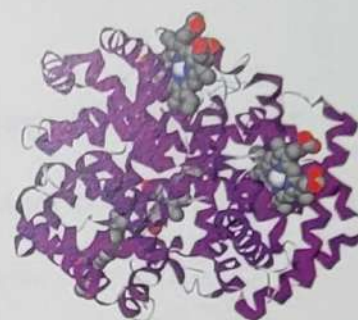
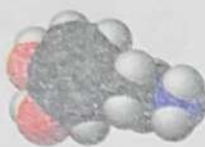
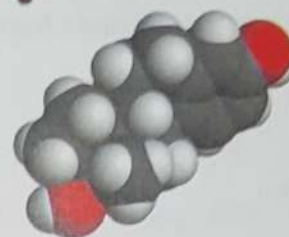
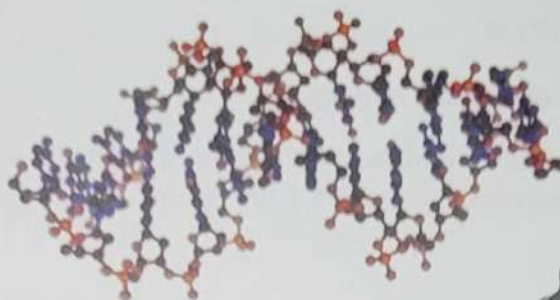
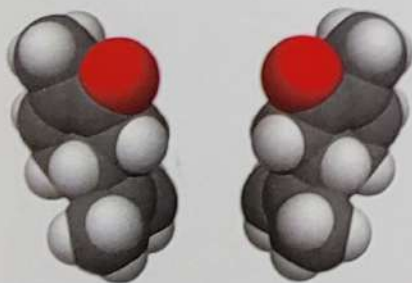


Organic Chemistry

- Hydrocarbons
- Alcohols and Ethers
- Aldehydes, Ketones, Carboxylic Acids, and Esters
- Amines and Amides
- Chirality



Carbon is unique amongst the elements in being very good at forming bonds to itself as well as other elements. There is an enormously rich chemistry characterized by molecules whose backbone is made up of chains and rings of carbon atoms, which we call organic chemistry. Understanding organic molecules and the functional groups that give organic molecules their incredibly broad range of properties is crucial to appreciating the underpinnings of life itself. We'll learn about how organic molecules can exhibit isomerism of different types, from cases where the difference is obvious (e.g. ethanol and dimethyl ether both have the formula C_2H_6O , but ethanol is an intoxicating liquid while dimethyl ether is a gas used to freeze off warts) to those where the difference is quite subtle (the scent of spearmint and the scent of caraway seeds come from two molecules whose only difference is that they are mirror images of each other).



Chemistry

2e

*This chapter corresponds to
Chapter 20 "Organic Chemistry"
of the online textbook.*



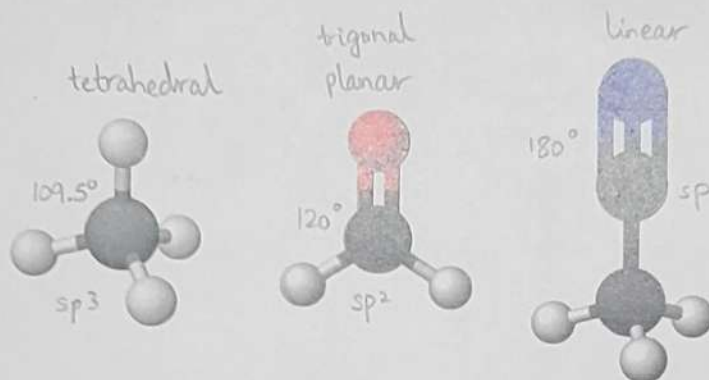
General Characteristics of Organic Molecules

Organic chemistry is the branch of chemistry that studies carbon compounds

The structures of organic molecules

The shapes of organic and biochemical molecules are important in determining their physical and chemical properties. Consider carbon:

As well as C-C bonds (the "backbone"), C-H bonds occur in almost every organic molecule



The stabilities of organic substances

The stability of organic substances varies:

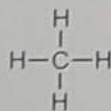
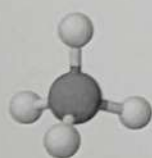
C-C and C-H bonds are strong and non-polar - and hence unreactive.
A group of atoms that determines how an organic molecule functions or reacts is a functional group.

