

What is Organic Chemistry?

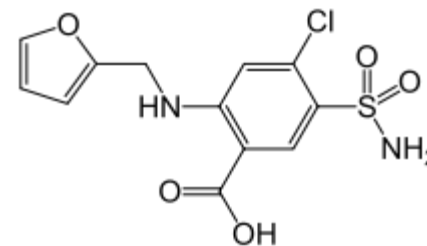
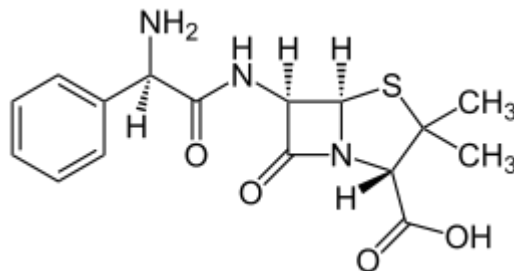
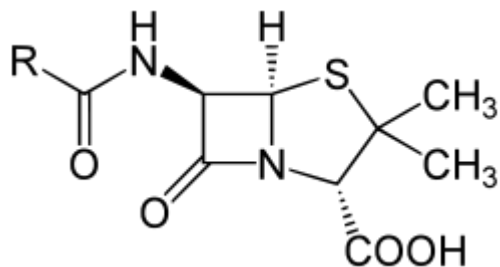
Originally, the study of **naturally occurring** molecules from live sources.

Expanded to include non-naturally occurring molecules **similar in structure**:

Penicillin and **streptomycin** are naturally occurring **antibiotics**,

Ampicillin is a **semisynthetic** antibiotic whose structure is essentially a modified penicillin; it's still considered to be an organic molecule.

Sulfonamides ("sulfa drugs") are **completely synthetic** antibiotics, but they're also considered to be organic molecules.



What's the common thread that ties these molecules together?

CARBON

Organic chemistry is the study of carbon-containing molecules that aren't minerals.

CO_2 , CaCO_3 and NaHCO_3 contain carbon but aren't organic.

What is Organic Chemistry?

Examples of subdisciplines:

Drug design

- i) Some chemists use computers to **model** what shape/polarity a drug needs to be in order to get to and **bind** to a target site.
- ii) Other chemists work out how to make molecules that will have this shape/polarity, often designing **new reactions** in the process.
- iii) Another group of chemists designs a series of reactions that can make the potential drug in a safe manner on a **large scale**.

Structural determination

Natural products are routinely found in extracts of plants/marine life/etc. have interesting useful properties.

Chemist specialize in **isolating** the different molecules in these extracts and uses **modern equipment** to help them determine the **structures** of the molecules involved – a lot like solving puzzles

Energy-related research

Petroleum products are organic molecules. (Biofuels)

What is Organic Chemistry?

Materials/Alternative energy

Plastics, coatings, membranes, electrolytes, etc.

Environmental, agricultural sciences, green chemistry

- i) Design of newer, better, safer **herbicides** and **pesticides**.
- ii) Development of environmental **remediation** methods – methods to try and remove (or at least detoxify) chemicals from the environment.
- iii) **Cleaner** ways to make chemicals on a large scale without pollution.

Basic research/Education

- i) In every field of science, there are some scientists who do research just for the sake of **learning**.
- ii) To produce ideas that **lead** to completely **new** understanding of our world.

Drawing Organic Molecules

Carbon is the **backbone** of any organic molecule.

A **neutral carbon** atom has **4 bonds** and **0 lone pairs**.

A carbon atom is in the tetrahedral shape family:

i) tetrahedral : 4 σ -bonds (sp^3)

ii) trigonal planar: 3 σ -bonds + 1 π -bonds (sp^2)

iii) linear 2 σ -bonds + 2 π -bonds (sp)

Carbon needs to form 4 bonds in order to be neutral and obey the octet rule, as a result able to **form a wide variety of chains and rings**.

More than **7 billion** organic compounds are currently known and over a **million new** ones are discovered every year!

Drawing Organic Molecules

It is important to know which atoms are connected to which.

It is not enough to write **C₂H₆O**. (Empirical formula)

We must show how the atoms are connected:

The structures above are **structural formulas**.

They show the location of **every** atom in the molecule.

For **very large** molecules, structural formulas take a long time to draw and can be **confusing** to read.

Condensed structural formula: group hydrogen atoms with the atoms they're attached to and leave out the single bonds:

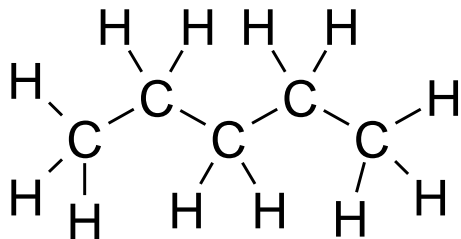


Drawing Organic Molecules

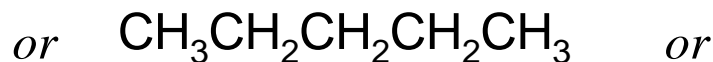
line-bond structure:

- 1) do not draw the **hydrogen** atoms attached to carbon.
- 2) replace each '**C**' with a **dot** and connect the dots with **lines** (i.e. bonds)

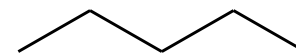
NB: If you write the 'C', you must write all the atoms bonded to it as well.



