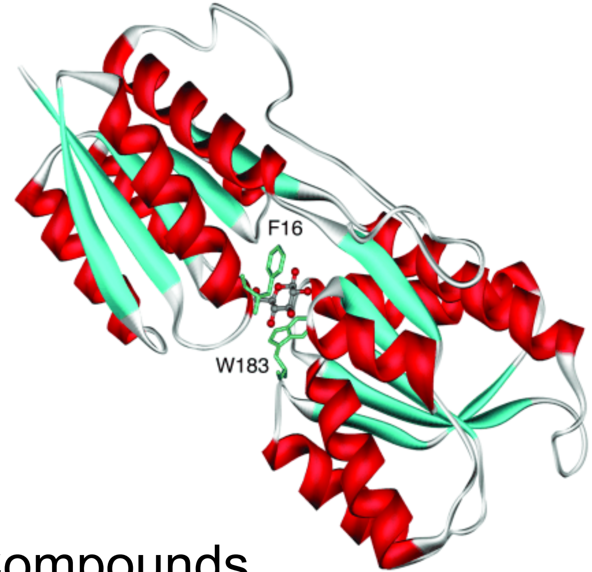
Chemistry of Life:
Organic and Biological Chemistry

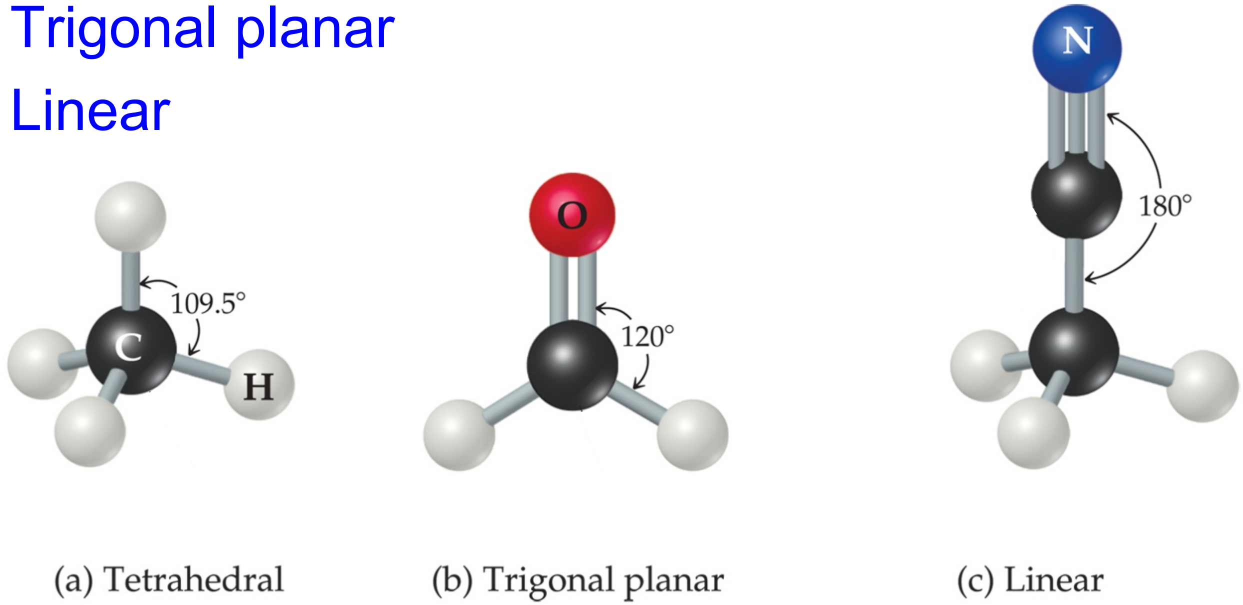


What's Ahead:

1. Structures and Nomenclature of Organic Compounds
2. Hydrocarbons: Alkane, Alkene, Alkyne and Aromatic
3. Isomers and Chirality
4. Amino Acids and Proteins

Structure of Organic Compounds

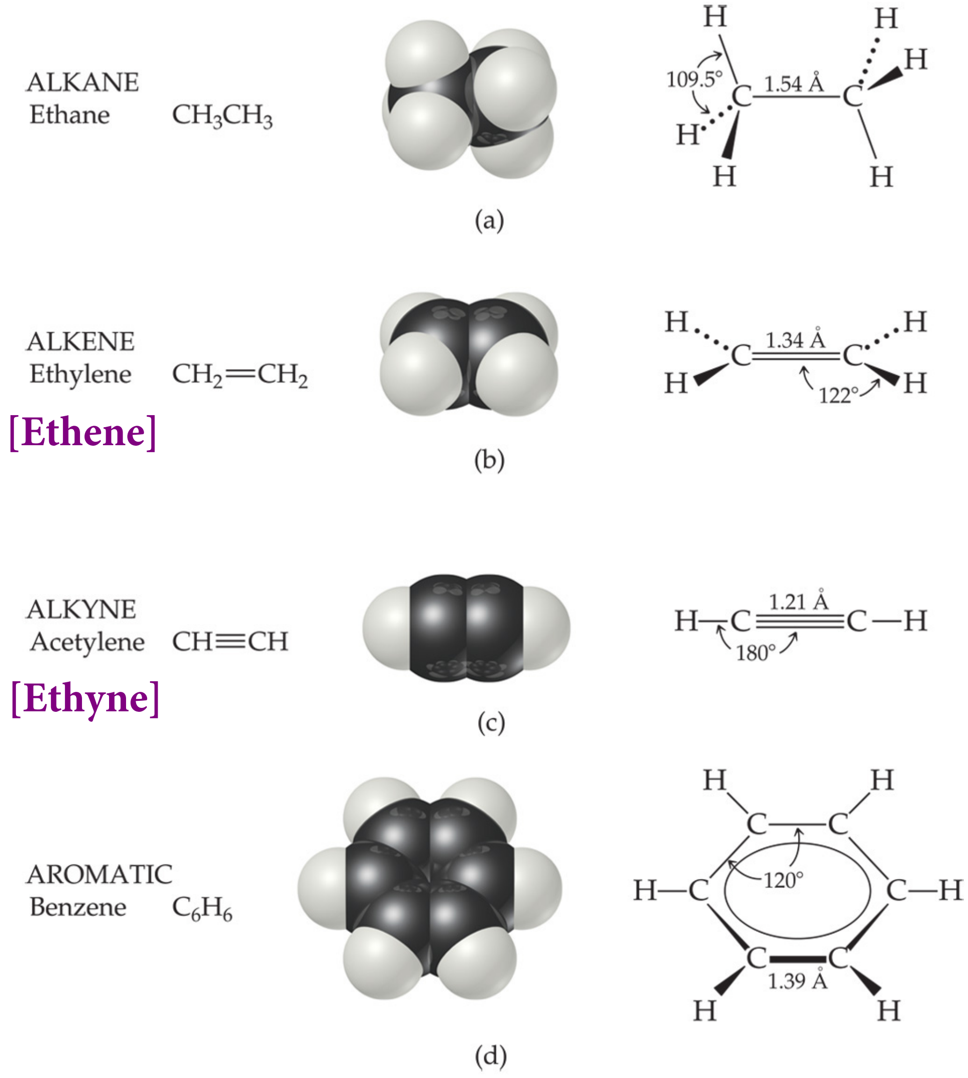
- There are three common geometries in organic compounds:
  - ➢ Tetrahedral
  - ➢ Trigonal planar
  - ➢ Linear



(a) Tetrahedral C is bonded to 4 atoms; (b) trigonal planar C bonded to 3 atoms; (c) linear C bonded to 2 atoms.