Alkanes

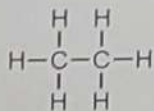
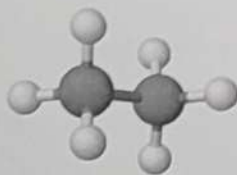
diamagnetic = all electrons are paired

paramagnetic = 1 or more unpaired electrons

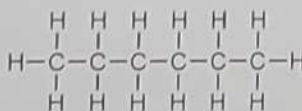
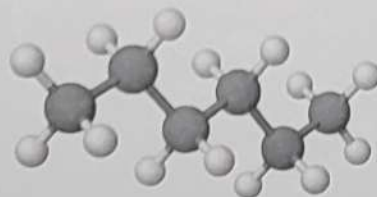
Alkanes contain only single covalent bonds between carbon atoms.



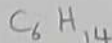
methane



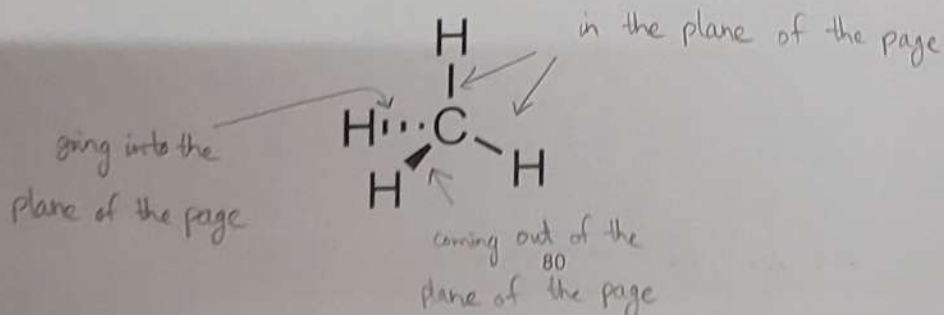
ethane



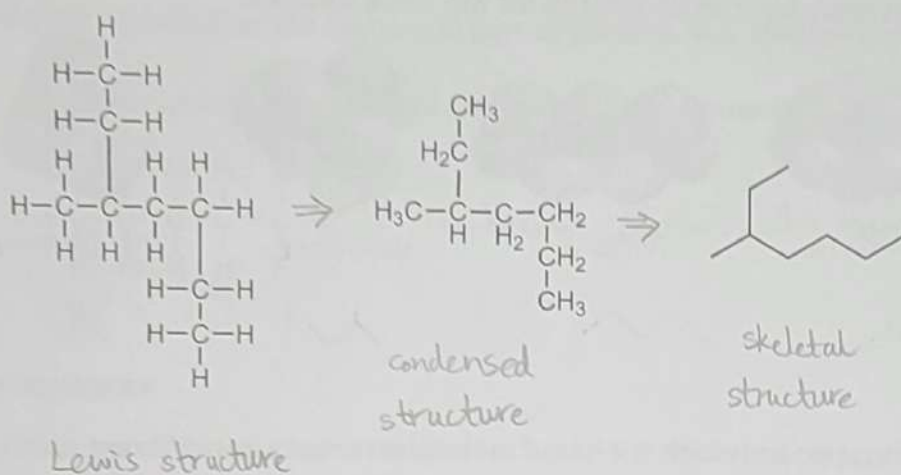
hexane



3D representation (drawings) for the structure of hydrocarbons:



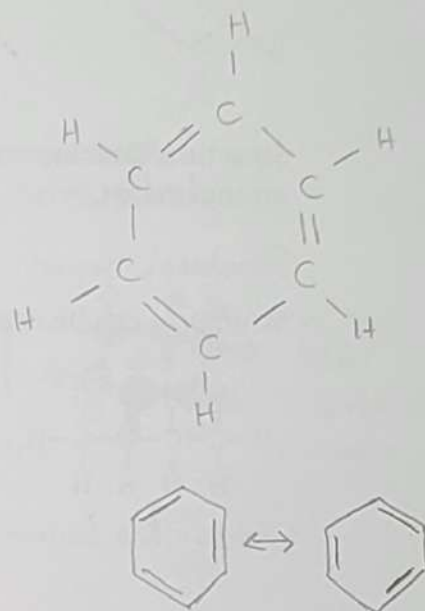
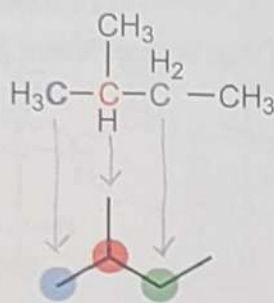
Chemists use shorthand forms to draw organic compounds