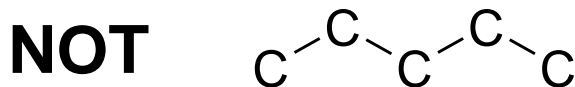
(structural formula)



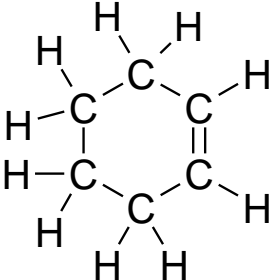
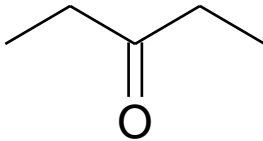
(condensed structural formula)



(line-bond structure)



Drawing Organic Molecules

Structural Formula	Condensed Structural Formula	Line-Bond Structure
 <p>A structural formula of cyclohexene, showing a six-membered carbon ring with one double bond. Each carbon atom is bonded to two hydrogen atoms, except for the two carbons in the double bond, which are each bonded to one hydrogen atom.</p>		
	$\text{H}_2\text{C}=\text{CHCH}_2\text{Cl}$	
		 <p>A line-bond structure of 2-butanone, showing a four-carbon chain with a double-bonded oxygen atom on the second carbon.</p>

Functional Groups

Organic compounds are **classified** according to their **functional groups**.

Functional groups are essential in determining their **physical** and **chemical** properties.

A **functional group** is part of an organic molecule that contains:

i) a **heteroatom** (atom **other** than C or H; usually N, O or S)

and/or

ii) a **multiple bond** (double or triple)

So, essentially what we're looking for are:

i) polar bonds - **CO**, **CN**, **CX** (X = F, Cl, Br, I)

ii) lone pairs - **N**, **O**, **S**, **X**

iii) π bonds - **C=C**, **C=N**, **C=O**

Functional Groups

Functional groups with carbon-carbon **multiple** bonds:

i) **Alkene**: C=C

ii) **Alkyne**: C≡C

iii) **Arene**: 6 atoms in a ring with 3 π bonds



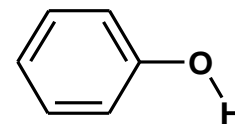
Functional groups with **single bonds** to N, O or S:

i) **Amine**: C–N

ii) **Ether**: C–O–C

iii) **Alcohol**: C–O–H

iv) **Phenol**: C–O–H where C is part of an arene:

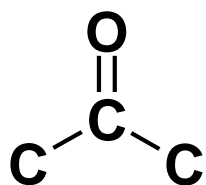


v) **Thiol** : C–S–H

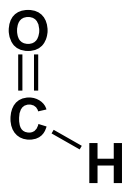
Functional Groups

Functional groups with **multiple bonds** to N, O or S:

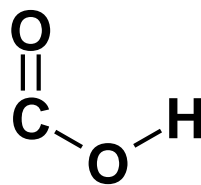
- i) **Ketone**: C=O with **two C's** attached
- ii) **Aldehyde**: C=O with **H** attached
- iii) **Carboxylic Acid**: C=O with **OH** attached
- iv) **Ester**: C=O with **O-C** attached
- v) **Amide**: C=O with **N** attached
- vi) **Nitrile**: contains C≡N



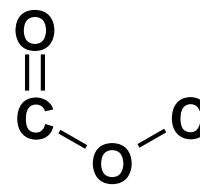
ketone



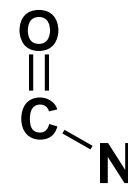
aldehyde



carboxylic acid



ester



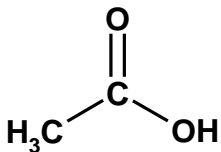
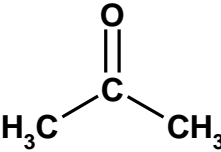
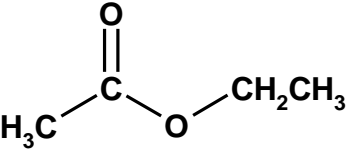
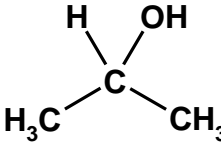
amide

C=O is called a **carbonyl**.

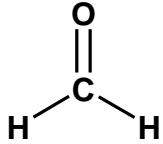
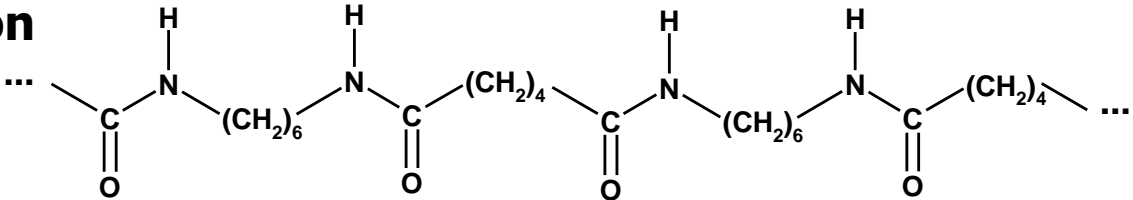
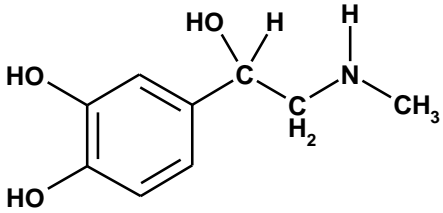
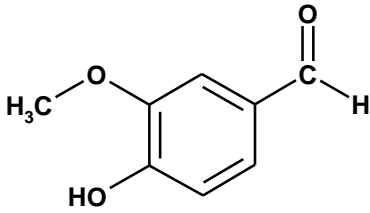
hydroxy is often used to describe just the **-OH** part of an alcohol and

carboxy refers to the **CO₂** part of an ester or carboxylic acid.

