









Unit 3 - Organic Chemistry

Organic compounds: compounds that contain carbon, except $\text{CO}_{(g)}$, $\text{CO}_{2(g)}$, and ionic compounds with carbon.

Hydrocarbons: organic compounds that contain carbon and hydrogen atoms in their molecular structure.

Straight Chain Alkanes

Alkanes: a hydrocarbon with only single bonds between carbon atoms

IUPAC Name	Molecular formula	Structural formula	Line formula
Methane	CH_4	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H} \end{array}$	N/A
Ethane	C_2H_6	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$	N/A
Propane	C_3H_8	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$	
Butane	C_4H_{10}	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	
Pentane	C_5H_{12}	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	
Hexane	C_6H_{14}	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	
Heptane	C_7H_{16}	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	
Octane	C_8H_{18}	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \quad \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	
Nonane	C_9H_{20}	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \quad \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \quad \quad \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	
Decane	$\text{C}_{10}\text{H}_{22}$	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \quad \quad \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \quad \quad \quad \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	
-ane	$\text{C}_n\text{H}_{(2n+2)}$		

From textbook: Read pg 180-183, Do pg 183 # 1, 2

Branch-Chain Alkanes

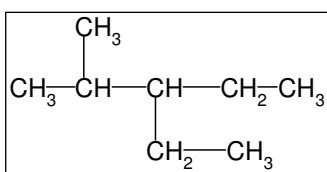
Alkyl group: a hydrocarbon group derived from an alkane by the removal of a hydrogen atom.

Some examples of alkyl groups include $-\text{CH}_3$ (methyl), $-\text{C}_2\text{H}_5$ (ethyl), $-\text{C}_3\text{H}_7$ (propyl), etc.

Nomenclature steps:

- 1) Find the longest carbon chain. This will be the parent chain.
- 2) Start numbering the carbons on the parent chain starting at the carbon closest to the first branch.
- 3) Write branches in alpha order, not numerically.

Ex. 1



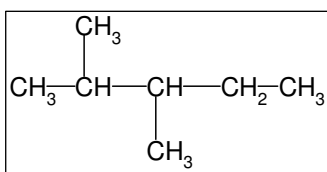
The longest carbon chain is 5 carbons long. The parent chain is pentane

There are two branches. A methyl group and a ethyl group.

Therefore, this hydrocarbon is **3-ethyl-2-methylpentane**

If there are more than one of the same type of alkyl group, use the *di*, *tri*, etc. prefixes.

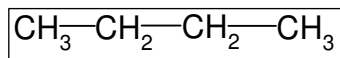
Ex. 2



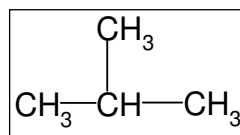
2,3-dimethylpentane

Structural Isomers: chemicals with the same molecular formulas but have different structural formulas and different names.

Ex 4 - C_4H_{10}



butane



isobutane or 2-methylpropane

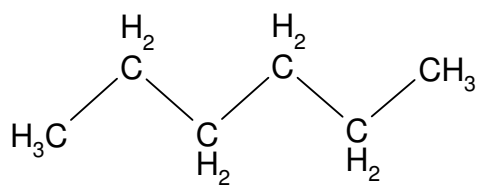
Cycloalkanes

Acyclic hydrocarbons: open-chain hydrocarbons without any rings of carbon atoms.

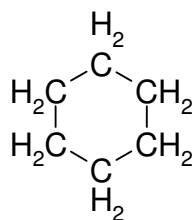
Alicyclic hydrocarbons: hydrocarbons with a carbon-carbon bond structure forming a closed ring. Sometimes just called cyclic hydrocarbons

Nomenclature

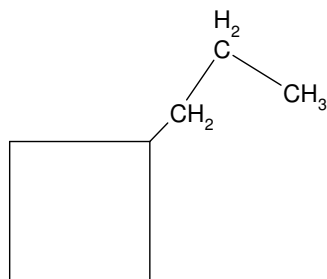
A cyclic compound has the prefix **cyclo-** to indicate the ring structure.