How to draw a skeletal structure

- C is at the end of every line
- Bond angles 120°
- Hydrogens are not drawn

Assume there are enough H to complete octet on every C



Non-cyclic alkanes have the formula C_nH_{2n+2} , where n can be any number. Properties of alkanes (such as melting and boiling points) change as n increases.

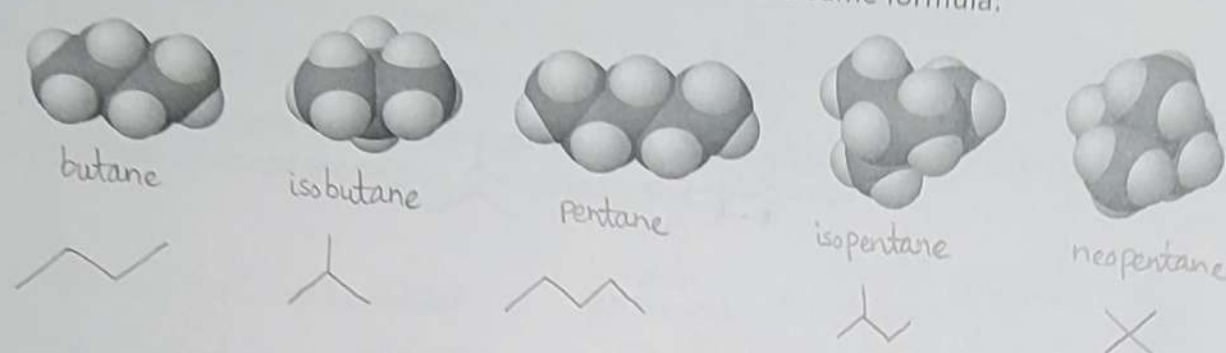
Alkane	Formula	Structural formula	Melting point ($^\circ\text{C}$)	Boiling point ($^\circ\text{C}$)	Phase at 0°C and 1 atm	# of isomers
methane	CH_4	CH_4	-182	-161	gas	1
ethane	C_2H_6	CH_3CH_3	-183	-89	gas	1
propane	C_3H_8	$\text{CH}_3\text{CH}_2\text{CH}_3$	-190	-44	gas	1
butane	C_4H_{10}	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$	-138	-0.5	gas	2
pentane	C_5H_{12}	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	-130	36	liquid	3
hexane	C_6H_{14}	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	-95	68	liquid	5
heptane	C_7H_{16}	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	-91	98	liquid	9
octane	C_8H_{18}	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	-57	126	liquid	18
nonane	C_9H_{20}	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	-54	151	liquid	35
decane	$\text{C}_{10}\text{H}_{22}$	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	-30	174	liquid	75
tetradecane	$\text{C}_{14}\text{H}_{30}$	$\text{CH}_3(\text{CH}_2)_{12}\text{CH}_3$	28	254	solid	1858

C_nH_{2n+2}

Naming of alkanes requires you to learn prefixes for 1-10 carbon atoms:

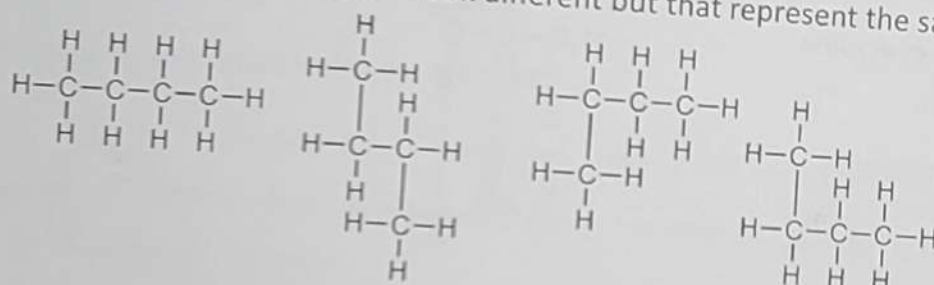
meth-, eth-, prop-, but-, pent-, hex-, hept-, oct-, non-, dec-

