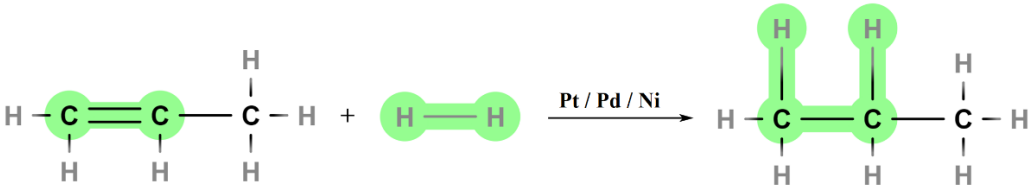
Typical reactions of various functional groups

1. Addition of alkene with halogen (Cl_2, Br_2)



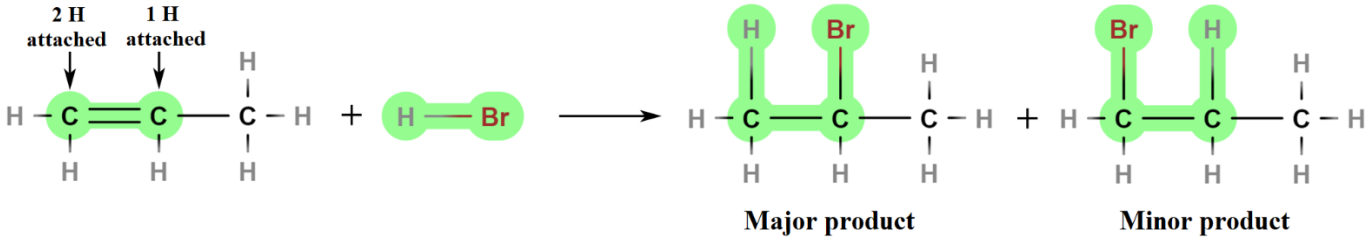
- Observation for the reaction between Cl_2 (in organic solvent) and alkene: Solution turns from pale green to colorless rapidly
- Observation for the reaction between Br_2 (in organic solvent) and alkene: Solution turns from orange to colorless rapidly

2. Addition of alkene with hydrogen



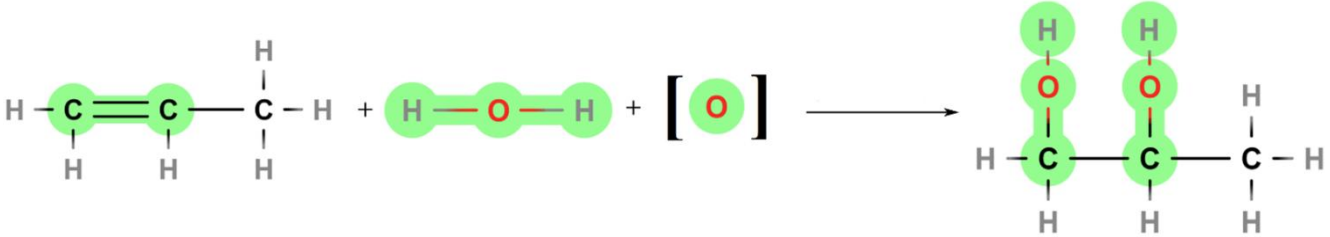
- Platinum (Pt), palladium (Pd) or nickel (Ni) is often used as a catalyst to speed up the reaction
- This reaction is also known as hydrogenation. Alkene is reduced (as H atoms are added) in this reaction

3. Addition of alkene with hydrogen halide (HCl, HBr, HI)



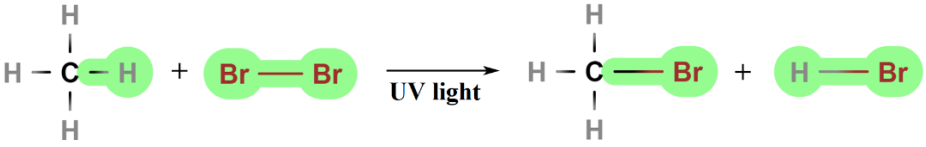
- Hydrohalogenation of some asymmetrical alkenes (such as propene) may give two different products.
- Markovnikov's rule: The hydrogen atom in HX is added to the carbon atom of the carbon-carbon double bond that already has the greater number of hydrogen atoms.
- In the above reaction, 2-bromopropane is the major product as predicted by Markovnikov's rule.

4. Addition of alkene with cold acidified $KMnO_4$



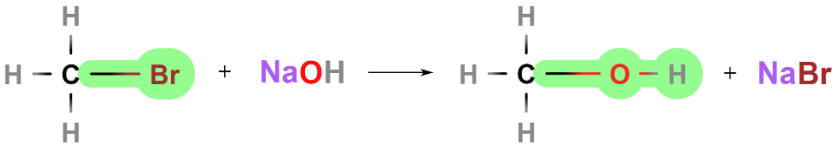
- Observation: Purple solution turns colorless
- Cold, acidified $KMnO_4$ should be used. Otherwise, further oxidation of alcohol may occur
- Acidified $K_2Cr_2O_7$(aq) CANNOT be used in this reaction.

5. Substitution of alkane (Cl_2, Br_2)



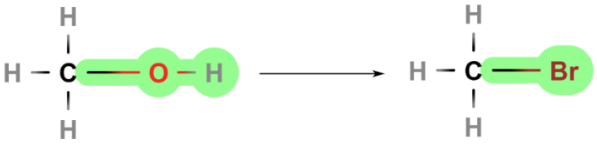
- Observation for the reaction between Cl_2 (in organic solvent) and alkane: Solution turns from pale green to colorless slowly
- Observation for the reaction between Br_2 (in organic solvent) and alkane: Solution turns from orange to colorless slowly
- For detailed mechanism, please refer to topic 5 (fossil fuels and carbon compounds)