hexane



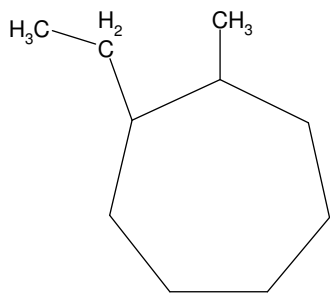
cyclohexane



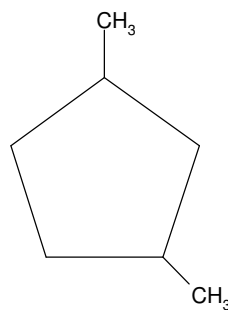
propylcyclobutane

When cyclic hydrocarbons have multiple substituent groups, or branches, they are listed in alphabetical order, and the first substituent is assigned to carbon #.

Ex.



1-ethyl-2-methylcycloheptane



1,3-dimethylcyclopentane

Alkenes & Alkynes

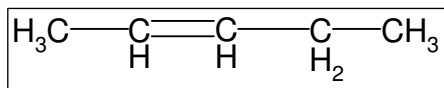
Alkenes: a hydrocarbon with one or more double bonds between carbon atoms

Alkynes: a hydrocarbon with one or more triple bonds between carbon atoms

Nomenclature steps:

- 1) Find the longest carbon chain. This will be the parent chain.
- 2) If the carbon chain contains a double bond, use the suffix **-ene**
If the carbon chain contains a triple bond, use the suffix **-yne**
- 3) Start numbering the carbons on the parent chain starting at the carbon closest to the largest multiple bond.
- 4) Write branches in alpha order, not numerically.

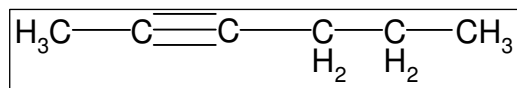
Ex. 1



The longest carbon chain is 5 carbons long. The parent chain is pentane

There is a double bond starting at the 2nd carbon

Therefore, this hydrocarbon is **2-pentene**



Ex. 2

The longest carbon chain is 6 carbons long. The parent chain is

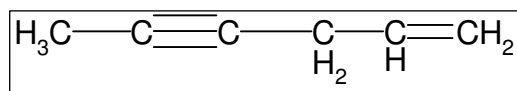
There is a triple bond starting at the 2nd carbon

Therefore, this hydrocarbon is **2-hexyne**

If there is only one multiple bond and it is on the first carbon, there is no need to prefix the name with the number 1.

ie. 1-pentene can simply be called pentene.

If there is more than one multiple bond, use the *di*, *tri*, etc. prefixes as before.

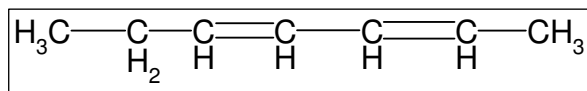


Ex. 3

The longest carbon chain is 6 carbons long. The parent chain is

There is a double bond on the 1st carbon and a triple bond starting at the 2nd carbon

Therefore, this hydrocarbon is **1-hexene-4-yne**



Ex. 4

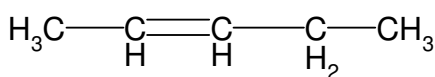
The longest carbon chain is 7 carbons long. The parent chain

There are double bonds on the 2nd and 4th carbons

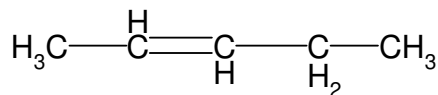
Therefore, this hydrocarbon is **2,4-heptadiene**

Cis / Trans

Looking at 2-pentene, the hydrogens located on the 2nd and 3rd carbons are on the same side, however it is possible for them to be on opposite sides, as well. These are two different isomers of 2-pentene. Therefore, we must distinguish between them. When hydrogens are on the same side of the double (or triple) bond, we use the suffix **cis**, if they are on opposite sides we use **trans**.