Branched-chain hydrocarbons are possible for alkanes with four or more C atoms. Structures with different branches can be written for the same formula:



Structural isomers are compounds with the same molecular formula but different bonding arrangements.

Structural isomers have somewhat different physical and chemical properties. Structures can be drawn that look different but that represent the same molecule:



focus on the connectivity of the C chain

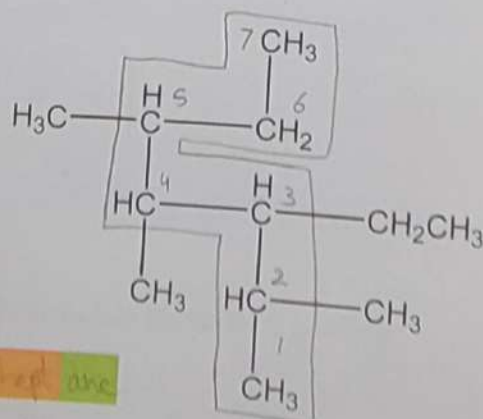
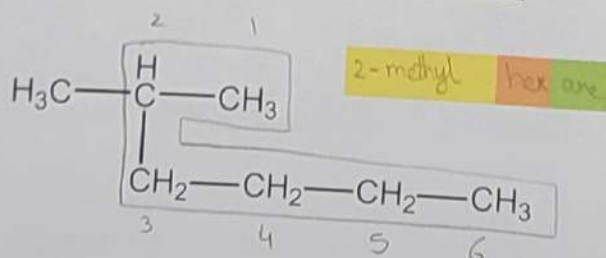
Naming Alkanes

Names have three parts:

prefix	base	suffix
what substituents?	how many carbons?	what family?

To name a compound...

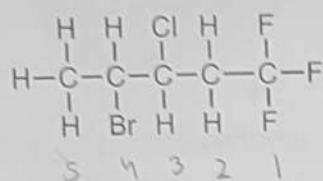
- Find the longest chain (the one with the most substituents, if more than one)
- Number the chain from the end nearest the first substituent encountered
- List the substituents as a prefix along with the number(s) of the carbon(s) to which they are attached: replace -ane with -yl
- When two or more substituents are present, list them in alphabetical order.



Use prefixes di-, tri-, tetra-, penta- for more than one substituent of the same type.

5. Do not alphabetize the numerical part of prefixes (e.g. triethyl comes before methyl).

6. Use fluoro, chloro, bromo, iodo for Group 17 substituents.

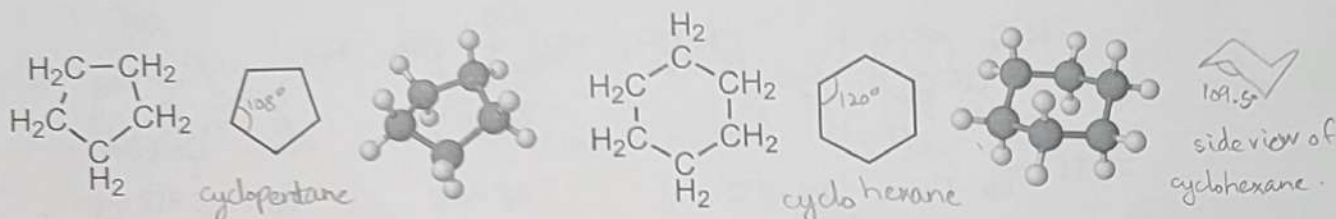


4-bromo-3-chloro-1-trifluoropentane

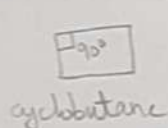
Cycloalkanes

Carbon can also form ringed structures. 5- and 6-membered rings are most stable:

can take on conformation in which angles are ~ tetrahedral:



smaller rings - cyclobutane, cyclopropane - are quite strained and reactive



Alkane reactivity

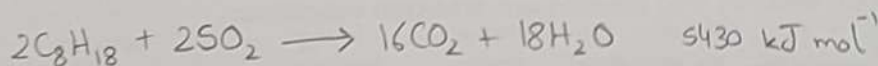
Rather unreactive due to presence of only C-C and C-H σ -bonds (non-polar).