Functional Groups

Compound	Structure	Functional Group(s)
Acetic acid (vinegar)		
Acetone (nail polish remover)		
Ethyl acetate (acetone-free nail polish remover)		
Isopropanol (rubbing alcohol)		

Functional Groups

Compound	Structure	Functional Group(s)
Formaldehyde (biology labs)		
Nylon		
Adrenaline (Epinephrine)		
Vanilla extract (Vanillin)		

Isomers

Shape is **crucial** in organic chemistry.

Shape determines how it **interacts** with other molecules (recall IMFs).

Isomers are compounds that have the **same** molecular formula but **different** arrangements of atoms.

Isomers can be divided into **two** main categories:

1) Structural isomers have **different connectivity**. There is a be a differences in which atoms are connected to which:

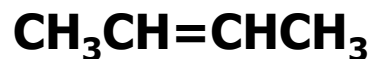


Ethanol



dimethyl ether

2) Stereoisomers have the **same connectivity** but different shapes.



2-butene

Structural Isomers

Structural isomers have different **physical properties**:

melting pt, boiling pt, etc.....

NB: This is also the **only** kind of isomerism for which **isomers** can have **different functional groups**.

Ex) C₃H₈O has three structural isomers:		BP (°C)
CH₃CH₂CH₂OH	Propanol	98
CH₃CH₂OCH₃	Ethyl-methyl-ether	7.4
(CH₃)₂CHOH	2-methyl-ethanol (isopropanol)	82

How many structural isomers can you draw for C₃H₆?



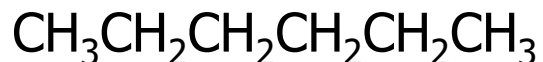
(1-)propene



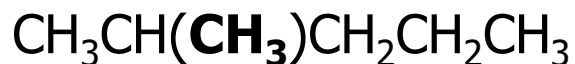
cyclopropane

Structural Isomers

How many structural isomers can you draw for C₆H₁₄?



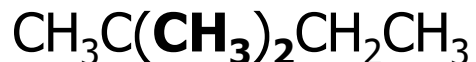
Hexane



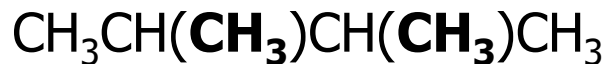
2-methylpentane



3-methylpentane



2,2-dimethylbutane



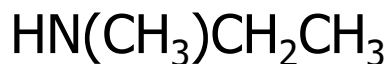
2,3-dimethylbutane

Structural Isomers

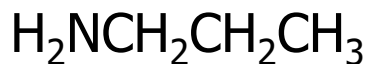
How many structural isomers can you draw for C_3H_9N ?



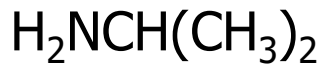
trimethyl amine



ethyl-methyl amine



n-propyl amine



isopropyl amine

Stereoisomers

Stereoisomers can be further divided into different groups

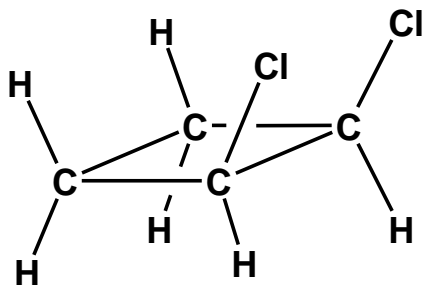
Geometric isomers have the **same connectivity** but different **spatial arrangement**.

1) double bond with two different groups attached to each atom.

2) ring with two different groups attached to two of the carbon atoms in the ring.

cis- isomer - **same** side of the ring/double bond

trans- isomer **opposite** sides of the ring/double bond.



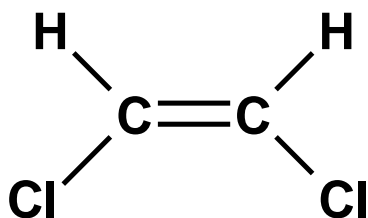
***cis* -1,2-dichlorocyclobutane**

***trans* -1,2-dichlorocyclobutane**

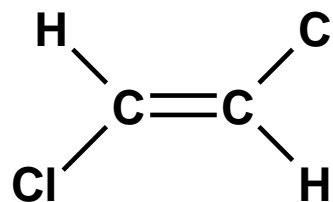
Stereoisomers

Geometric isomers have different physical and chemical **properties**.

Of the geometric isomers shown below, which would you expect to have a **higher boiling point**?



vs.



cis-1,2-dichloroethene

trans-1,2-dichloroethene

BP 60.2 °C

48.5 °C

μ 1.9 D

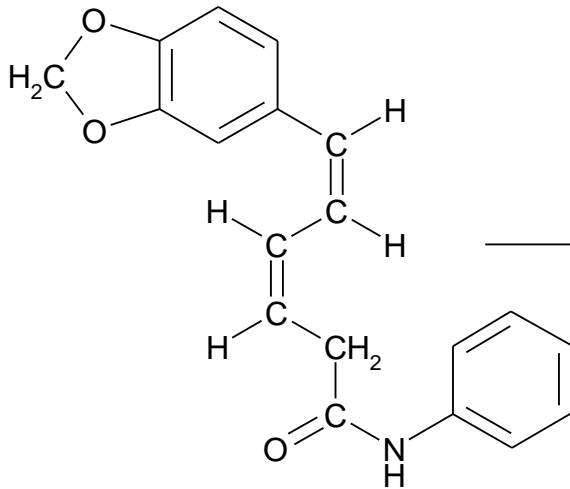
0 D

Stereoisomers

Ex) Chavicine is the molecule responsible for the flavour and smell of black pepper.

In the peppercorn, it exists as the ***cis,cis*** - isomer.