6. Substitution of haloalkane (NaOH, KOH)



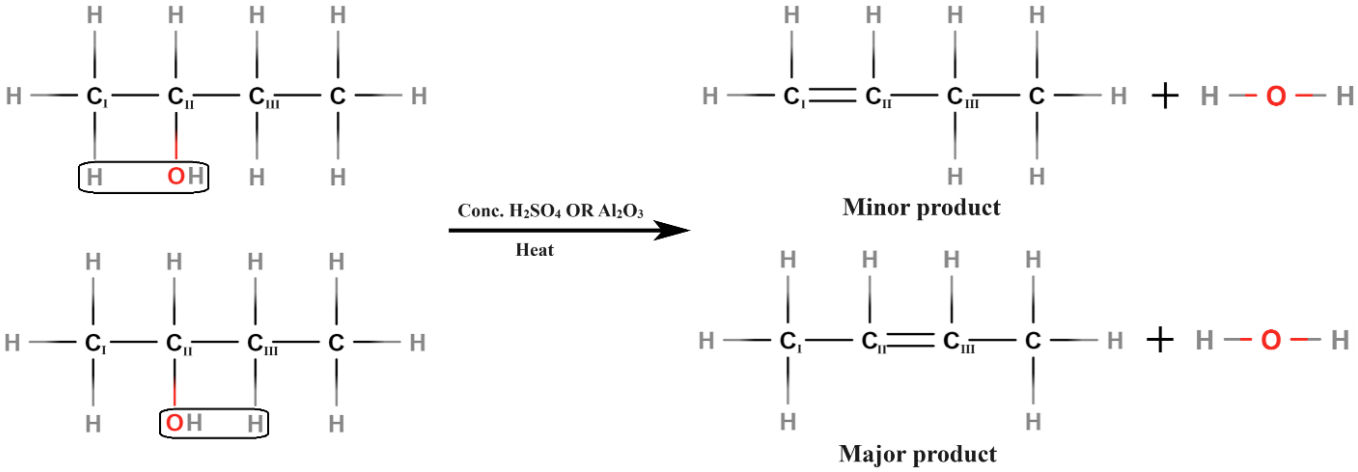
- Heating is required in this reaction. As the boiling point of haloalkanes are low, heating is performed under reflux.

7. Substitution of alcohol



- Reagent and condition 1: HX(g) OR concentrated HX(aq) (H_2O is the by-product formed)
- Reagent and condition 2: PX_3, heat under reflux (H_3PO_3 is the by-product formed)

8. Dehydration of alcohol

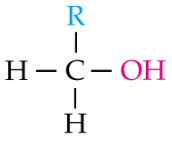
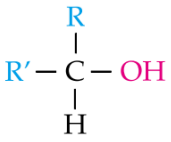
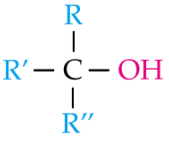


- Dehydration of some secondary or tertiary alcohol may give two or more products.
- But-2-ene formed can also exhibit cis-trans isomerism.
- In the above reaction: (Not expected in HKDSE syllabus)

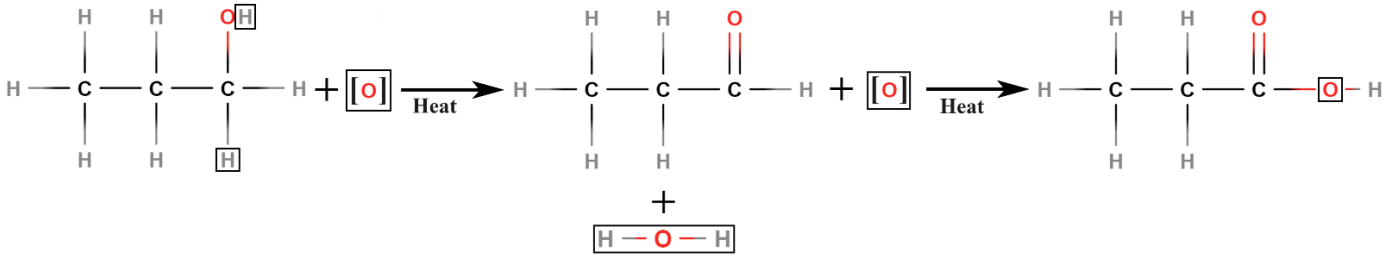
  But-1-ene is a minor product (-OH from C_{II} and H from C_I are removed, a carbon with more H attached)

  But-2-ene is a major product (-OH from C_{II} and H from C_{II} are removed, a carbon with less H attached)

Classification of alcohol

Class of alcohol	1°	2°	3°
Structural characteristic **R = alkyl group (C_nH_{2n+1})**			

9. Oxidation of 1° alcohol



- Observation for the reaction between $K_2Cr_2O_7$ / H^+ and 1° alcohol: Orange solution ($Cr_2O_7^{2-}$(aq)) turns green (Cr^{3+})
- Observation for the reaction between $KMnO_4$ / H^+ and 1° alcohol: Purple solution (MnO_4^-(aq)) turns colourless (Mn^{2+})
- Primary alcohol will be first oxidized to aldehyde and then further oxidized to carboxylic acid.

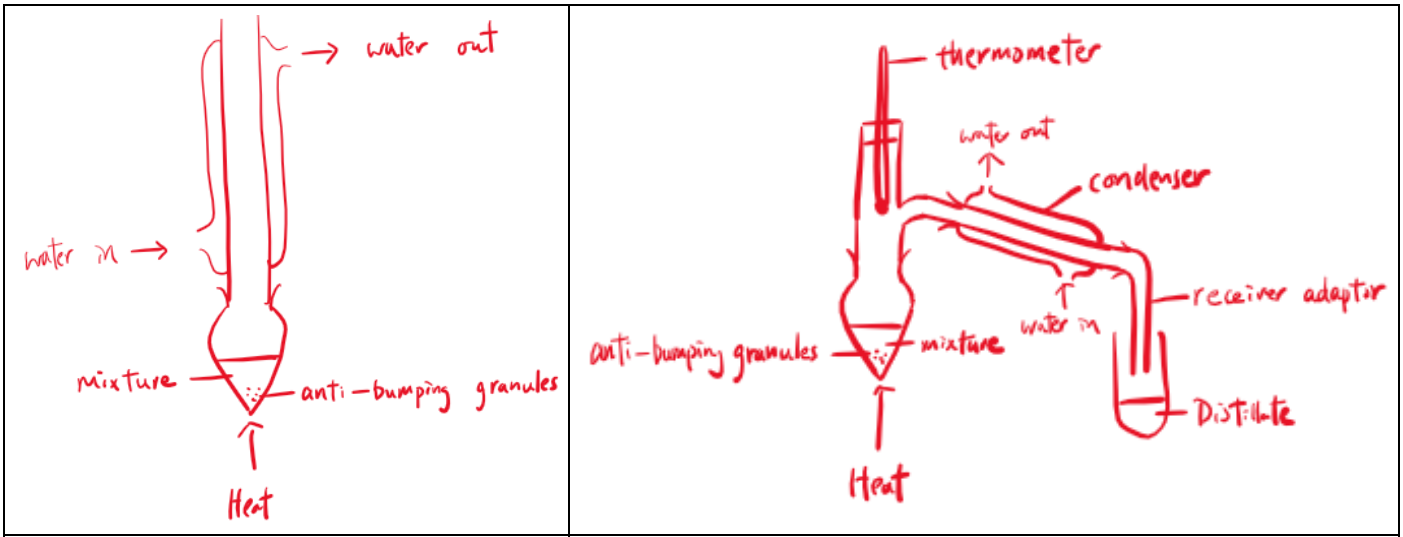
  To prepare carboxylic acid: 1° alcohol and **acidified $K_2Cr_2O_7$ (or $KMnO_4$)** is **heated under reflux**