Used as non-polar solvents

Are fuels because combustion is exothermic



Combustion of octane:



Alkenes

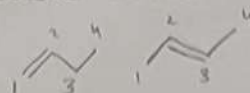
Alkenes are **unsaturated** hydrocarbons that contain C and H atoms and at least one C-C double bond.

↑ i.e. have fewer than maximum number of H

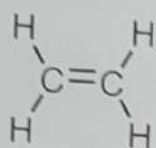
Alkenes are named in the same way as alkanes with the suffix -ene replacing the -ane in alkanes. The location of the double bond is indicated by a prefix

chain numbered so double bond gets smallest possible number

e.g. 1-or 2-butene but NOT 3-or 4-butene



Alkenes cannot rotate freely about the double bond (π bond = side-to-side overlap)



π bond



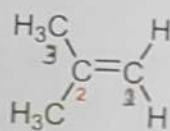
90° rotation
compromise π -overlap

No rotation means geometric isomers are possible in alkenes.

differ from each other in the spatial arrangement of groups about the double bond

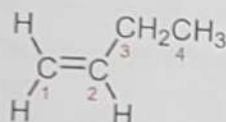
The structure determines the physical properties of alkenes, such as their boiling points.

Cis and *trans* isomers do not interconvert.



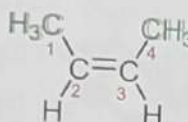
bp -7°C

2-methyl-1-propene



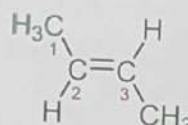
bp -6°C

1-butene



bp $+4^\circ\text{C}$

cis-2-butene



bp $+1^\circ\text{C}$

trans-2-butene

cis = "this side of"
trans = "the other side of"

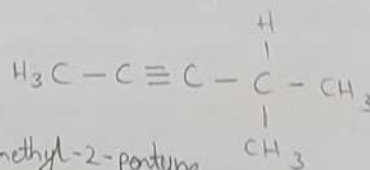
Alkynes

Unsaturated hydrocarbons that contain at least one carbon-carbon triple bond.

carbons in triple bond are *sp* hybridized and have linear geometry

Naming is analogous to alkenes

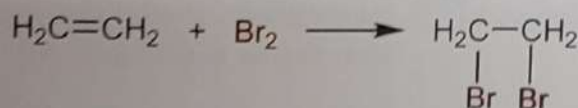
but... suffix is -yne rather than -ene



4-methyl-2-pentyne

Addition Reactions of Alkenes and Alkynes

The dominant reactions for alkenes and alkynes are **addition reactions**:



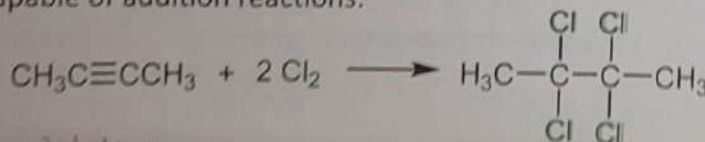
1,2-dibromoethane

Two atoms (e.g. bromine)

add across the double bond

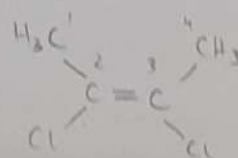
one π bond is replaced by two σ bonds

Common additions include H_2 (hydrogenation), H_2O or hydrogen halides. Alkynes are also capable of addition reactions:



2-butyne

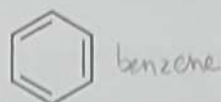
2,2,3,3-tetrachlorobutane



2,3-dichloro-2-butene

Aromatic Hydrocarbons

Aromatic structures are formally related to benzene (C_6H_6):