After it is ground, it is slowly converted to the ***trans,trans*** - isomer which has less flavour and aroma:



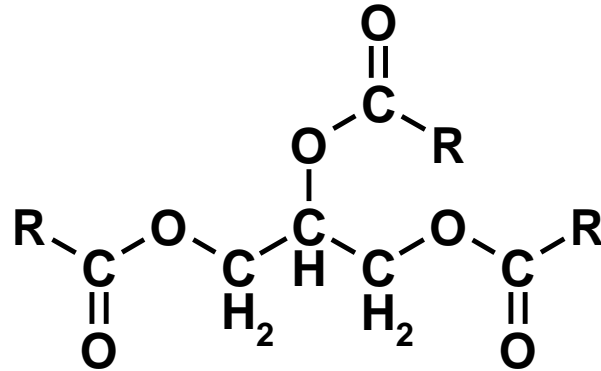
cis,cis - isomer.

trans,trans - isomer

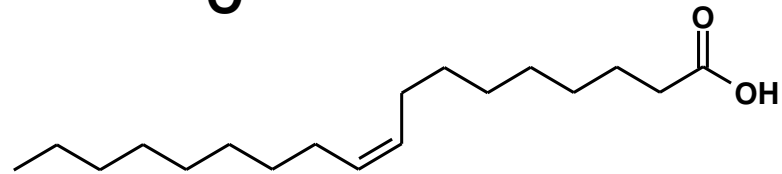
Stereoisomers

Ex) Unsaturated fats such as olive oil and canola oil contain ***cis* double bonds**.

Each fat molecule contains **three fatty acids** ($R\text{-CO}_2\text{H}$) attached to a **glycerol** ($\text{HOCH}_2\text{CH}(\text{OH})\text{CH}_2\text{OH}$) residue:



Monounsaturated fats have fatty acids with one ***cis***- double bond.



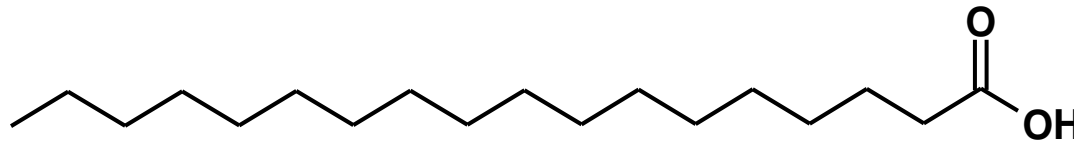
oleic acid (in olive oil)

Polyunsaturated fats have fatty acids with several ***cis***- double bonds.

Stereoisomers

Fats containing ***cis*-double bonds** tend to exist as liquids at room/body temperature.

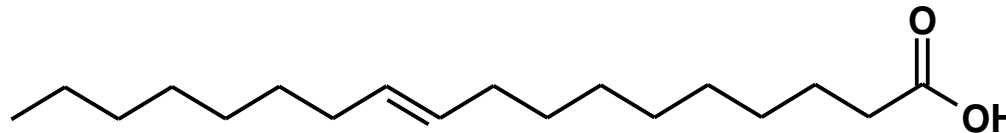
To make **solid** fats **hydrogenation** is used to '**saturate**' the fats with hydrogen:



stearic acid (a saturated fatty acid)

Saturated fats **pack** together more closely than **unsaturated** fats.

***Trans*-fats** contain fatty acids with unnatural ***trans*-double bonds** which also pack together easily **and** which the body doesn't have the enzymes to break down properly:



a trans fatty acid

***Trans*-fatty acids** are a **by-product** of partial hydrogenation.

The reaction conditions for adding H to double bonds also allows any **remaining** double bonds to **isomerize**.

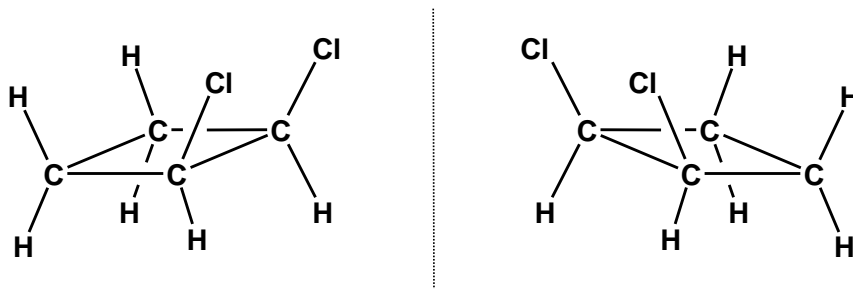
Stereoisomers

Enantiomers are isomers which are mirror images of each other.

They must have the **same connectivity** and the **same distances** between atoms.

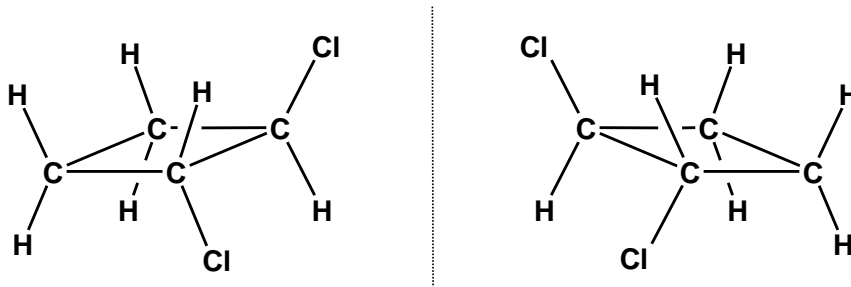
The two molecules below are **mirror images** but **can be superimposed**

These are **not** enantiomers! They are the **same** molecule!



The two molecules below are **mirror images** they **cannot** be **superimposed**.

These are **enantiomers**!