Hydrocarbons

- Contain only C and H atoms and stable carbon-carbon bonds.
- Four basic types:
  - ➢ Alkanes
  - ➢ Alkenes
  - ➢ Alkynes
  - ➢ Aromatic hydrocarbons

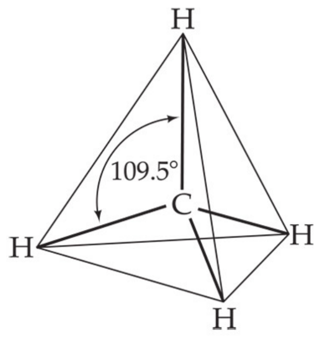


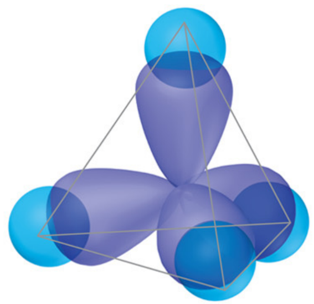
Alkanes

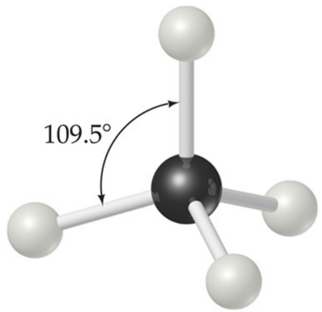
Molecular Formula	Condensed Structural Formula	Name	Boiling Point (°C)
CH_4	CH_4	Methane	−161
C_2H_6	CH_3CH_3	Ethane	−89
C_3H_8	$CH_3CH_2CH_3$	Propane	−44
C_4H_{10}	$CH_3CH_2CH_2CH_3$	Butane	−0.5
C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$	Pentane	36
C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$	Hexane	68
C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	Heptane	98
C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Octane	125
C_9H_{20}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Nonane	151
$C_{10}H_{22}$	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Decane	174

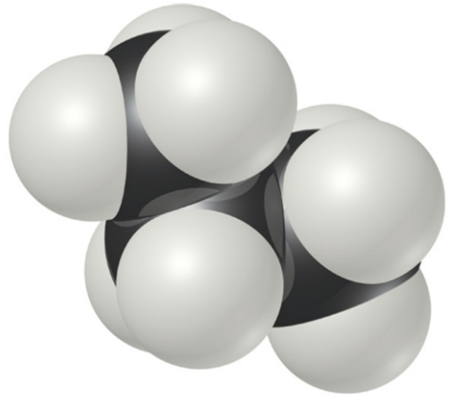
- Saturated hydrocarbons: contain highest possible number of H atoms per C atom
- General formula: $\mathbf{C}_n\mathbf{H}_{2n+2}$ (only C–C single bonds)
- Boiling point increases with length of chain.
- Consequence of

Structures of Alkanes



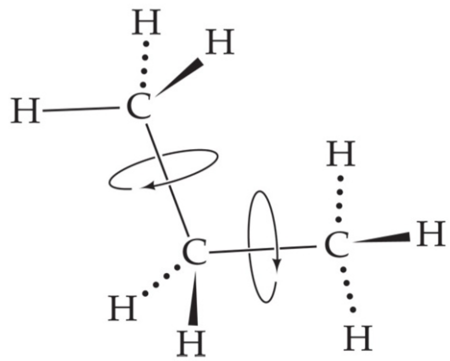




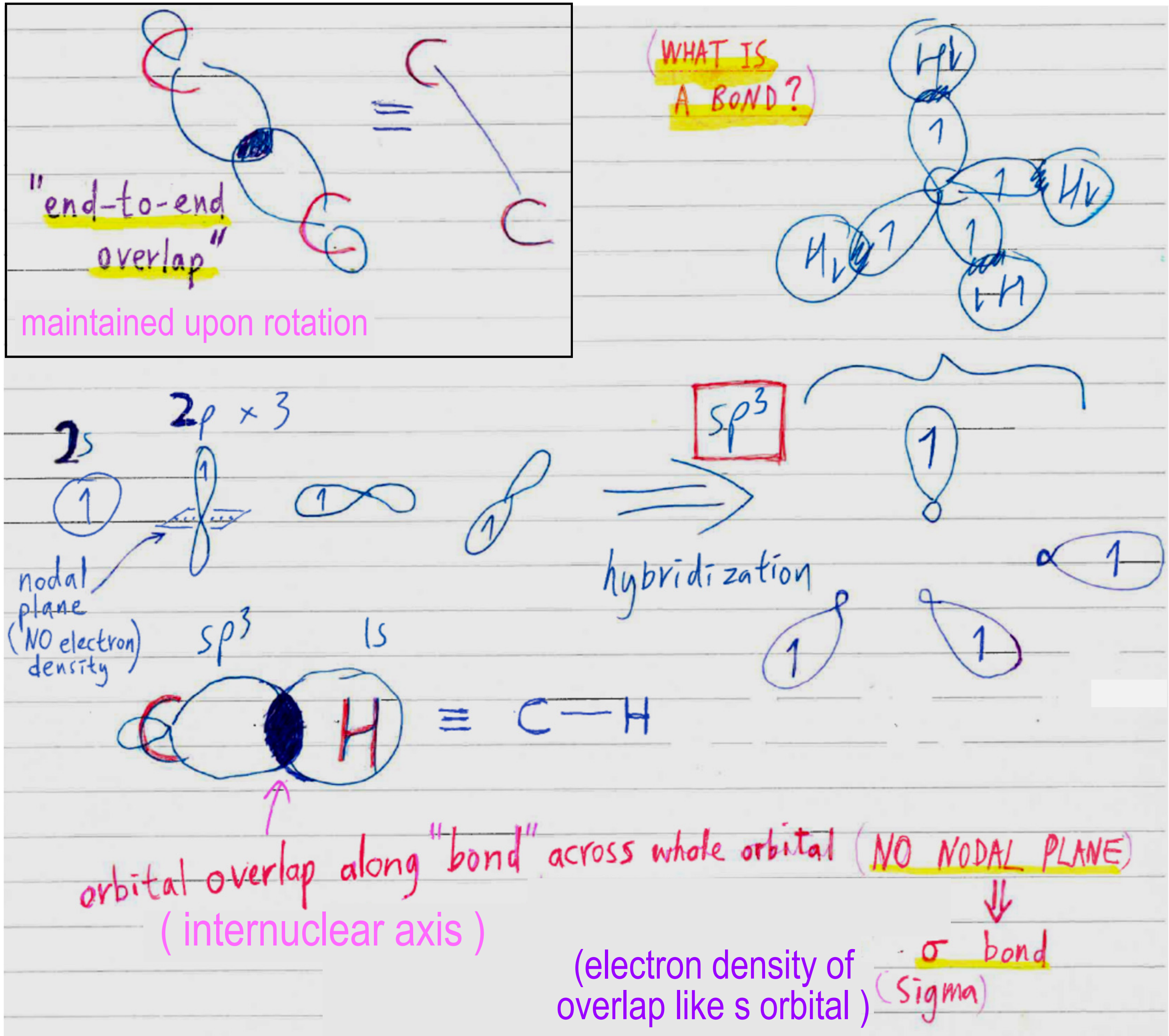


- **sp^3-hybridized** C atoms in alkanes have tetrahedral geometry.
- Form **σ-bonds** with H atoms (1s orbitals).
- 109.5° bond angles.