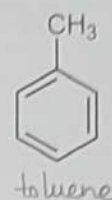
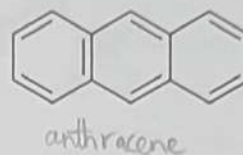
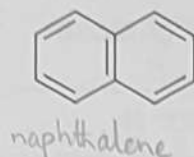


Highly unsaturated: very reactive? **NO!**

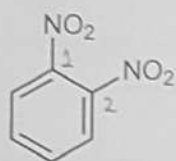
- delocalized π electrons confer special stability to aromatic compounds

- aromatic hydrocarbons do not readily undergo addition reactions

many have common names:



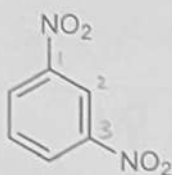
2 substituents on a benzene ring have 3 possible relationships:



mp = 118 °C

ortho-dinitrobenzene

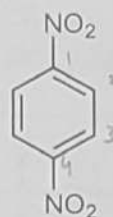
adjacent



mp = 90 °C

meta-dinitrobenzene

1 carbon between



mp = 174 °C

para-dinitrobenzene

opposite

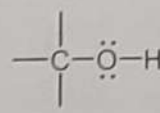
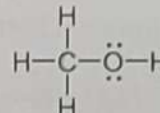
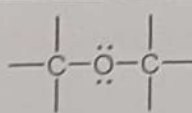
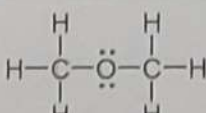

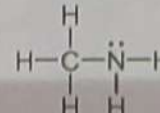
Functional Groups

Hydrocarbons are relatively unreactive; for an organic molecule to be reactive it needs something additional.

a site of reactivity in an organic molecule is called a functional group

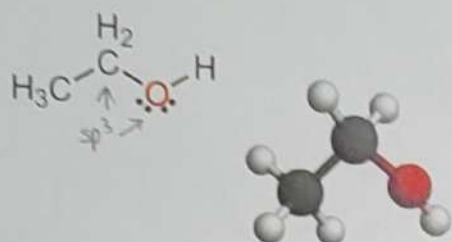
Alcohols, ethers and amines

Incorporating an oxygen atom with two single bonds into a hydrocarbon generates either an **alcohol** or an **ether**. Incorporating a nitrogen atom makes an **amine**.

Functional group	Type of compound	Suffix or prefix	Example	Systematic name (common name)
	alcohol	-ol		methanol (methyl alcohol)
	ether	-oxy		methoxy methane (dimethyl ether)
	amine	-amine		methylamine (aminomethane)

Alcohols

Inserting an oxygen between C and H makes an alcohol. In the $-OH$ (hydroxyl) group the oxygen is strongly and covalently bonded to both C and H.



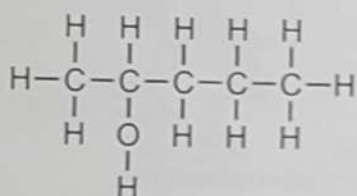
ethanol is made by fermentation of sugars



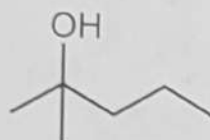
Named from parent hydrocarbon; suffix changed to $-ol$

Longest carbon chain numbered from end closest to hydroxyl group (OH).

Number designates the carbon to which hydroxyl is attached



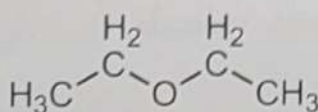
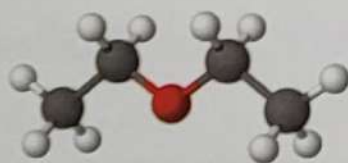
2-pentanol



2-methyl-2-pentanol

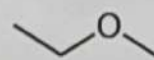
Ethers

Molecules with an oxygen atom between two carbon atoms are **ethers**. When naming ethers, the longest carbon chain is listed second, and the shorter one listed first with the suffix $-oxy$:



ethoxy ethane

common name "diethylether"



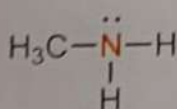
methoxy ethane

relatively unreactive, often used as solvents

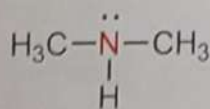
Amines

Amines are organic bases with general formula NR_3 .