cis-2-pentene

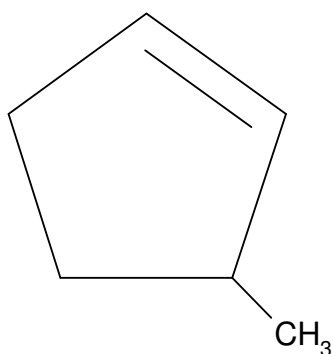


trans-2-pentene

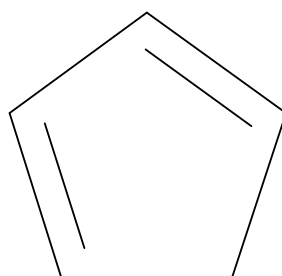
Cycloalkenes & Cycloalkynes

Nomenclature for cyclic alkenes and alkynes is the same as cycloalkanes, except that numbering starts at the multiple bond.

Ex. 5



3-methylcyclopentene



1,3-cyclopentadiene

From textbook: Read pg 184-186, Do pg 186 #3, 4

Fractional Distillation

Distillation is a process used to separate the various hydrocarbons in a mixture from one another by using the differences in boiling points.

For example, crude oil is a mixture of various hydrocarbons. These hydrocarbons can range from relatively short chains up to long chains (over 40 carbons long).

# Carbon Atoms	Boiling Point	Primary use
1 – 5	Under 30° C	Fuels for heat and cooking
5 – 6	30° C to 90° C	Camp fuel/dry-cleaning solvents
5 – 12	30° C to 200° C	Gasoline
12 – 16	175° C to 275° C	Kerosene and diesel fuels
15 – 18	250° C to 375° C	Furnace oil
16 – 22	Over 400° C	Heavy greases for lubrication
Over 20	Over 450° C	Waxes, cosmetics and polishes
Over 26	Over 500° C	Asphalt and tar for roofs and roads

To separate high demand (and cost) from the low demand products, the oil subjected to a distillation process. Notice the boiling points - as a general rule, the lower the number of carbon atoms, the lower the boiling point.

Steps to Fractional Distillation:

- 1) The mixture is heated at a high temperature. This will ensure that all hydrocarbons evaporate.
- 2) The temperature is then slowly lowered
- 3) The gases will condense at different temperatures (their particular boiling points)
- 4) As the hydrocarbon gases condense back to a liquid, they are collected

Why does this occur?

Hydrocarbons are **non-polar** molecules, which means they are held together by weak **London Dispersion Forces**. As a hydrocarbon chain increases in size, more energy is required to separate the molecules from each other, thus the boiling point increases.

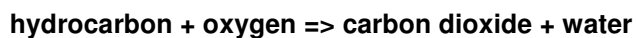
Cracking

High value hydrocarbons are gasoline and its immediate by-products. These are typically branched chains with 5 to 12 carbon atoms. As discussed above, crude petroleum is mixture of many hydrocarbons; most straight hydrocarbon chains some as long as 40. Cracking is a process of converting these long straight chains into the more profitable shorter branched chains.

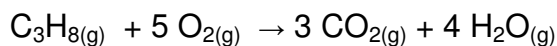
From textbook: Read pg 193-195

Chemical Reactions

Complete Combustion:



by-products are light and heat; hydrocarbons are very useful as fuels

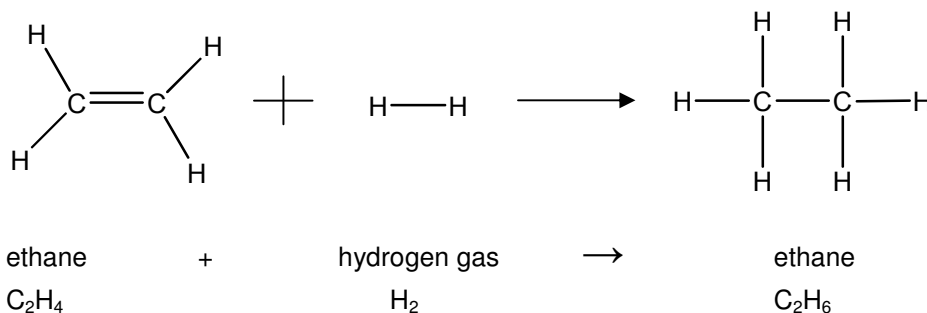


Addition Reactions of Alkenes and Alkynes:

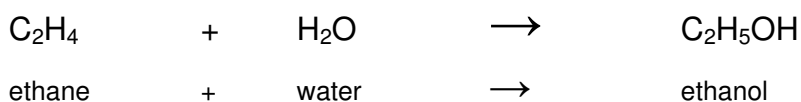
A saturated hydrocarbon contains only single bonds

An unsaturated hydrocarbon contains at least one double or triple bonds

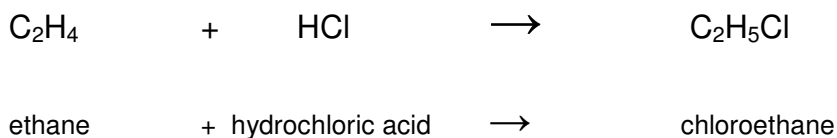
Unsaturated hydrocarbons (alkenes and alkynes), because of the multiple bonds, are more reactive than alkanes. The double and triple bonds are targets for addition reactions, which cause molecule to go from an unsaturated state to a saturated state.



Similarly,



and



Note: in the event that a double bond is not in the middle of the compound, the more electronegative atom will choose to bond to the C closest to the end

Functional Groups

A functional group is a combination of atoms that determine the physical and chemical characteristics of a compound.

Carbon-Carbon double or triple bonds

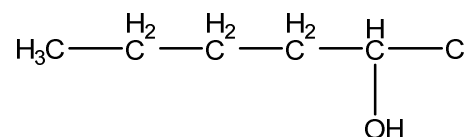
- Double and triple bonds are easier to break than single bonds
- Hence compounds containing these are more reactive than those with single bonds

Halogens

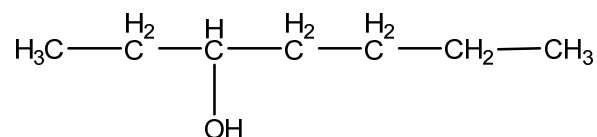
- Unequal sharing of electrons result in polar bonds
- This increases intermolecular attraction, increasing the boiling point and melting point

Alcohols

- Alcohols are organic compounds that contain the presence of hydroxyl functional group $-OH$
- General form alcohol is $R-OH$ (R implies a general alkane chain)
- Examples:
 - o Methanol CH_3OH (from methane CH_4) = very toxic compound
 - o Ethanol CH_3CH_2OH (beer and wines)
 - o 2-Propanol $CH_3CH(OH)CH_3$ (rubbing alcohol)
- To name alcohols, give the location of the $-OH$ and add the prefix "ANOL"



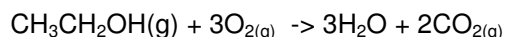
2-pentanol



3-heptanol

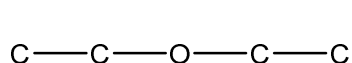
Properties of alcohol

- o Polar hydroxyl group allow hydrogen bonds to occur between molecules
- o Hence boiling points and melting points are increased compared to their respective alkanes
 - Ethanol (CH_3CH_2OH) boils at $73^\circ C$
 - Ethane (CH_3CH_3) boils at $-89^\circ C$
- o Alcohols also have a higher solubility in water than alkanes; but the longer C chains on some alcohols also allow them to mix with nonpolar solvents as well
- o Alcohols also burn in the presence of O_2

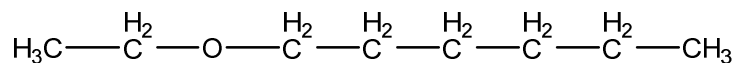


Ethers

- organic compounds that have an oxygen attached to TWO hydrocarbon alkyl chains
- general form is R-O-R'
- To name ethers:
 prefix of shorter hydrocarbon chain attached to oxygen + OXY + alkane name of the longer chain
- Examples:



ethoxyethane



ethoxyhexane

Properties of ethers

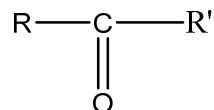
- o More polar than alkane types of hydrocarbons. Hence boiling points and melting points are increased compared to their respective alkanes
- o boiling points and melting points are higher than respective alkanes but lower than alcohols
- o ethers do mix well with both polar and nonpolar substances