- Only C—C single bonds exist.
- **End-to-end orbital overlap...** so **free rotation** can occur about the C—C bonds.

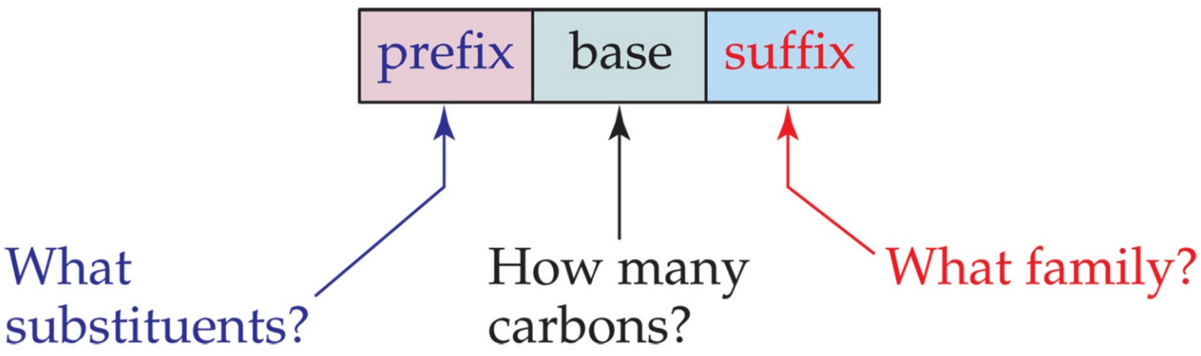


(quick guide) HYBRIDIZATION: sp^3

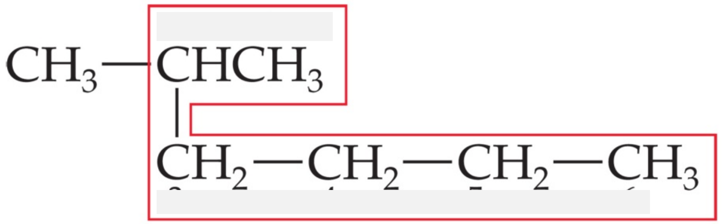


Organic Nomenclature

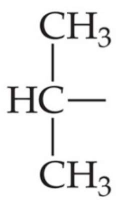
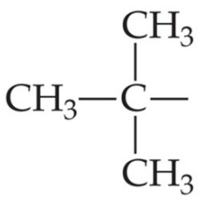
- Three parts to a compound name:
  - Base: Shows number of carbon atoms in the longest continuous chain.
  - Suffix: Shows the type or family of compound.
  - Prefix: Shows the nature and **position** of group(s) attached to chain.



To Name a Compound…



Name?

Group	Name
CH_3—	Methyl
CH_3CH_2—	Ethyl
$CH_3CH_2CH_2$—	Propyl
$CH_3CH_2CH_2CH_2$—	Butyl
	Isopropyl
	*tert*-Butyl

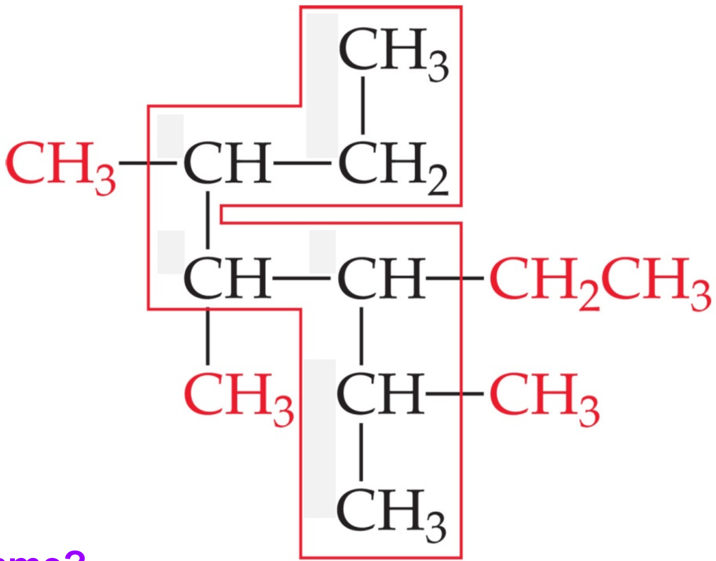
1. Find the longest chain and family of molecule.

1(b) Number double/multiple bond.

2. Number the chain from the end nearest the first substituent encountered.
3. List the substituents as a prefix along with the number of the carbon(s) to which they are attached.

Organic and Biological Chemistry

To Name a Compound…



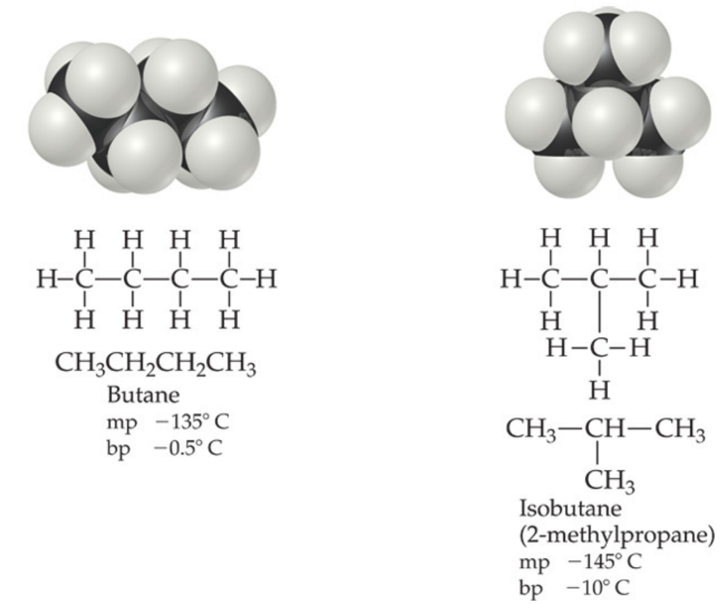
Name?