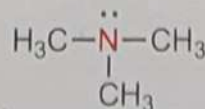
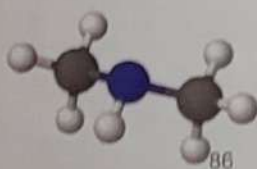
$\text{R} = \text{H}$ or a hydrocarbon group



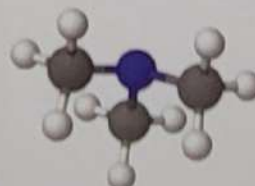
methylamine



dimethylamine



trimethylamine



Carbonyl-containing functional groups

All of these functional groups have in common the **carbonyl** group, **C=O**. The two other substituents on the sp^2 carbon atom determine the family of the compound.

Functional group	Type of compound	Suffix or prefix	Example	Systematic name (common name)
	aldehyde	-al		ethanol (acetaldehyde)
	ketone	-one		propanone (acetone)
	carboxylic acid	-oic acid		ethanoic acid (acetic acid)
	ester	-oate		methyl ethanoate (methyl acetate)
	amide	-amide		ethanamide (acetamide)

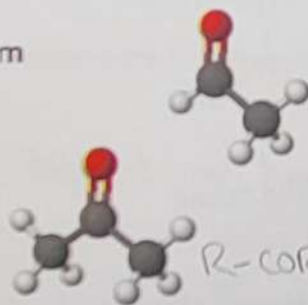
Aldehydes and Ketones

Aldehydes must have at least one H atom attached to the carbonyl C

Ketones have two carbons bonded to carbonyl carbon

start numbering from aldehyde end (position does not need to be specified)

$R-CHO$ not need to be specified

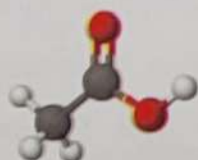


$R-COR'$

chain numbered from end closest to carbonyl group

Carboxylic Acids

Carboxylic acids contain a carbonyl group with an $-OH$ attached

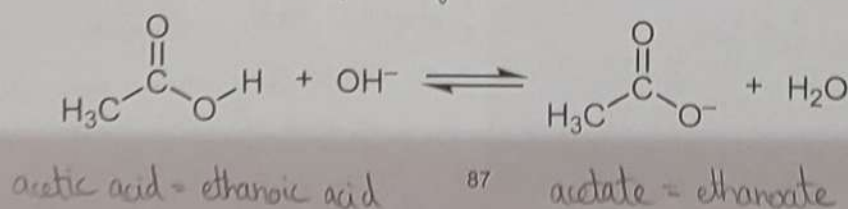


$R-COOH$

start numbering from acid end (position does not need to be specified)

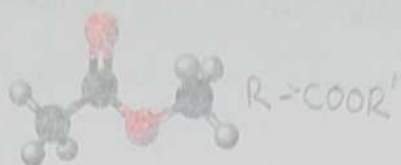
weak organic acids e.g. lactic, acetic, citric, acetylsalicylic acids

Acid-base reactions:



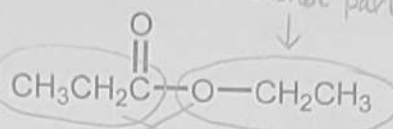
Esters

Esters can be prepared by condensation reactions involving a carboxylic acid and an alcohol; the products are the ester and water:



esters are named using the alcohol part first

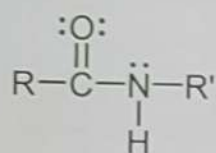
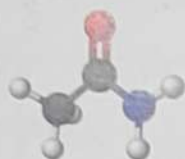
and then the acid part



ethyl

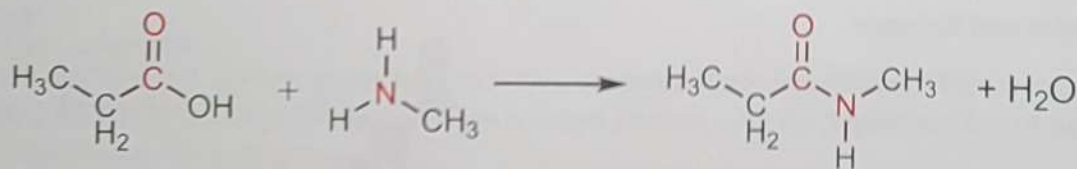
propanoate

Amides are composites of carbonyl and amine functionalities.