Stereoisomers

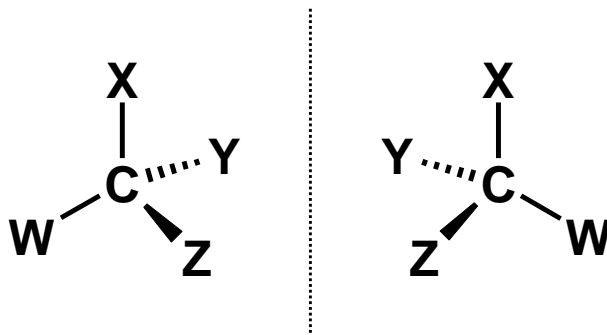
Any molecule which has an **enantiomer** is termed **chiral**. (Greek for hand)

Chiral molecules are **optically active**; they **rotate** plane-polarized light.

Any molecule which does **not** have an enantiomer is termed **achiral**.

All chiral molecules contain one or more **stereogenic centers**.

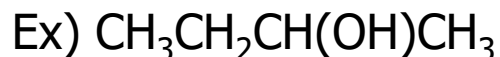
In organic chemistry, a **stereogenic center** is often a carbon atom with **4 different** groups attached:



NB: Some achiral molecules also contain **two or more** stereogenic centers, hence it is more straightforward to determine the **relationship** between the **molecule** and its mirror image.

Stereoisomers

The standard way to **draw chiral molecules** is to use **line-bond** structures with **wedges and dashes** to show stereochemistry:



The **longest chain** is drawn as a zigzag in the **plane** of the page.

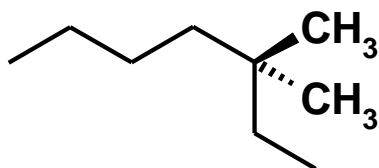
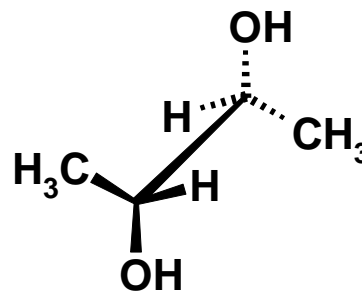
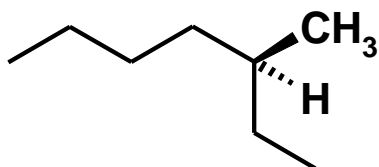
Wedges are used to show groups coming **out of the page** towards you.

Dashed lines are used to show groups going **into the page** away from you.

Stereoisomers

Exercise:

For each of the following molecules, **locate** the stereogenic center(s) and decide whether the molecule is **chiral** or **achiral**.



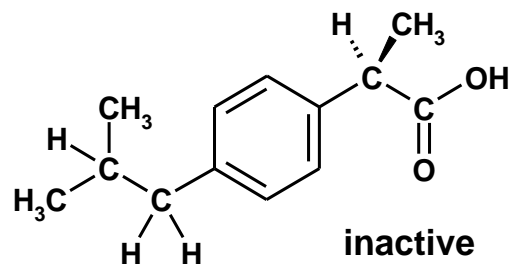
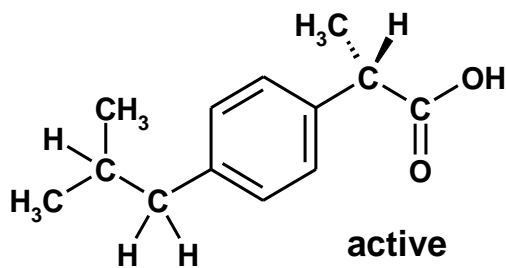
Stereoisomers

The physical and chemical **properties** of a pair of enantiomers are **identical** unless they are in a **chiral environment**.

Ex) A hormone may fit nicely into a pocket in a protein, but its **opposite** enantiomer won't and is thus **inactive**. (like gloves)

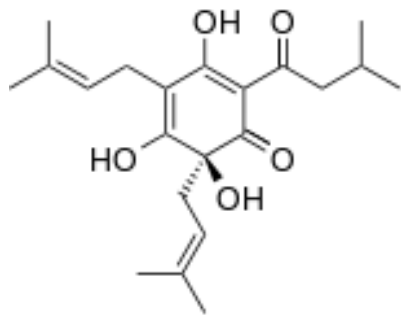
Many **drugs** are chiral and act in the same way.

Ex) **Ibuprofen** is sold as a **mixture** of enantiomers, but only one is active.