  To prepare aldehyde: 1° alcohol and **acidified $K_2Cr_2O_7$** is **heated, then distilled off the aldehyde**

  (The mixture should be warmed to a temperature that is above the boiling point of aldehyde but below that of alcohol)

  ($KMnO_4$ is a very strong oxidizing agent. It oxidizes 1° alcohol to carboxylic acid directly)

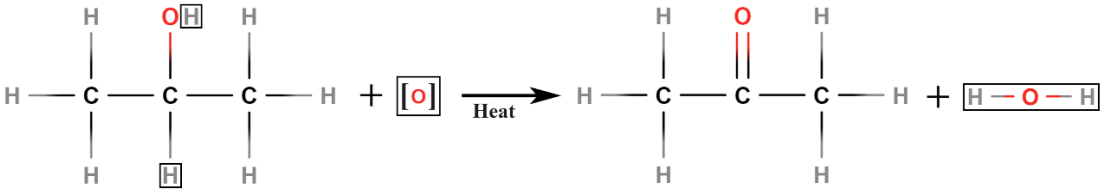
Experimental set-up of reflux and distillation



Reflux	**Distillation**

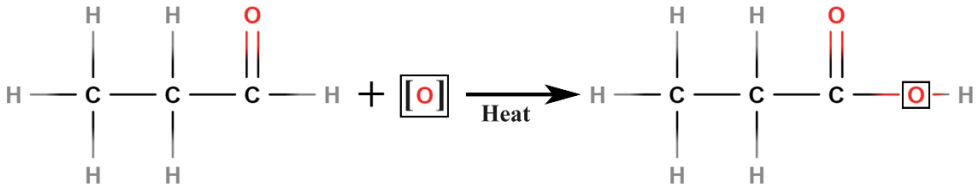
- For heating flammable liquids, naked flame (using Bunsen burner) should be avoided. Water / oil / sand bath can be used.
- Reflux can reduce the loss of volatile organic substances by evaporation during heating

10. Oxidation of 2° alcohol



- Observation for the reaction between $K_2Cr_2O_7$ / H^+ and 2° alcohol: Orange solution ($Cr_2O_7^{2-}$(aq)) turns green (Cr^{3+})
- Observation for the reaction between $KMnO_4$ / H^+ and 2° alcohol: Purple solution (MnO_4^-(aq)) turns colourless (Mn^{2+})
- Ketone (and 3° alcohol) is resistant to further oxidation.

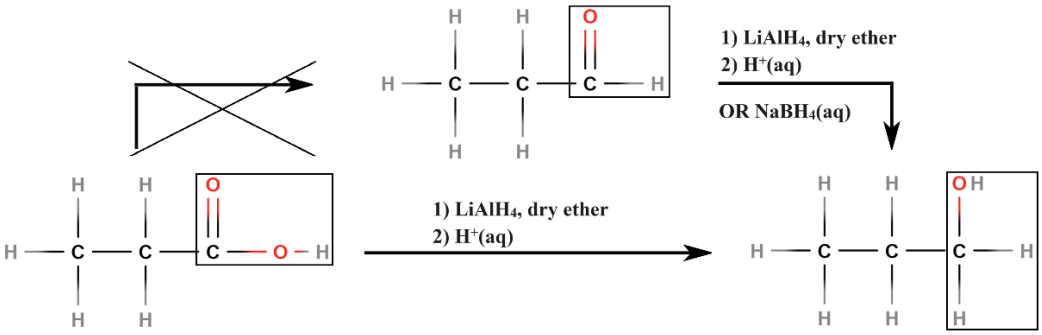
11. Oxidation of aldehyde



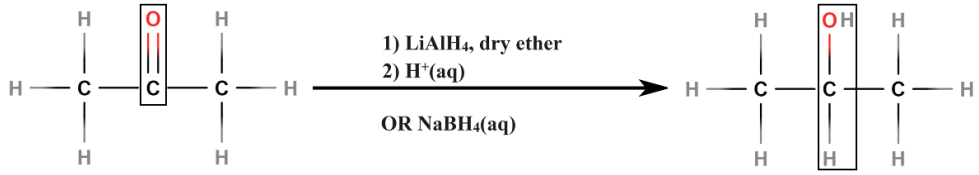
- Observation for the reaction between $K_2Cr_2O_7$ / H^+ and aldehyde: Orange solution ($Cr_2O_7^{2-}$(aq)) turns green (Cr^{3+})
- Observation for the reaction between $KMnO_4$ / H^+ and aldehyde: Purple solution (MnO_4^-(aq)) turns colourless (Mn^{2+})
- Ketone is resistant to further oxidation

12. Reduction of aldehyde, ketone and carboxylic acid

Reduction of aldehyde / carboxylic to 1° alcohol



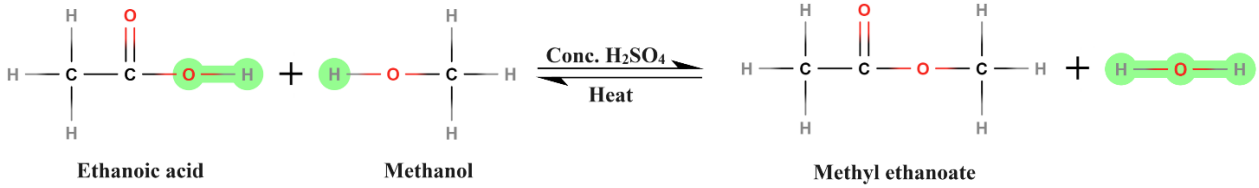
Reduction of ketone to 2° alcohol



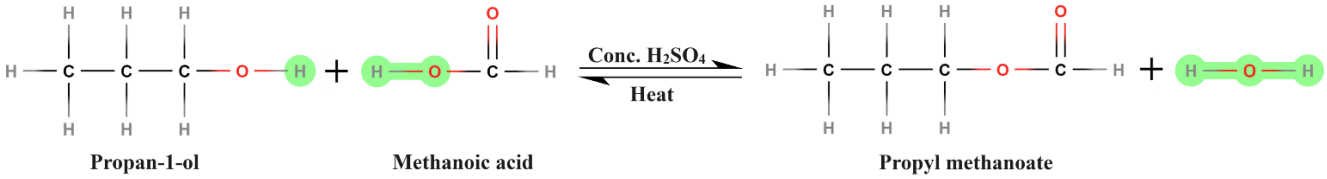
- $LiAlH_4$ is a strong reducing agent. It can reduce aldehyde / carboxylic acid to 1° alcohol and reduce ketone to 2° alcohol
- $NaBH_4$ is a weaker reducing agent. It can only reduce aldehyde to 1° alcohol and reduce ketone to 2° alcohol
- Carboxylic acid CANNOT be reduced to aldehyde. It will be reduced to 1° alcohol directly.