4. When two or more types of substituents are present in the molecule, list them alphabetically.

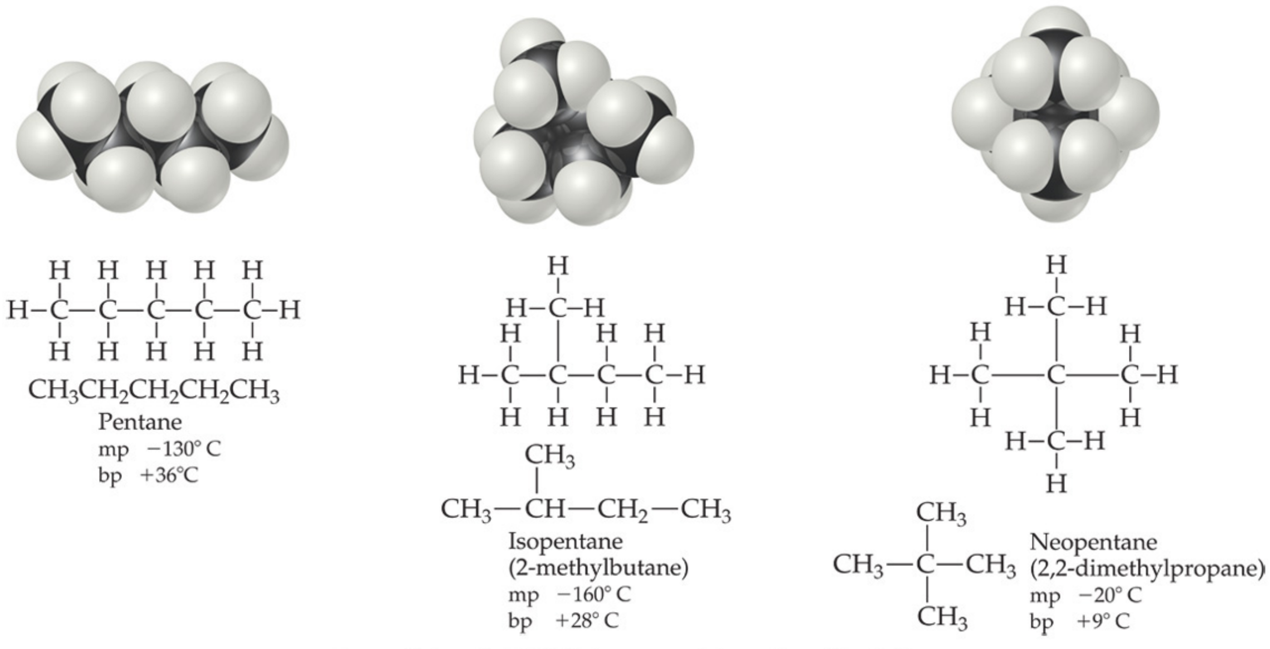
Prefix: di- (two), tri- (three), tetra- (four), penta- (five), etc.

Organic and Biological Chemistry

Structural Isomers



Same molecular formulas, but atoms are bonded in different order: **straight-chain** or **branched** hydrocarbons.



Organic and Biological Chemistry

Reactions of Alkanes

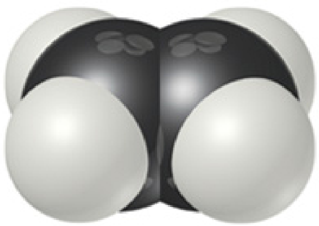
- Most alkanes are unreactive:
  - At room temperature, no reaction with acids, bases, and strong oxidizing acids.
  - No reaction even with boiling nitric acid.
- Low chemical reactivity due to **lack of** and strength of
- Therefore, they are excellent non-polar solvents.

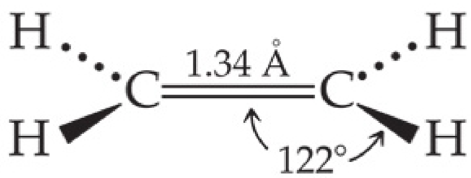
Unsaturated Hydrocarbons

- Unsaturated organic compounds have **less than maximum number of H** atoms per C.
- Hence they contain one or more multiple bonds, which make their structure and reactivity very different from saturated hydrocarbons.

ALKENE
Ethylene
[Ethene]

$CH_2{=}CH_2$

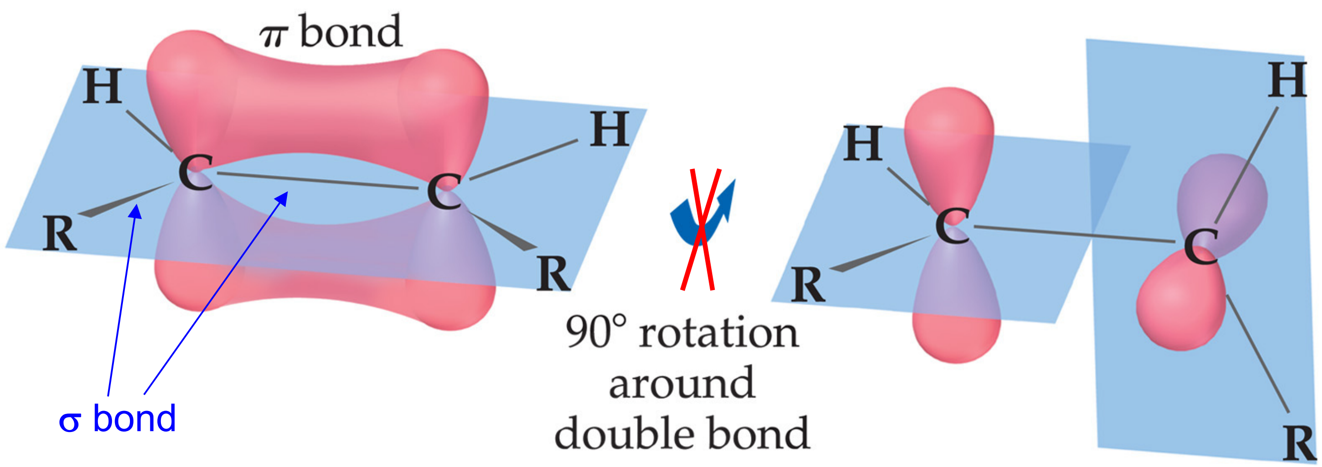




- Alkenes (olefins) contain at least one carbon–carbon **double bond.**
- General formula: $\mathbf{C_{\mathit{n}}H_{2\mathit{n}}}$