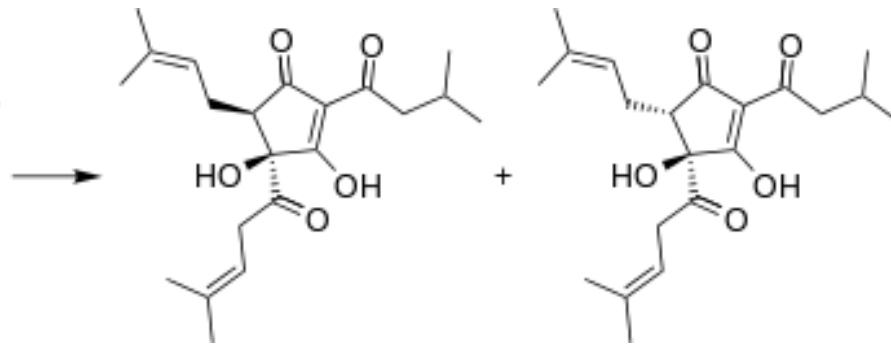


Beer - Hops

Humulone



cis and *trans* Isohumulone



Very bitter



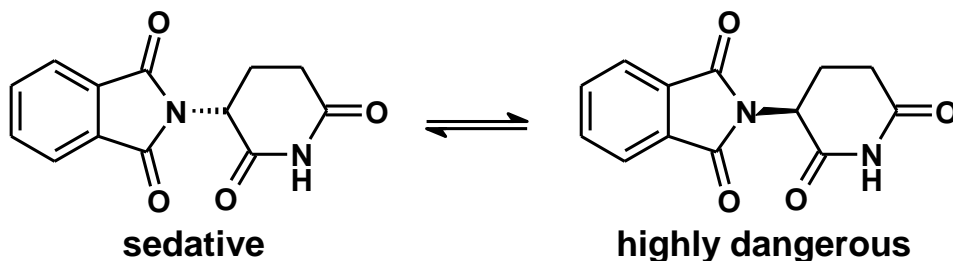
Stereoisomers

Sometimes, the 'wrong' enantiomer is can be a serious problem

It might fit into a different pocket in the protein (or another protein) or bind too strongly/weakly, giving a completely different effect from the 'right' enantiomer.

Ex) Thalidomide: which was prescribed as a medication for morning sickness in the late 1950s and early 1960s.

One enantiomer of this drug was **effective** in combating morning sickness; however, the other enantiomer caused **severe birth defects** in the children of the women who took it. It was pulled from the market 4 years after its release, but not before many 'Thalidomide babies' had been born.



Since this tragedy, there have been much tighter regulations on testing of chiral drugs. For any drug that can be converted to the other enantiomer within the body, both enantiomers must be tested as well as a mixture.

Reactions in Organic Chemistry

Synthesis - One of the major goals of organic chemistry

Need a tool kit!

By identifying the **reactive parts** a reaction can be placed into one of just a few categories.

Most organic reactions fit into one or more of the following **four** categories:

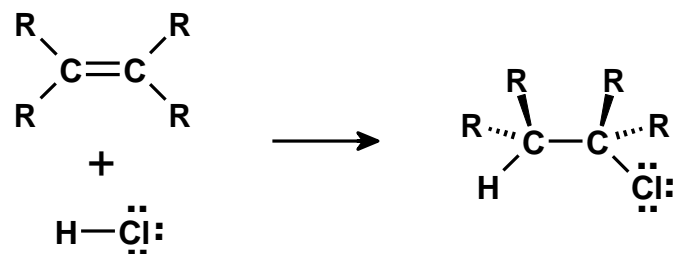
- 1) **Addition.** Two parts of a molecule are **added** across a π **bond**.
- 2) **Elimination.** Two parts of a molecule are **removed**, leaving a π **bond**.
- 3) **Substitution.** One group is **replaced** by another.
- 4) **Redox.** An atom changes **oxidation state**.

Addition Reactions

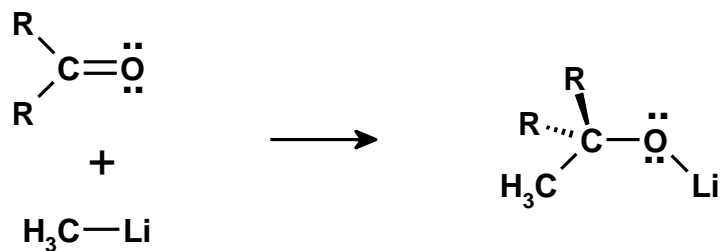
Addition reactions can be performed on most organic molecules with a π **bond**.

In an addition reaction, **two parts** of a molecule are **added** across a π **bond** of another molecule.

Ex) Addition of **HCl** across an **alkene**:



Ex) Addition of **CH₃Li** across a **ketone** or **aldehyde**:

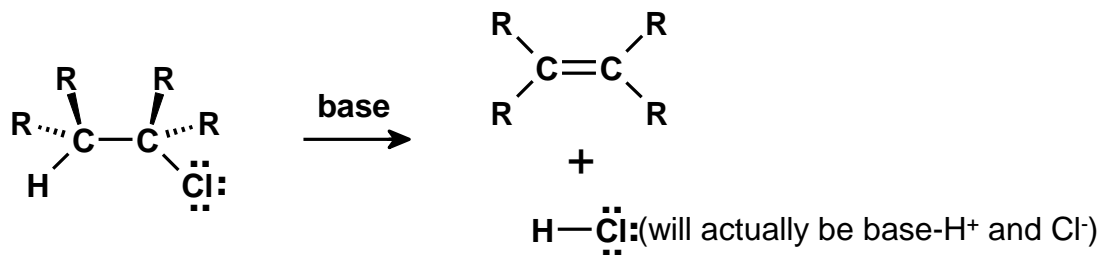


Elimination Reactions

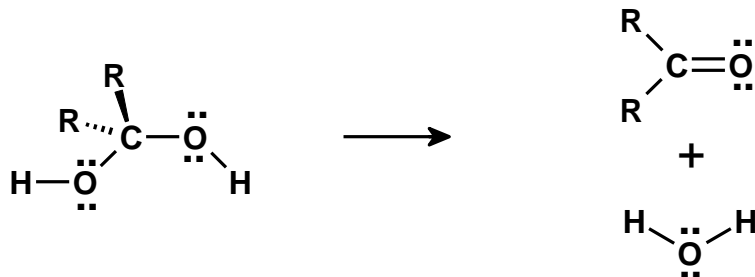
Elimination reactions are the reverse of addition reactions.

In an elimination reaction, **two parts** of a molecule are **removed** from a larger molecule, leaving behind a π **bond**.

Ex) Removal of **HCl** from a **haloalkane** (giving an alkene):



Ex) Removal of **water** from a **diol** (giving a ketone or aldehyde):



Substitution Reactions

Substitution reactions generally involve **tetrahedral** carbon atoms with good **leaving groups** attached.