From textbook: Read pg 199-201 & pg 204-208 Do pg 206 #1, 2 & pg 208 #1-4

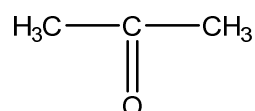
Ketones

Both aldehydes and ketones contain **carbonyl functional group** – oxygen with a double bond to carbon $C=O$

- The carbonyl group is found in the interior of the carbon chain
- The general form is



- To name ketones:
Location of carbonyl group + alkane name + “anone” suffix
- Examples:

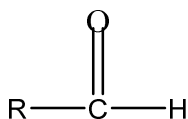


$\text{CH}_3\text{COCH}_3 \Rightarrow$ propanone (acetone)

$\text{CH}_3\text{CH}_2\text{CH}_2\text{COCH}_2\text{CH}_3 \Rightarrow$ 3-hexanone

Aldehydes

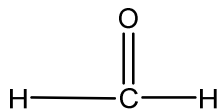
- The carbonyl group is located at the end of the carbon chain
- The general form is



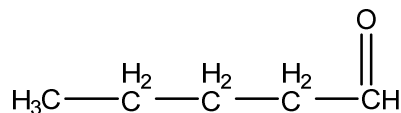
- To name aldehydes:
alkane name + “anal” suffix

NOTE – no number is necessary as by definition, the carbonyl group is at an end C

- Examples:



methanal (formaldehyde)



pentanal

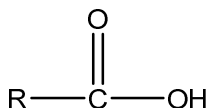
Properties of ketones & aldehydes

- o ketones and aldehydes have lower boiling points and melting points than alcohols but still higher than alkanes
- o less soluble in water than alcohols because they do NOT contain the $-\text{OH}$
- o good solvents because they mix relatively well with both polar and nonpolar compounds

From textbook: Read pg 212-217 Do pg 217 #1, 3

Carboxylic Acids

- Organic compounds that contain a **carboxyl functional group** – an end carbon with both a carbonyl and hydroxyl group.
- The general form is

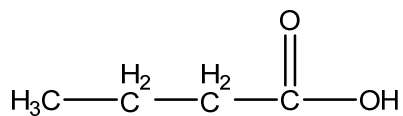


- To name aldehydes:
alkane name + “anoic acid” suffix

NOTE – As with aldehydes, no number is necessary as by definition, the carboxyl group is at an end C

- Examples:

CH_3COOH => ethanoic acid *a.k.a.* acetic acid *a.k.a.* vinegar



butanoic acid

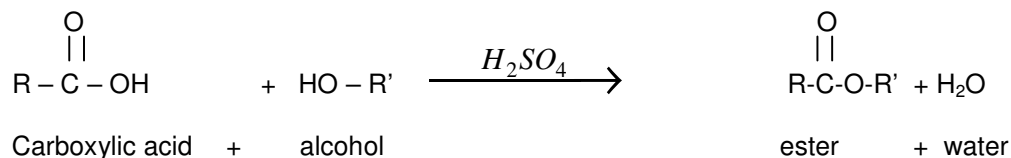
Properties of carboxylic acids

- o have some of the same properties of all other acids:
 - turns litmus paper red
 - neutralize bases
- o polar molecules; capable of forming hydrogen bonds
- o solubility is dependent on the length of the hydrocarbon chain of the acid => smaller chains are more soluble than longer chains
- o high boiling points and melting points