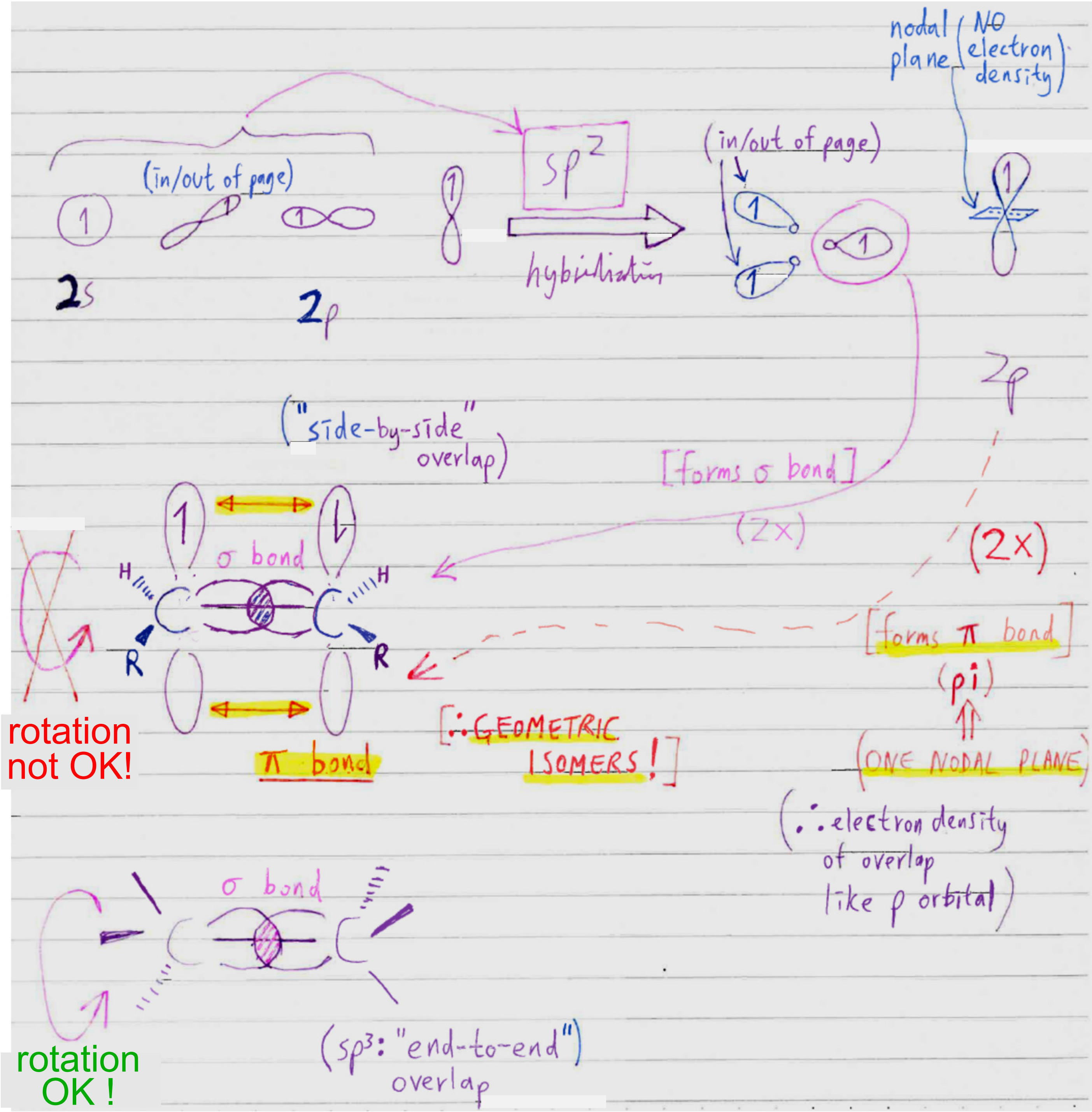
Multiple Bonding: Nature of π Bonds

- Two *p* orbitals overlap in **side-by-side** fashion to form π bond.
- Less orbital overlap in π bonds compared to σ bonds, so **π bonds are generally weaker**.
- Unlike alkanes, alkenes **cannot** rotate freely about the double bond.
  - The π bond must be broken during the rotation (requires about 250 kJ/mol).



(quick guide)

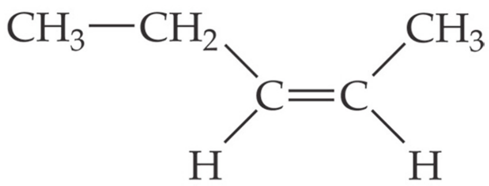
HYBRIDIZATION: sp^2



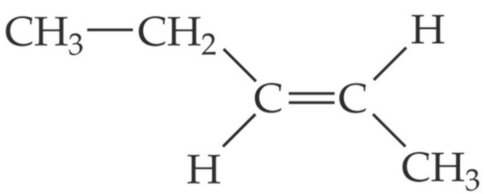
Nomenclature of Alkenes

- So we observe **geometric isomers**, which differ from each other in the spatial arrangement of groups about the double bond.
- Chain is numbered so double bond gets smallest possible number.
- Unbranched isomers of pentene, C_5H_{10} is given.
- ***cis***-Alkenes: **same** side of molecule.
- ***trans***-Alkenes: **opposite** sides.

$CH_3—CH_2—CH_2—CH{=}CH_2$

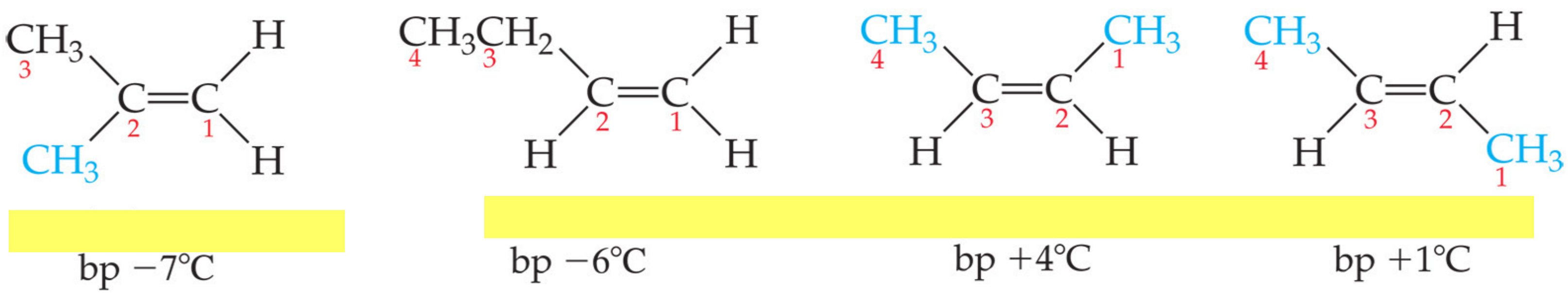


Names?



Structures and Properties of Alkenes

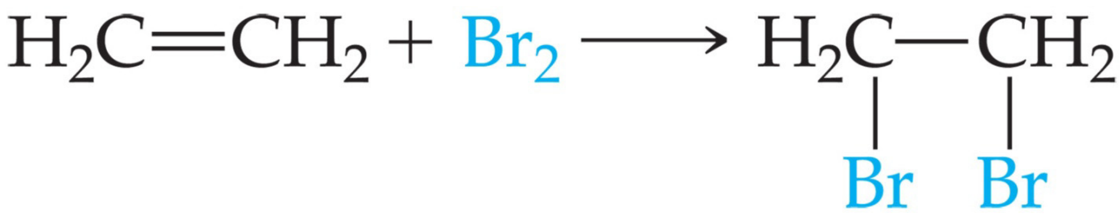
- *cis*-Alkenes: same side of molecule.
- *trans*-Alkenes: opposite sides.



Names?

- C_4H_8 structural isomers: structure also affects physical properties.