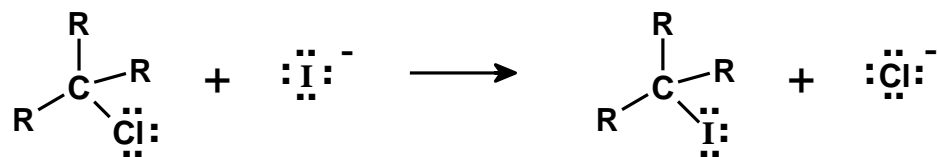
A **leaving group** is part of an organic compound that would be a **stable** molecule or ion on its own if it took a pair of electrons.

Ex) **R-Cl** becomes **Cl⁻** is stable => a good leaving group.

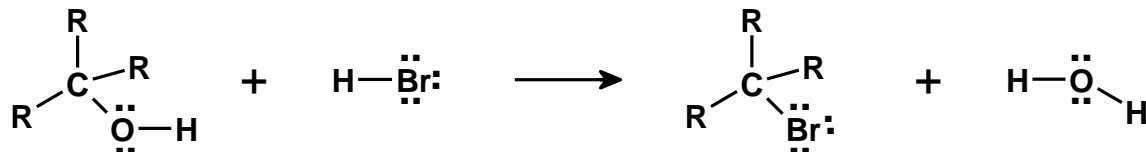
Ex) **R-OH** becomes **OH⁻** is not as stable as **OH₂** from **R-OH₂⁺** (Acid Helps).

In a substitution reaction, one group is replaced by another group:

Ex) Replacement of a **chloro** group by an **iodo** group:



Ex) Replacement of a **hydroxy** group by a **bromo** group:



Redox Reactions

Carbon can have any oxidation state from -4 to +4.

Any reaction in which the oxidation state of carbon changes is a **redox reaction**.

Many organic reactions fit into both the redox category and one of the other three categories.

We will focus on the other three categories of organic reactions.

Exercise: Propose a set of molecules showing the +4, +2, 0, -2, and -4 oxidation states of carbon.

Nucleophiles and Electrophiles

In reaction electrons **flow** from **electron-rich** atoms to **electron-poor** atoms.

Essentially **the same** as electrons flow from **Lewis base** to **Lewis acid**.

The electron **donors** are termed **nucleophiles** (lovers of nuclei or positive charges) and the **electron-rich** parts of them are the **nucleophilic sites**.

Nucleophilic sites typically have a partial (or full) **negative charge** and at least one **lone pair** of electrons, which they can **donate**. (like Lewis Base).

Ex NR_3 , OH^- , Cl^-

The electron **acceptors** are termed **electrophiles** (electron lovers) and the **electron-poor** parts of them are the **electrophilic sites**.

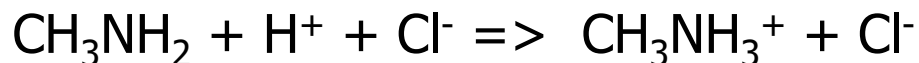
Electrophilic sites typically have partial (or full) **positive charge** and able to **accept electrons**. (Like a Lewis Acid).

Ex H^+ , $-\text{C}(=\text{O})-$, $^+\text{CR}_3$, $\text{X}-\text{C}(\text{R})_3$

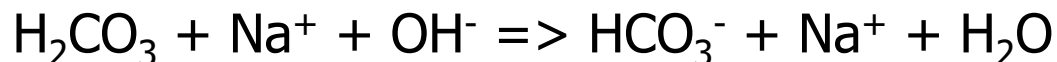
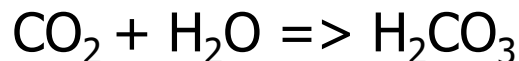
Following Electrons with Curly Arrows

Let's look at some **familiar reactions** to see how the curly arrows show the electron movement: *ie* **reaction mechanism**.

What happens when CH_3NH_2 is added to a solution of HCl?

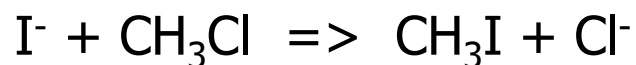


What happens when CO_2 is bubbled through an aqueous solution of NaOH?

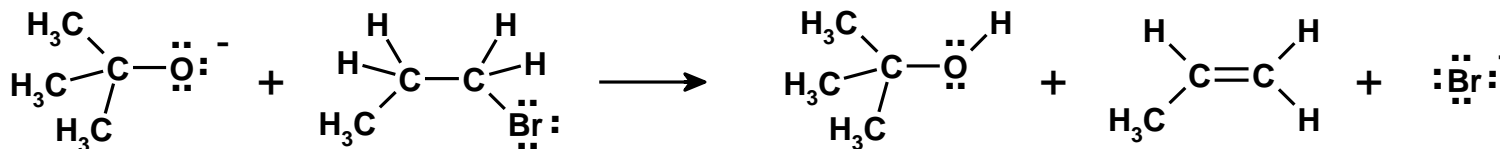


Following Electrons with Curly Arrows

What happens when an iodide anion reacts with chloromethane?



Use curly arrows to show the movement of electrons in the following reaction:

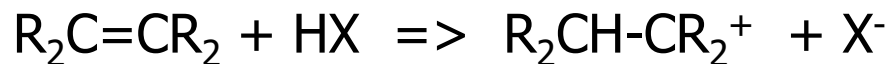


NB: the bromide ion that leaves in this reaction. Why doesn't hydrogen leave instead?

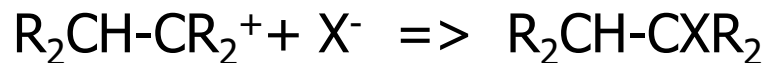
Addition Reactions of Alkenes and Alkynes (HX)

Alkenes and alkynes are good **nucleophiles** as they have **electron-rich π bonds**.