13. Esterification (Condensation)

Example 1



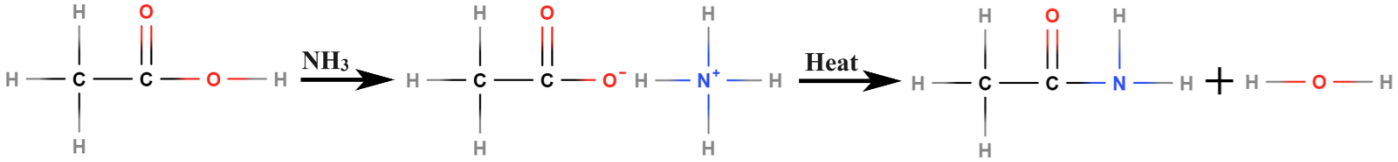
Example 2



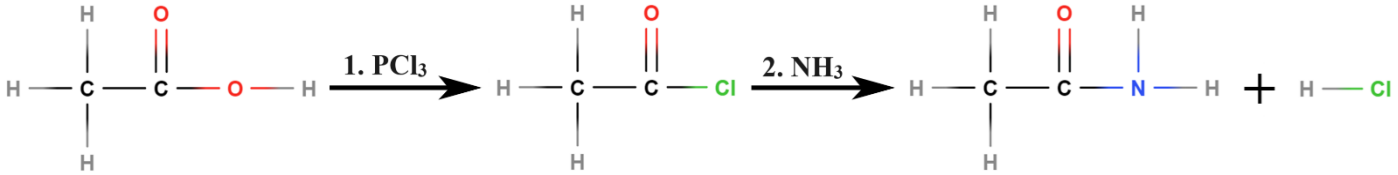
- Observation: Fruity smell ester is produced.
- Esterification is a reversible reaction
- The reaction mixture is heated under reflux in the presence of concentrated H_2SO_4 as catalyst to increase the rate of reaction
- In general, esters with 4 or more carbon atoms are immiscible and less dense than water.

14. Amide formation (Condensation)

Formation of amide from carboxylic acid by heating with NH_3



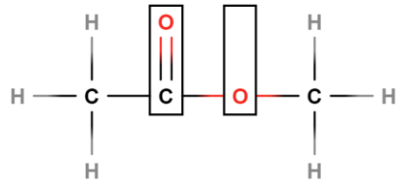
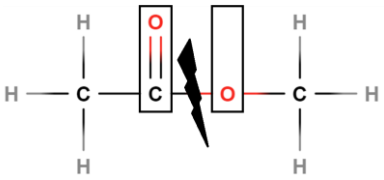
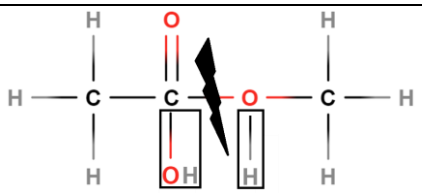
Formation of amide from carboxylic acid using PCl_3 and NH_3



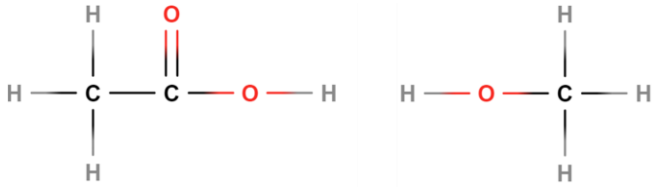
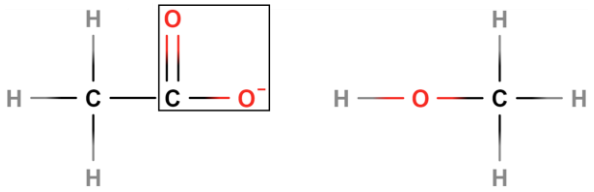
- Ethanamide formed is an unsubstituted amide (N atom in amide group is attached to 2 H atoms only)

15. Hydrolysis of ester

Steps for hydrolysis of ester

Step 1	Step 2	Step 3
		
Identify: 1) C=O 2) O atom bonded to C=O	The bond between O and C=O is cleaved	1) –OH is added to C in C=O 2) –H is added to O boned to C=O

Step 4

Hydrolysis using acid	Hydrolysis using alkali
	

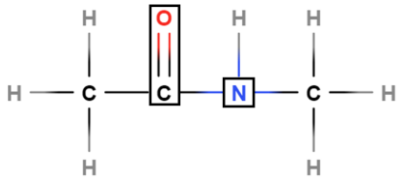
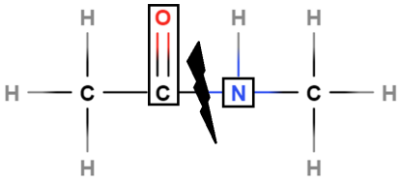
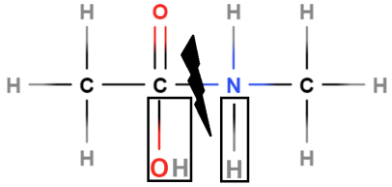
For the products obtained in step 3, check whether neutralization reaction occurs

(–COOH is acidic, it reacts with NaOH to become $–COO^-Na^+$. –OH is neutral, it does not react with acid or alkali)

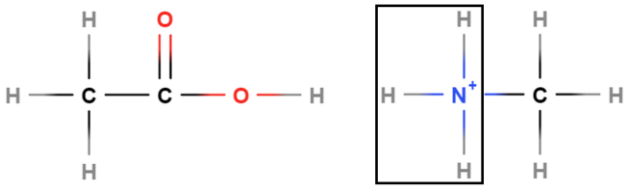
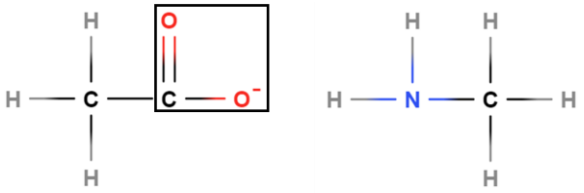
- Acid hydrolysis is a reversible reaction
- $R–COO^-Na^+$ can be converted to R–COOH again by adding dilute acid

16. Hydrolysis of amide

Steps for hydrolysis of amide

Step 1	Step 2	Step 3
		
Identify: 1) C=O 2) N atom bonded to C=O	The bond between N and C=O is cleaved	1) –OH is added to C in C=O 2) –H is added to N boned to C=O

Step 4

Hydrolysis using acid	Hydrolysis using alkali
	

For the products obtained in step 3, check whether neutralization reaction occurs

(–COOH is acidic, it reacts with NaOH to become $–COO^-Na^+$. $–NR_2$ is basic, it reacts with acid to become $–NR_2H^+$)