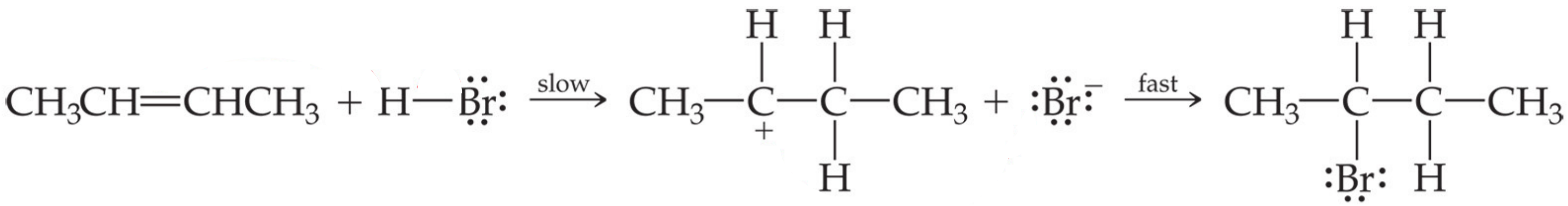
Reactions of Alkenes



- **Addition reactions** are characteristic:
  - Two atoms (e.g. bromine) add across the double bond.
  - One π-bond and one σ-bond are replaced by two σ-bonds; so heat (energy) is typically and ΔH is

Mechanism of Addition Reactions

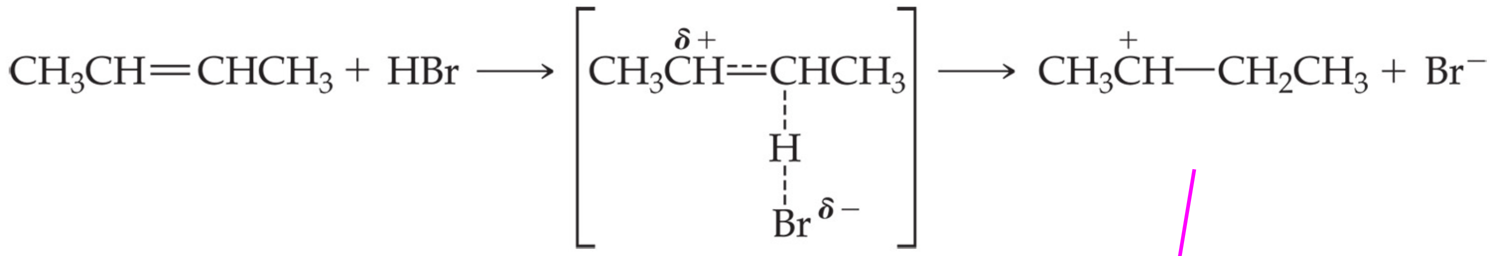
intermediate



- Two-step mechanism:
  - ➢ First step is slow, **rate-determining** step.
  - ➢ Second step is fast.

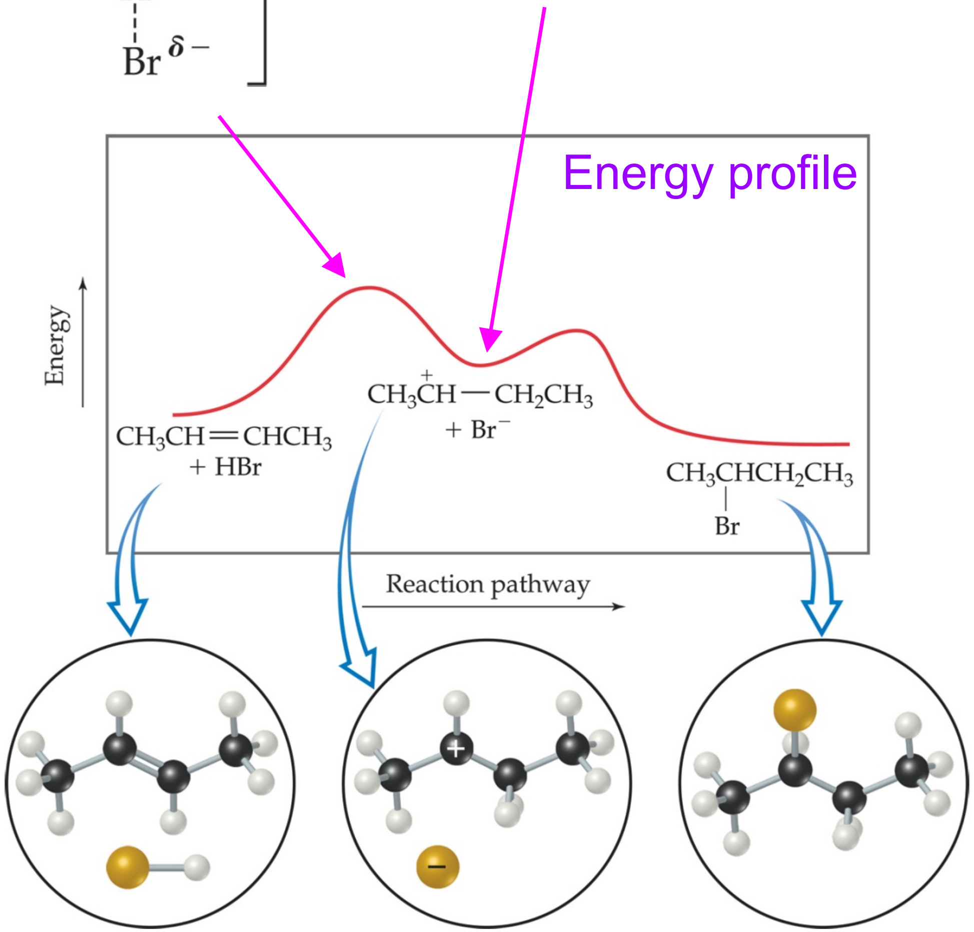
- Arrows show the direction of electron flow; from negative to positive charge....(draw them!)

Step 1 of Addition Reaction



- In 1st step, π-bond is broken, and the electron pair is used to form new __________ bond.

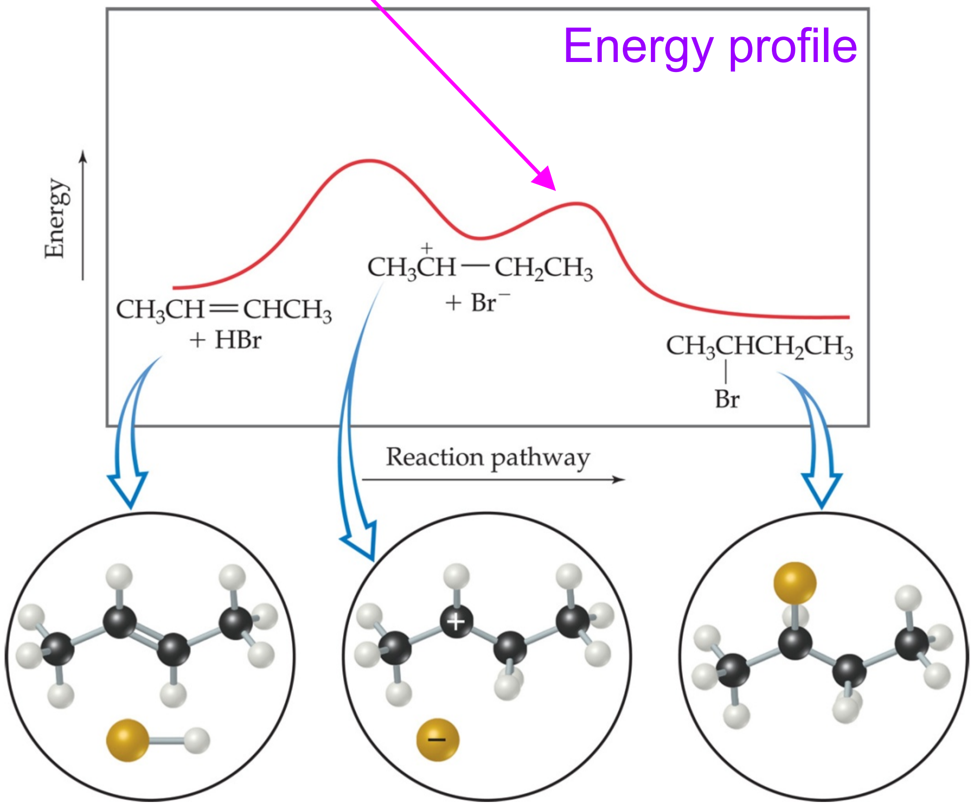
- This results in formation of cation (= intermediate).