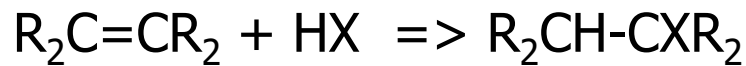
They **react** with good **electrophiles** like HCl, HBr and Br₂:



This gives a **carbocation**, a very **reactive electrophile** which immediately reacts with the remaining **nucleophilic halide**:



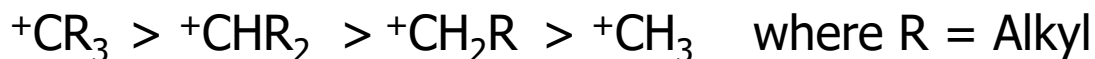
The **overall** reaction is:



Addition Reactions of Alkenes and Alkynes (HX)

Carbocations are **not** particularly **stable**.

They can be **stabilized** somewhat by **alkyl groups** (methyl, ethyl, etc.) attached to the carbon with the positive charge:



They can also be stabilized by **resonance**:



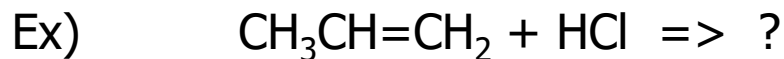
A carbocation will **not** form unless it has some type of **stabilization**.

Addition Reactions of Alkenes and Alkynes (HX)

If the alkene was **not symmetric**, we would have to decide **which carbon** bonded to the **H⁺** and which carbon bonded to the **Cl⁻**.

Compare the **two** possible carbocations formed.

Whichever is **more stable** will form more readily and then will react with Cl⁻ to give the product:



This is known as **Markovnikov's rule**.

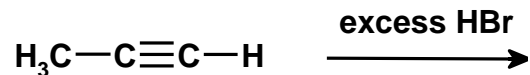
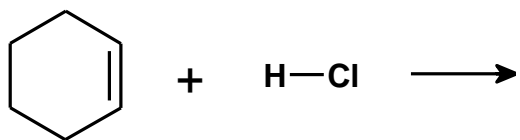
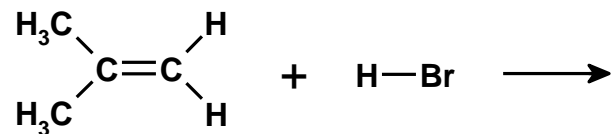
It's often misstated as: *The hydrogen adds to the side with **more** hydrogens.*

That works for many examples – but not all!

The real Markovnikov's rule is: *make the **more** stable carbocation.*

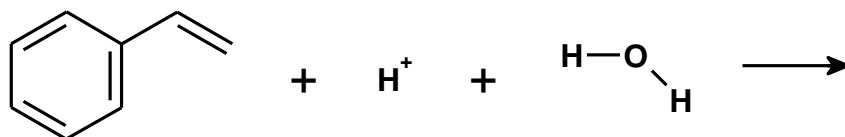
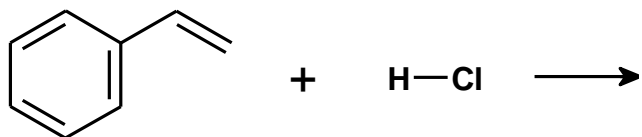
Addition Reactions of Alkenes and Alkynes (HX)

Draw the major organic product for the following reactions:



Addition Reactions of Alkenes and Alkynes (HX)

Draw the major organic product for the following reaction:

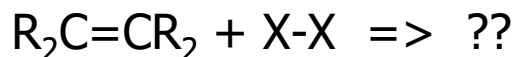


Addition of water to an alkene proceeds according to the same mechanism as addition of HCl, HBr or HI to an alkene.

This means that there needs to be some acid (e.g. H₂SO₄) in the flask.

Addition Reactions of Alkenes and Alkynes (X_2)

Addition of **chlorine** or bromine across a π bond works in a similar fashion:



The π bond is nucleophilic and the halogen molecule is electrophilic (??) .

The alkene donates its π electrons to the electrophilic end of the halogen, creating a carbocation :

NB: **resonance stabilization** from the halogen atom resulting in a ring.

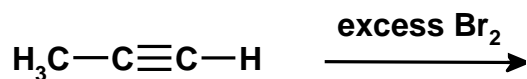
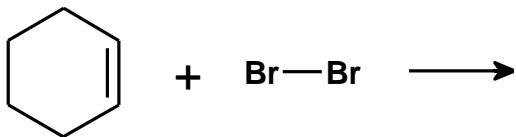
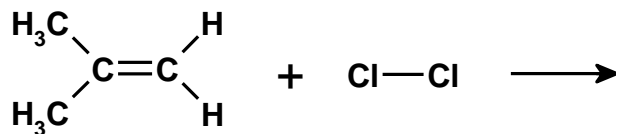
As the positive charge is on the halogen atom, it is referred to as a **chloronium** ion or a **bromonium** ion.

The special carbocation quickly reacts with the remaining halide ion.

As the halogen atom is **leaning over** to resonance stabilize the carbocation, it blocks that side of the carbocation and the halide must attack from the other side:

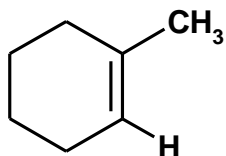
Addition Reactions of Alkenes and Alkynes (HX)

Draw the major organic product for the following reactions:



Addition Reactions of Alkenes and Alkynes

In summary, we can add a variety of small molecules across a carbon-carbon double bond. In the diagram below, X is a halogen (specifically Cl, Br or I):



Because we understand the mechanism behind these reactions, we can predict which isomer will be the major product.