Reactions		Remarks
1. Addition of alkene with halogen (Cl_2, Br_2) $CH_2=CHCH_3 + Br_2$ ➔ $CH_2BrCHBrCH_3$		Br_2 should be dissolved in organic solvent as Br_2 is toxic and volatile
Reagent: Br_2 / Cl_2 (in organic solvent)		
2. Addition of alkene with hydrogen $CH_2=CHCH_3 + H_2$ ➔ $CH_3CH_2CH_3$		This reaction is also known as hydrogenation
Reagent: H_2 using Pt / Pd / Ni as catalyst		
3. Addition of alkene with hydrogen halide (HCl, HBr, HI) $CH_2=CHCH_3 + HBr$ ➔ $CH_3CHBrCH_3$ (Major product)		$CH_2BrCH_2CH_3$ is the minor product produced in this reaction
Reagent: HCl / HBr / HI		
4. Addition of alkene with cold acidified $KMnO_4$ $CH_2=CHCH_3 + [O] + H_2O$ ➔ $CH_2(OH)CH(OH)CH_3$		This is also an oxidation reaction
Reagent: Cold, dilute acidified $KMnO_4$(aq)		
5. Substitution of alkane (Cl_2, Br_2) $CH_4 + Br_2$ ➔ $CH_3Br + HBr$		CH_2Br_2, $CHBr_3$ and CBr_4 may also be produced. To increase the yield of CH_3Br, excess CH_4 is used
Reagent: Cl_2 / Br_2, UV light		
6. Substitution of haloalkane (NaOH, KOH) $CH_3Br + NaOH$ ➔ $CH_3OH + NaBr$		
Reagent: NaOH(aq) / KOH(aq), heat		
7. Substitution of alcohol $CH_3OH + HCl$ ➔ $CH_3Cl + H_2O$		PCl_3 can also be used in this reaction (H_3PO_3 will be the by-product)
Reagent 1: HCl (in $ZnCl_2$) / HBr	**Reagent 2: PCl_3 / PBr_3, heat**	
8. Dehydration of alcohol $CH_3CH(OH)CH_2CH_3$ ➔ $CH_3CH=CHCH_3$ (Major product)		$CH_2=CHCH_2CH_3$ is the minor product produced in this reaction
Reagent 1: Al_2O_3, heat	**Reagent 2: Conc. H_2SO_4, heat**	
9. Oxidation of 1° alcohol $CH_3CH_2OH + [O]$ ➔ $CH_3CHO + H_2O$		Heat, distill off: Aldehyde will be obtained. Heat under reflux: Carboxylic acid will be obtained
Reagent: Acidified $K_2Cr_2O_7$(aq), heat distil off		
$CH_3CH_2OH + 2[O]$ ➔ $CH_3COOH + H_2O$		
Reagent: Acidified $K_2Cr_2O_7$(aq) / $KMnO_4$(aq), heat under reflux		
10. Oxidation of 2° alcohol $CH_3CH(OH)CH_3 + [O]$ ➔ $CH_3COCH_3 + H_2O$		Ketone formed and 3° alcohol are resistant to oxidation by $K_2Cr_2O_7$(aq)
Reagent: Acidified $K_2Cr_2O_7$(aq) / $KMnO_4$(aq), heat under reflux		
11. Oxidation of aldehyde $CH_3CHO + [O]$ ➔ CH_3COOH		
Reagent: Acidified $K_2Cr_2O_7$(aq) / $KMnO_4$(aq), heat under reflux		

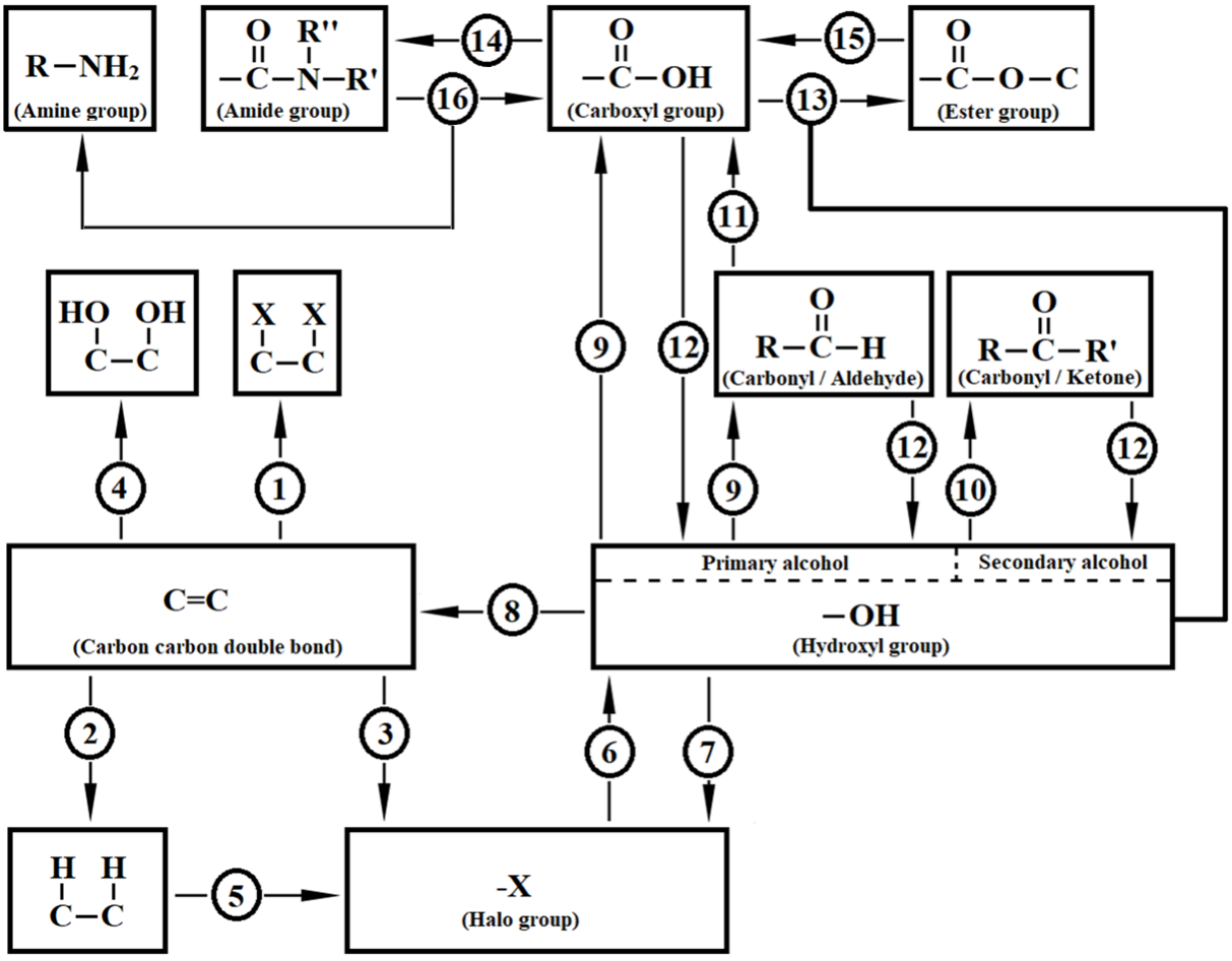
12. Reduction of aldehyde, ketone and carboxylic acid CH_3COOH ➔ CH_3CH_2OH	
Reagent: 1) $LiAlH_4$, dry ether, **2) H^+(aq)**	
CH_3CHO ➔ CH_3CH_2OH CH_3COCH_3 ➔ $CH_3CH(OH)CH_3$	
Reagent 1: 1) $LiAlH_4$, dry ether, **2) H^+(aq)** / **Reagent 2: $NaBH_4$(aq)**	
13. Esterification (Condensation) $CH_3OH + CH_3COOH \rightleftharpoons CH_3COOCH_3 + H_2O$	H_2SO_4(l) is a catalyst and dehydrating agent
Reagent: Conc. H_2SO_4, heat under reflux	
14. Amide formation (Condensation) CH_3COOH ➔ CH_3COCl ➔ CH_3CONH_2	
Reagent 1: 1) PCl_3 **2) NH_3**	
CH_3COOH ➔ $CH_3COO^-NH_4^+$ ➔ $CH_3CONH_2 + H_2O$	
Reagent 2: NH_3, heat	