Step 2 of Addition Reaction

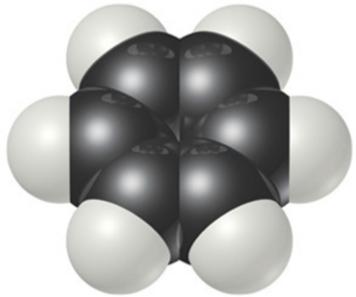
$$CH_3\overset{+}{C}H-CH_2CH_3 + Br^- \longrightarrow \left[CH_3\underset{\vdots\atop Br^{\delta-}}{\overset{\delta+}{C}H}-CH_2CH_3 \right] \longrightarrow CH_3\underset{|\atop Br}{C}HCH_2CH_3$$

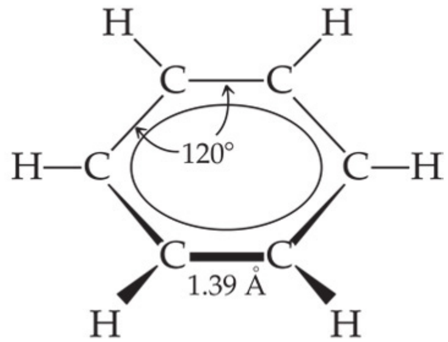
- In 2nd step, bromide anion donates pair of electrons to cationic carbon atom, forming new bond.



Aromatic Hydrocarbons

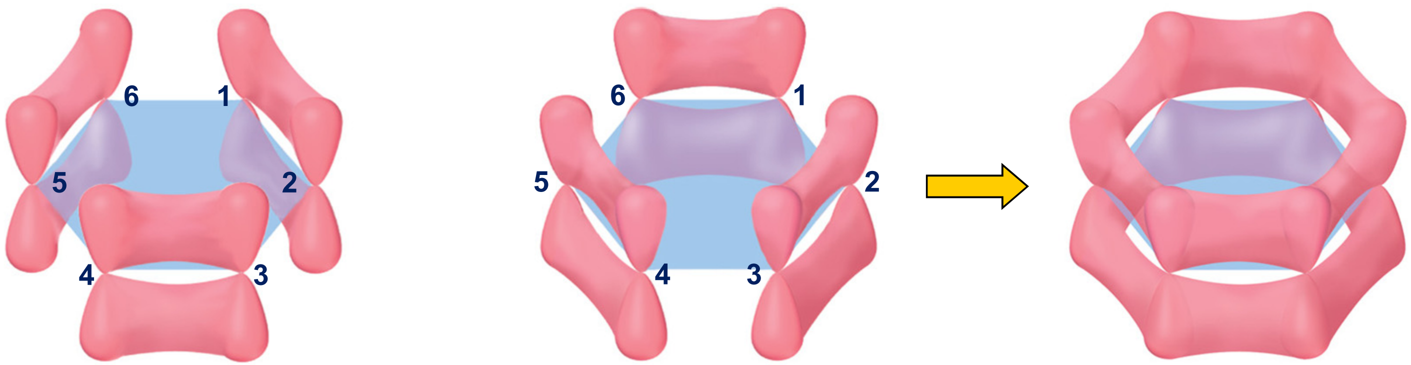
AROMATIC
Benzene C_6H_6





- Cyclic hydrocarbons.
- *p*-orbital on each C atom: planar, highly symmetric structure.

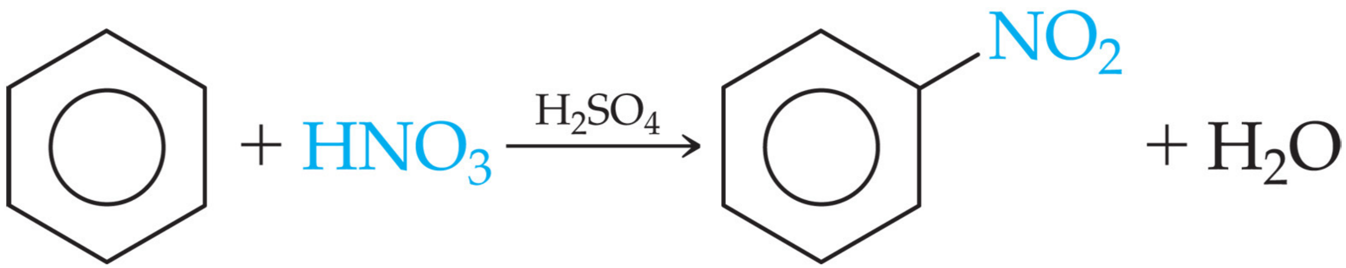
unusually stable !



The six 2*p* orbitals of benzene can make localized π bonds. These π bonds correspond to the two resonance structures for benzene.

Spreading out or delocalization of the three C–C π bonds among the six C atoms.

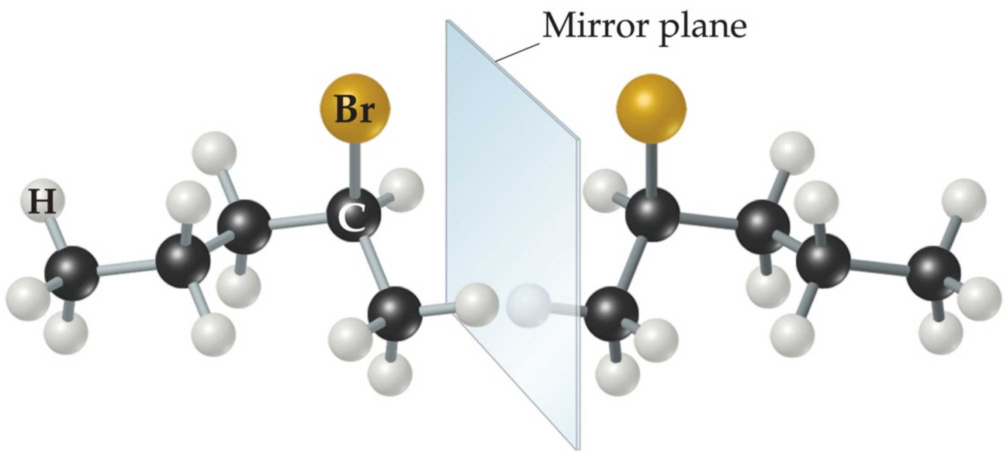
Reactions of Aromatic Compounds



- Unlike in alkenes, the π electrons are not localized between two C atoms.
- Due to delocalization, unsaturated aromatic compounds are stabilized compared to alkenes and do **NOT** undergo addition reactions.
- Instead, they undergo substitution reactions, where H is replaced by another substituent: **electrophilic aromatic substitution**.