= the amide linkage, the key functional group in the structure of proteins

Amides are produced by a **condensation reaction** between carboxylic acids and amines. When there are different options for the substitution pattern, the prefix "N-" is used to indicate the group(s) bound to the nitrogen atom.



Propanoic acid

methylamine

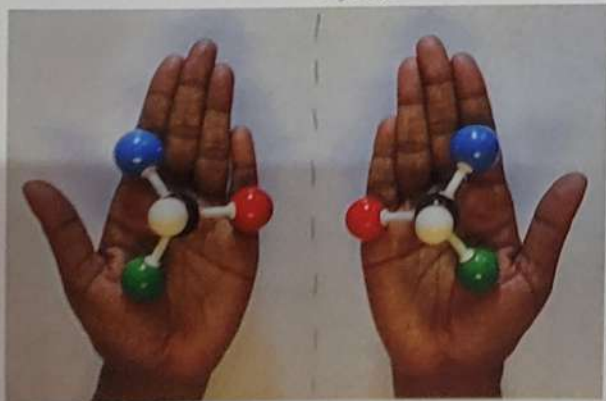
N-methylpropanamide

water

Chirality in Organic Chemistry

Isomers that are mirror images of each other, but are non-superimposable are **chiral**.

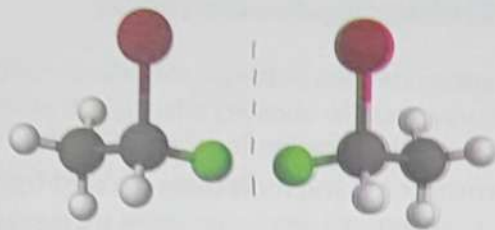
A carbon atom that has 4 different groups attached is a **chiral center** and renders the molecule chiral



Chiral molecules are mirror images of each other

objects and molecules that have a plane of symmetry are not chiral

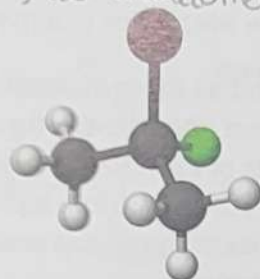
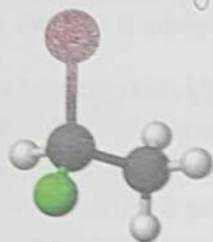
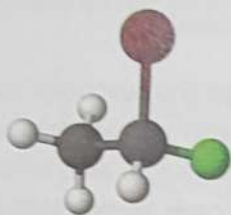
Enantiomers = two isomeric molecules that are mirror images of each other:



the physical properties of enantiomers are generally identical
Chemists use the labels *R*- and *S*- to distinguish between enantiomers (also called "optical isomers").

enantiomers = are a type of stereoisomer

if one stereoisomer is "right-handed", its enantiomer is "left-handed"



NOT chiral

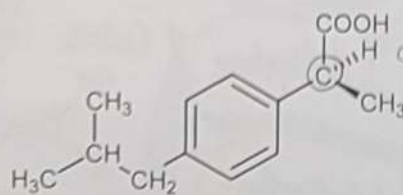
different representation
of the same molecule

A mixture of two enantiomers in the same quantity is called a **racemic** mixture.

Enantiomers exhibit different chemical properties when they interact with other chiral molecules

e.g. they often taste and smell different and have different effects as drugs

Many pharmaceuticals are chiral; enantiomers often have different biological activity.



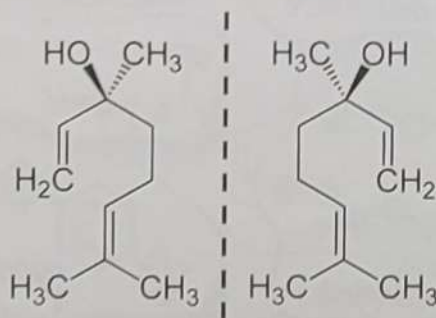
chiral center

S-ibuprofen

non-steroidal analgesic



scent of
coriander



S-linalool

R-linalool



scent of
lavender

olfactory receptors contain chiral groups