15A. Acid hydrolysis of ester
$CH_3COOCH_3 + H_2O \rightleftharpoons CH_3OH + CH_3COOH$
	For (A), it is the reverse of esterification
	
	For (B), carboxylate will be obtained. $CH_3COO^-Na^+$ can be converted to CH_3COOH again by adding H^+(aq)

Reagent: Dilute H_2SO_4(aq), heat	
15B. Alkaline hydrolysis of ester CH_3COOCH_3 + NaOH ➔ $CH_3OH + CH_3COO^-Na^+$	
Reagent: NaOH(aq), heat	
16A. Acid hydrolysis of amide $CH_3CONR_2 + H_2O$ ➔ $CH_3COOH + H_2NR_2^+$	R can be H or alkyl groups For (B), carboxylate will be obtained. $CH_3COO^-Na^+$ can be converted to CH_3COOH again by adding H^+(aq) (In this case, HNR_2 will become $H_2NR_2^+$)
Reagent: Dilute H_2SO_4(aq), heat	
16B. Alkaline hydrolysis of amide CH_3CONR_2 + NaOH ➔ $CH_3COO^-Na^+ + HNR_2$	
Reagent: NaOH(aq), heat	
17. Typical reactions of acids (A) Reaction with metal oxide / metal hydroxide CH_3COOH + NaOH ➔ $CH_3COO^-Na^+ + H_2O$ (B) Reaction with carbonate / hydrogencarboante $2CH_3COOH + Na_2CO_3$ ➔ $2CH_3COO^-Na^+ + H_2O + CO_2$ (C) Reaction with metal $2CH_3COOH + Mg$ ➔ $Mg(CH_3COO)_2 + H_2$	The carboxylic acid used must be in aqueous state. In aqueous state, carboxylic acid can ionize in water to give H^+(aq) which is responsible for the properties of acid.

Functional group	Test	Equation
C=C	Add Br_2 (dissolved in organic solvent). **Positive result: Orange solution turns to colorless**	$CH_2=CHCH_3 + Br_2 \rightarrow CH_2BrCHBrCH_3$
	Add acidified $KMnO_4$(aq). **Positive result: Purple solution turns to colorless**	$CH_2=CHCH_3 + H_2O + [O] \rightarrow CH_2(OH)CH(OH)CH_3$
Hydroxyl (1°, 2° -OH) Aldehyde (-CHO)	Add acidified $K_2Cr_2O_7$(aq) **Positive result: Orange solution turns green** Add acidified $KMnO_4$(aq) **Positive result: Purple solution turns colorless**	$CH_3CH_2OH + [O] \rightarrow CH_3CHO + H_2O$ $CH_3CHO + [O] \rightarrow CH_3COOH$
		$CH_3CH(OH)CH_3 + [O] \rightarrow CH_3COCH_3 + H_2O$
-OH (1°, 2°,3°)	Heat with CH_3COOH in the presence of H_2SO_4(l) **Positive result: Fruity smell ester forms**	$CH_3-\overset{O}{\overset{\|}{C}}-OH + CH_3CH_2-OH \underset{\text{heat}}{\overset{\text{conc. } H_2SO_4}{\rightleftharpoons}} CH_3-\overset{O}{\overset{\|}{C}}-O-CH_2CH_3 + H_2O$
Carboxyl group (-COOH)	Add Na_2CO_3(aq) **Positive result: colorless gas forms**	$2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + CO_2 + H_2O$

Interconversion table

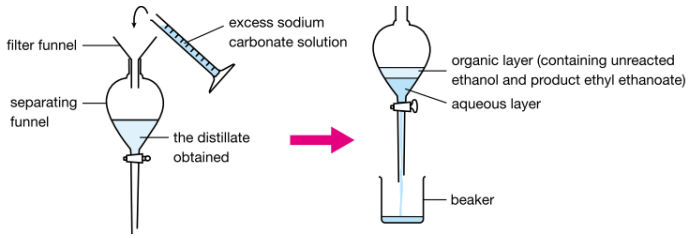


Laboratory preparation and purification of ethanoic acid

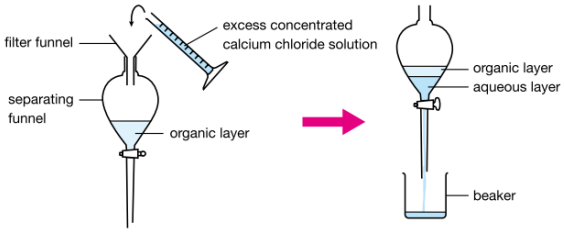
1. CH_3COOH is prepared by heating CH_3CH_2OH with acidified $K_2Cr_2O_7$(aq) under reflux
2. CH_3COOH is separated from the reaction mixture by distillation. (Liquid that boils between 110℃ to 114℃ is collected)
3. The aqueous solution is redistilled using fractional distillation so that CH_3COOH with higher purity can be collected.