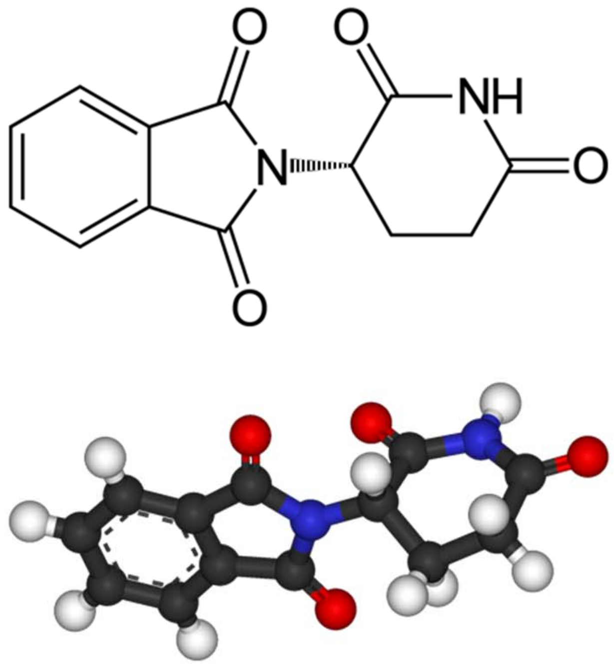
Chirality

- Compounds containing carbon atom(s) with four different groups attached to them are **chiral (mirror image is non-superimposable)**; e.g. 2-bromopentane.

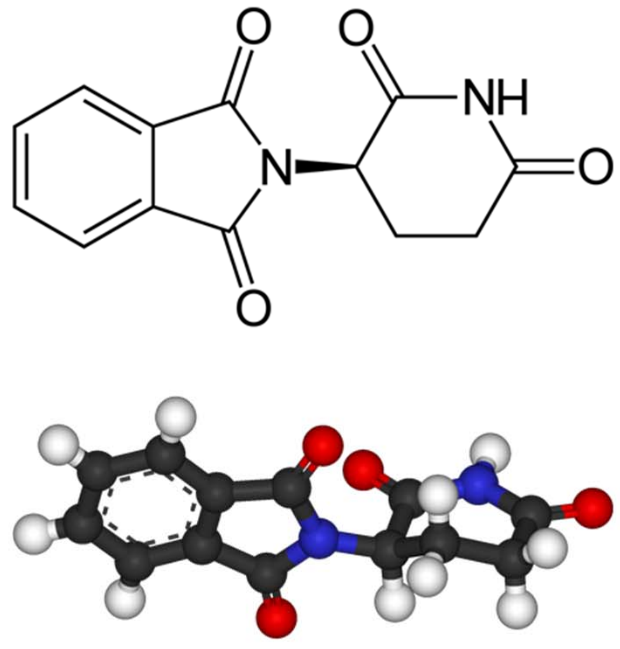


- The mirror images are called optical isomers or **enantiomers** (*R* and *S* for right- and left-handed).
- Enantiomers exhibit **identical** melting and boiling points, but behave **differently** in chiral environments and reactions...

(*R*)-Thalidomide



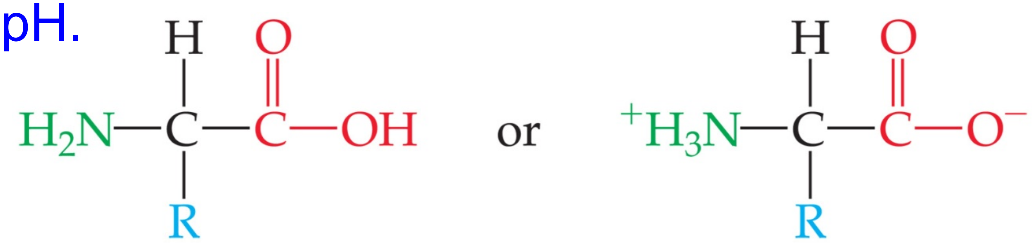
(*S*)-Thalidomide



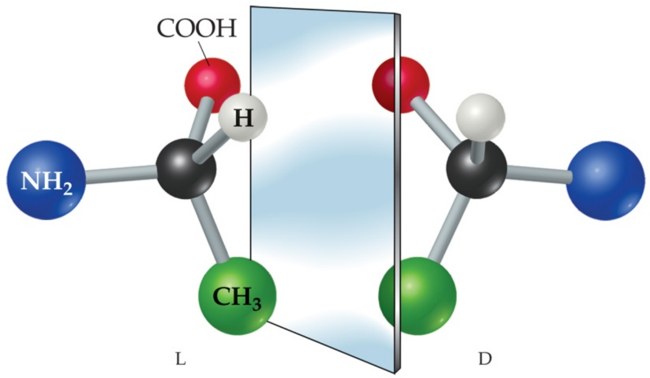
- The thalidomide drug contained both left- and right-handed **isomers**.
- ***(R)*** **enantiomer** is effective against morning sickness, but ***(S)*** is **teratogenic** and causes birth defects.

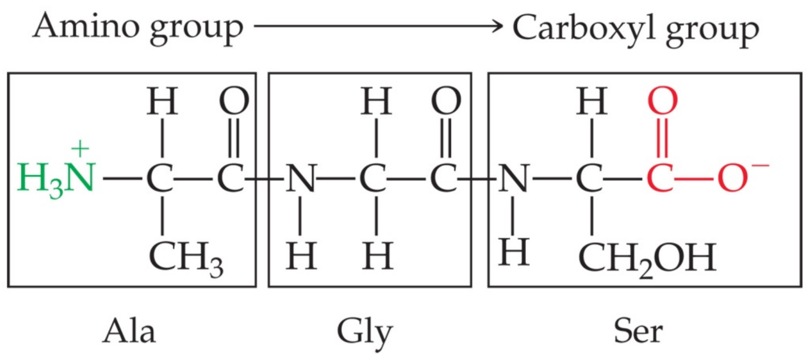
Amino Acids and Proteins

- Proteins are polymers of **α-amino acids**, which exist as at neutral pH.



- Alanine (R = CH_3) is chiral, and two enantiomers are possible, but **only the left-handed L form is found in nature.**
- A condensation reaction between amine end of one amino acid and acid end of another produces a **bond**.





tri

Amino Acids and Proteins

- Sequence of amino acids is the **primary structure**.
- "Intermolecular" forces (incl. H-bonding) in peptide chain result in coils and helices: **secondary structure**.
- Overall characteristic shape determined by kinking and folding of the coiled chain: **tertiary structure**.
- Most enzymes (biological catalysts) are proteins.
- ***Shape*** of **'active site'** fits ***shape*** of relevant substrate (**lock-and-key** model).