From textbook: Read pg 218-220 Do pg 220 #3

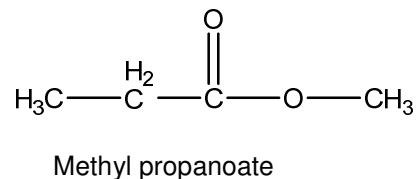
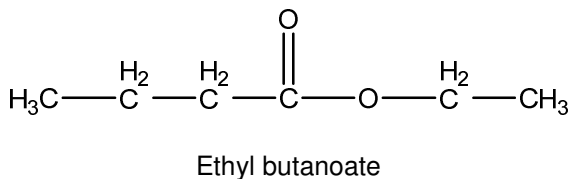
Esters

- Esters are responsible for many of the artificial smells and tastes in products – cherry coke for example. (See p 223 for some common examples)
- Created by a process called **esterification** – example of a condensation reaction in which larger molecule is produced from two smaller ones, with release of water
- Esters are formed by reacting a carboxylic acid and an alcohol



- General form is $\begin{array}{c} \text{O} \\ || \\ \text{R}-\text{C}-\text{O}-\text{R}' \end{array}$
- To name esters:
first part of name is alkyl group attached to –O-; second part is prefix of HC attached to carboxyl + “ANOATE”

- Examples:



Reactions:

- can be split back into their components by process of hydrolysis
- esters are fats and oils of long chain carboxylic acids; in presence of strong bases (such as NaOH) and water hydrolysis occurs to create sodium salts (SOAP) and alcohol
 - o can be separated by distillation

Properties of esters:

- o esters do NOT contain –OH => not as capable of forming hydrogen bonds => lower intermolecular forces
- o lower boiling points and melting points than carboxylic acids
- o less soluble in water than carboxylic acids

From textbook: Read pg 223-225

Amines

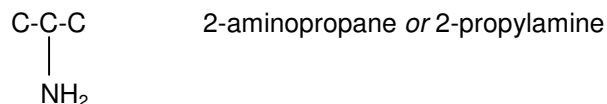
- Amine is an organic compound which contains a nitrogen attached to one or more alkyl groups
- There are three types of amines, and are named depending upon the carbon to which they are attached
 - An amine that has only one alkyl group attached to the nitrogen is called a **primary** (1°) amine
 - o General form is $R-NH_2$
 - An amine that has two alkyl groups attached to the nitrogen is called a **secondary** (2°) amine
 - o General form $R-N-H$
 - An amine that has three alkyl groups is called a **tertiary** (3°) amine
 - o General form $R-N-R'$
- You can think of an amine as an ammonia molecule NH_3 in which one or more H has been replaced by an alkyl group.
- To name amines:

(1°) Location of NH_2 on C-chain – “AMINO” + alkane name of the HC chain
OR

(1°) Location of NH_2 on C-chain - alkane name of the HC chain + “AMINE”

NOTE: You will only be responsible for naming primary amines

- Examples:
 $CH_3CH_2NH_2$ aminoethane *or* ethylamine (location of 1 is assumed)



Amides

- characterized by the presence of a carboxyl group ($C=O$) attached to the nitrogen
 - o general form $R-C-N-R'$

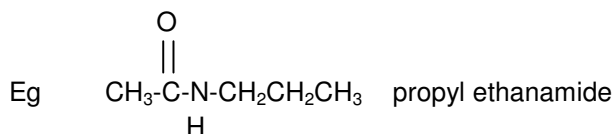


- To name amides:
(similar to ethers)

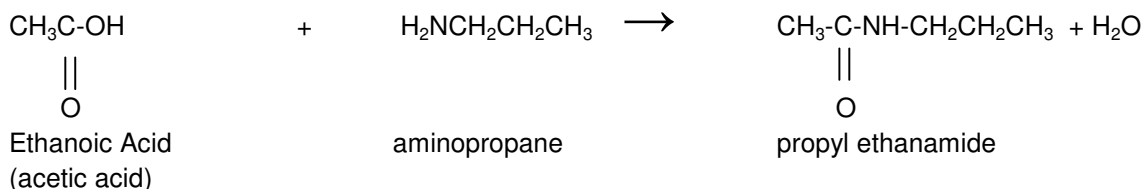
First part is alkyl
Name attached to N

second part is
prefix of HC beside the
 $C=O$ (from acid)