Laboratory preparation and purification of ethyl ethanoate

1. $CH_3COOCH_2CH_3$ is prepared by heating a mixture of CH_3COOH and CH_3CH_2OH under reflux in the presence of concentrated H_2SO_4 as catalyst
2. The reaction mixture is distilled. The distillate collected mainly contains CH_3OH, CH_3COOH and $CH_3COOCH_2CH_3$
3. The distillate contains acid impurities (CH_3COOH and H_2SO_4). The mixture is treated with Na_2CO_3(aq) in a separating funnel. The lower aqueous layer is discarded and the upper organic layer (contains $CH_3COOCH_2CH_3$ and unreacted CH_3CH_2OH) is collected.
4. Concentrated $CaCl_2$(aq) is added to the organic layer collected to remove unreacted CH_3CH_2OH. $CH_3COOCH_2CH_3$ remains in the organic layer and the aqueous layer is discarded.



Step 3



Step 4

5. Anhydrous $CaCl_2$(s) is added to the organic layer. The anhydrous $CaCl_2$(s) is a drying agent that removes remaining traces of water from the organic layer. The organic layer is then decanted into a pear-shaped flask.
6. The decanted organic layer is redistilled and the liquid that boils between 75°C and 79°C is collected as distillate. The distillate is ethyl ethanoate.

Percentage yield calculation

Example

In an experiment to prepare X, 10.0 cm^3 of ethanol is heated with 20.0 cm^3 of propanoic acid in the presence of catalyst. Upon separation and purification, 8.31 g of **X** is obtained. Calculate the percentage yield of **X**.

	Ethanol	**Propanoic acid**
Density	0.789	0.988
Relative molecular mass	46	74

Answer: Mole of ethanol = (10 x 0.789) / 46 = 0.17152

0.17152 mole ethanol requires 0.17152 mole propanoic acid for complete reaction.

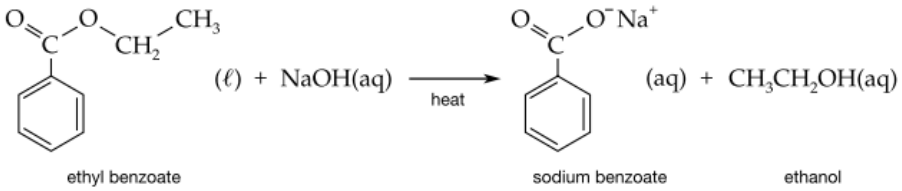
Mole of propanoic acid = (20 x 0.988) / 74 = 0.267 > 0.17152 (ethanol is limiting)

Theoretical mass of X = 0.17152 x 102 = 17.5 g

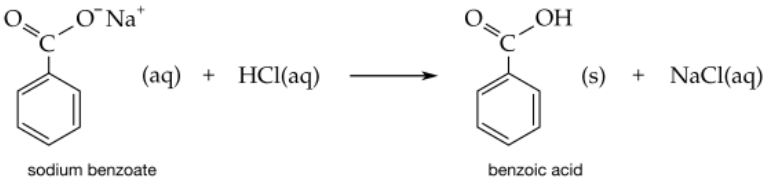
Percentage yield = 8.31 / 17.5 = 47.5%

Laboratory preparation and purification of benzoic acid

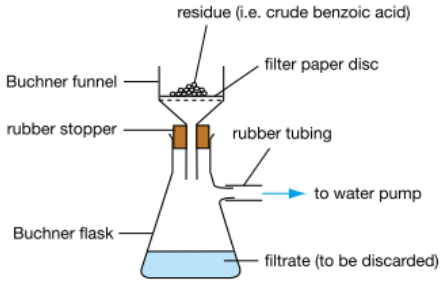
1. Excess NaOH(aq) is heated under reflux with ethyl benzoate



2. The mixture is cooled in an ice-water bath. Concentrated HCl(aq) is added to the reaction mixture so that sodium benzoate is converted to benzoic acid. White solid benzoic acid forms (as it is slightly soluble in water)

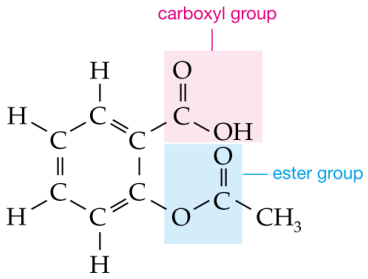


3. The crude benzoic acid solid is separated from the product mixture by filtration under reduced pressure (suction filtration)



4. Pure benzoic acid can be obtained from the crude benzoic acid by recrystallization:
   - Dissolve the crude benzoic acid in a minimum volume of hot distilled water.
   - Filter the solution to remove insoluble impurities
   - Cool the filtrate at room temperature and then in an ice-water bath.
   - Crystals of benzoic acid slowly form and they are collected by suction filtration

Aspirin (Acetylsalicylic acid)



Medical application of acetylsalicylic acid:

- Relieve pains
- Reduce fever
- Anti-inflammatory
- Prevent heart attack

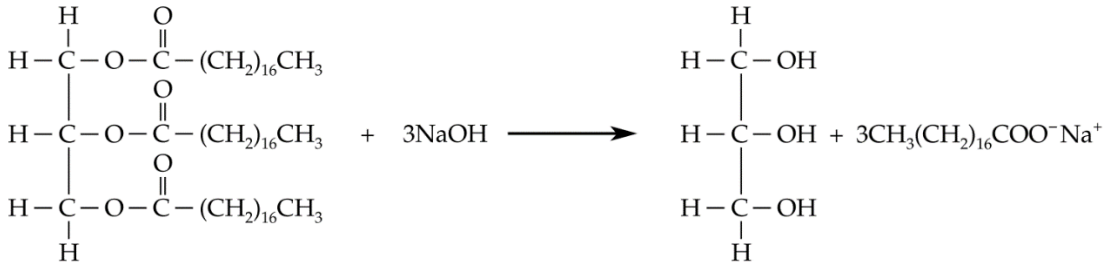
However, it also induces stomach lining bleeding and slow blood clotting

Soaps and soapless detergents

	Soap (soapy detergent)	Soapless detergent
Raw materials	Animal fats / vegetable oil	Petroleum
Ionic head	$-COO^-$	$-SO_3^-$ or $-OSO_3^-$
Example	$CH_3(CH_2)_{16}COO^-Na^+$	$CH_3(CH_2)_{11}$–C$_6$H$_4$–$SO_3^-Na^+$

Laboratory preparation of soap

Soaps (or soapy detergents) can be made by saponification (alkaline hydrolysis) of fats and oils. $CH_3(CH_2)_{16}COO^-Na^+$ is soap.



Glyceryl tristearate (a triglyceride) | Glycerol (Propane-1,2,3-triol) | Sodium stearate (A soap)

Steps for preparation of soap:

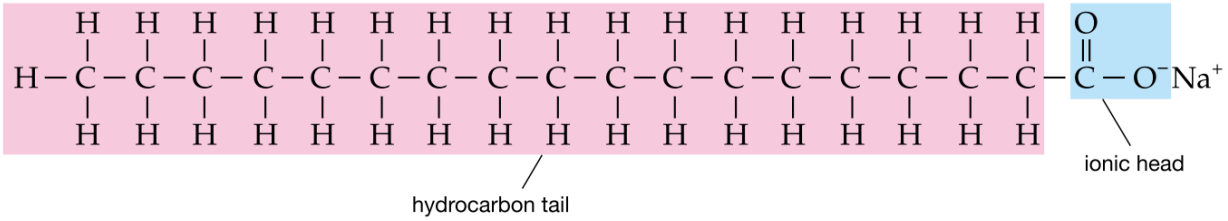
Step 1. A mixture of vegetable oil and concentrated NaOH(aq) is heated gently with stirring for 15 minutes

Step 2. Saturated NaCl(aq) is added to the mixture obtained in Step 1 to 'salt out' the dissolved soap

Step 3. Filter the white creamy solid (soap). Wash the solid with distilled water and dry them with filter paper

Cleansing action of soap

Consider the structure of sodium stearate:



Sodium stearate is a **wetting agent**. It can reduce the surface tension of water.

- Sodium stearate can weaken the strong intermolecular forces between molecules

Sodium stearate is also an **emulsifying agent**.

- The hydrophilic ionic head [$-COO^-$)] of sodium stearate dissolves in water
- The hydrophobic hydrocarbon tail [$-(CH_2)_{16}CH_3$] of sodium stearate dissolves in oil
- Water molecules attract the hydrophilic heads of detergent anions, lifting up the grease from the surface into water.
- By stirring, grease is split up into tiny droplets which carry negative charges. Repulsion of the negatively charged droplets prevents them from joining together.

Note: The hydrocarbon tail cannot be too short (or it would be insoluble in oil) or too long (or it would be insoluble in water).

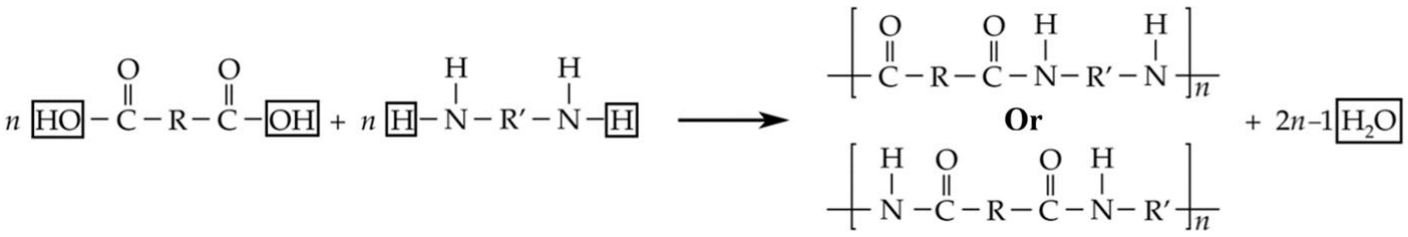
Condensation polymer

Condensation polymerization:	Monomer molecules join together repeatedly to form polymer molecules with the elimination of small molecules (such as H_2O or HCl)

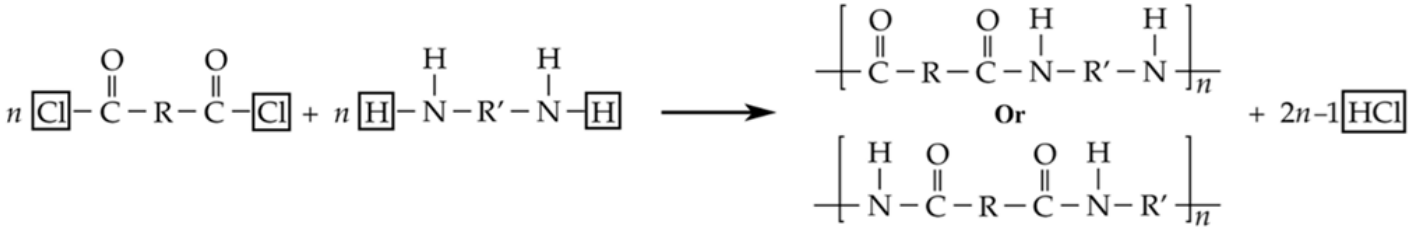
- Monomers should be bifunctional (with 2 functional groups)

A. Formation of polyamide (Nylon)

General equation for the formation of nylon from dioic acid + diamine:



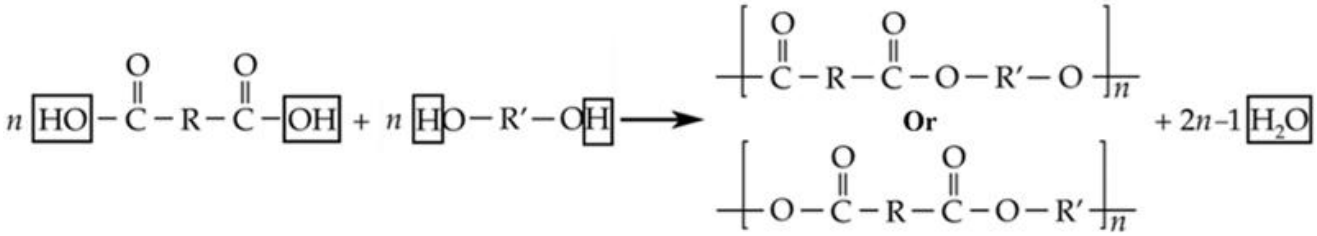
General equation for the formation of nylon from dioyl dichloride+ diamine:



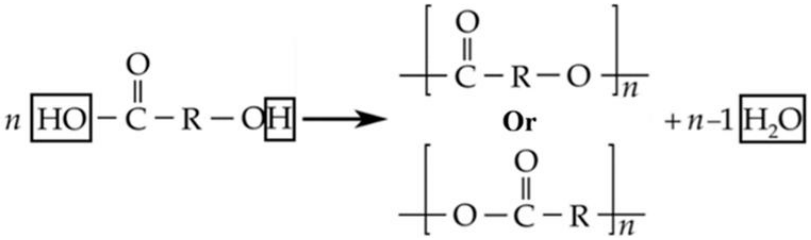
- For nylon 6.6, the first 6 denotes the number of C atoms in the diamine molecule while the second 6 denotes the number of C atoms in the dioic acid molecule

B. Formation of polyester

General equation for the formation of polyester from dioic acid + diol:



General equation for the formation of polyester from single monomer (containing both hydroxyl group and carboxyl group)



	Polyamide	Polyester
Linkage between monomers	Amide	Ester
Intermolecular forces	Van der Waals' forces and hydrogen bonds	Van der Waals' forces
Properties	Tough, strong, elastic, easily cleaned and dyed	Strong, tough, smooth, low densities
Uses	Ropes, fishing lines, badminton racket strings	Lightweight sails, bottles for water / drinks