+ anamide



- Generally formed when a carboxylic acid reacts with an amine (similar to esterification)



Properties of amines and amides:

- have higher boiling points and melting points than corresponding hydrocarbons
- small amines are soluble in water but as number of C in the chain increases, solubility decreases
- N is more electronegative than C or H which makes the N-H and N-C bonds polar
 - o This increases the intermolecular forces
- presence of N-H in amines allows for hydrogen bonds to occur but N-H bonds are less polar than O-H bonds (N is less electronegative) so takes less energy to boil amines than it does to boil the corresponding alcohols

eg	CH ₃ CH ₃	-89°C
	CH ₃ NH ₂	-6°C
	CH ₃ OH	65°C

Refer to table 1 on page 229 for additional boiling points

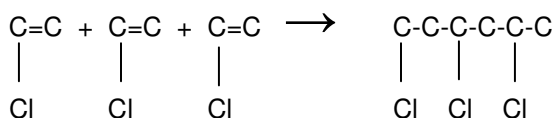
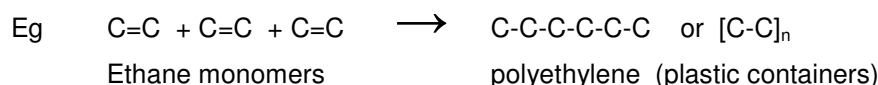
From textbook: Read pg 228-230, pg 231-232 Do pg 230 #2, 3, 4, 5

Polymers

- an extremely large organic compound made of many repeating sub-units
- sub-units are called monomers
 - o not necessarily identical but do occur in a repeating pattern
- plastics are generally synthetic polymers
- depending on desired characteristics, polymers can be designed to have certain properties of strength, flexibility, durability, transparency or stability
- natural polymers include complex carbohydrates , proteins and DNA

Addition Polymers

- polymers that form when monomer unit are linked through addition reactions.
- Therefore, the monomers must contain double or triple bonds



Chloroethene
(vinyl chloride)

polyvinyl Chloride (PVC)

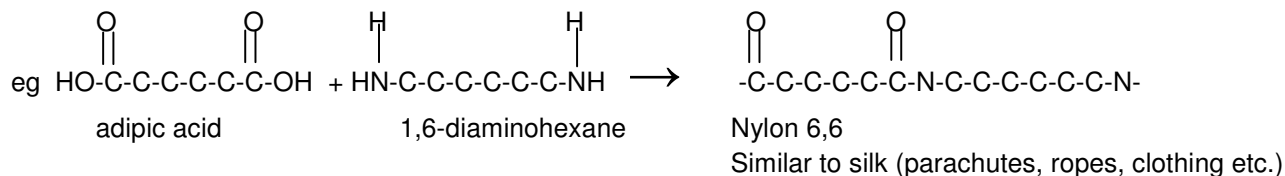
- coating on fabrics
- insulation around electrical wires

Properties of Addition Polymers

- addition polymers (plastics) tend to be chemically unreactive
- the double bonds of the monomers are changed to the less reactive single bonds
- polymer chains can 'slide along' each other which makes them flexible
- intermolecular forces are abundant but weak so if heated, plastics can be molded
- if a monomer unit has two double bonds, they can form covalent bonds between adjacent polymer chains
- bonds between adjacent polymer chains are called 'crosslinks'; these add rigidity to the polymer

Condensation Polymers

- polymers that are formed when monomer units are linked together by condensation reactions
 - o recall: carboxylic acids react with alcohols and amines in a condensation reaction to form, respectively, esters and amides
- polymers formed by ester or amide monomers are called polyesters or polyamides respectively



Properties of Condensation Polymers

- polymers are capable of hydrogen bonding between the –N-H and –C=O of the different chains
 - o therefore polyamides are very strong
- polyesters also have many intermolecular forces holding the chains together making them strong and durable (but not so strong as polyamides)
- eg Kevlar => polyamide used in bullet proof vests, light-weight canoes and airplane parts

From textbook: Read pg 237-241 Do pg 242 #1, 4