CHIMICA ORGANICA I

Organizzazione

Docente:

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  - Tel.: 040 558 3924
  - Ricevimento: per appuntamento (e-mail)

Organizzazione

8 CFU / 64 ore

Lezioni frontali (teoria) ed esercizi

Lavagna/power point

Raccomandato prendere appunti e usare un libro.

Libri di testo

John McMurry
Chimica Organica
PICCIN-NUOVA LIBRARIA

D'Auria M.V.; Taglialatela Scafati O.; Zampella A.
Guida ragionata allo svolgimento di esercizi di chimica organica
LOGHIA

Brown W.H.; Foote, C.S.; Iverson, B.L.
Chimica Organica
EdiSES

Janice Gorzynski Smith
Organic Chemistry
McGraw-Hill

Vollhardt K. Peter; Schore Neil E.
Chimica organica
Zanichelli

Solomons T.W. Graham;
Fryhle Craig B.
Chimica organica
Zanichelli

Seyhan N. Ege
Chimica Organica: Struttura e reattività
Idelson-Gnocchi

Modalità di esame

Scritto e orale

Scritto: 2 verifiche in itinere o prova scritta in appello

Esito: ammesso o non ammesso alla prova orale

In caso di superamento il voto resta valido per tutto l'anno accademico (fino alla sessione straordinaria)

Orale: negli appelli ufficiali

Prerequisiti: aver superato l'esame di Chimica Generale ed Inorganica

L' ATTUALE SITUAZIONE LEGATA AL COVID E ALLA SUA EVOLUZIONE POTREBBERO INFLUIRE SULL' ORGANIZZAZIONE DEL CORSO E SULLE MODALITA' DI ESAME. QUESTI ASPETTI VERRANNO DISCUSSI CON IL DOCENTE

Obiettivi formativi

Acquisire le conoscenze di base su:

- struttura e legame di molecole organiche semplici (monofunzionali),
- meccanismi delle principali reazioni organiche,
- reattività dei principali gruppi funzionali,
- sintesi delle principali classi di composti organici,
- proprietà stereochimiche delle molecole organiche e chiralità.

Materiale in Moodle

ORGANIC CHEMISTRY = Chemistry of Carbon Compounds

Joseph Proust 1754-1826

The Inorganic World
Non-Living Entities
Rational Laws

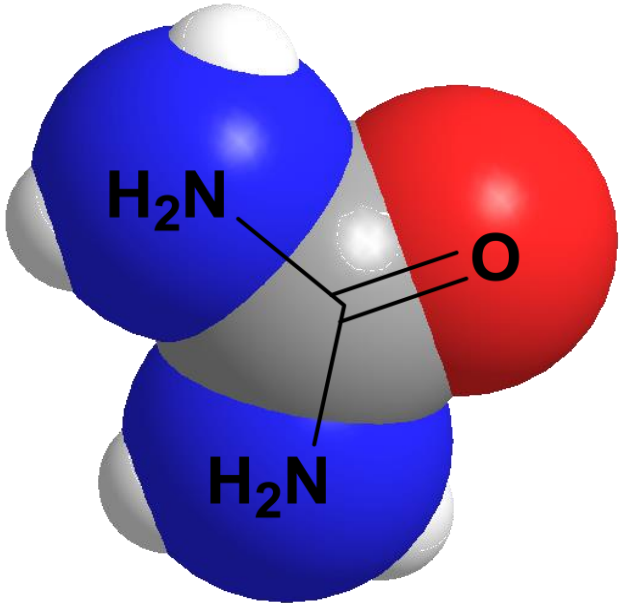
Organic World
Living Entities
Vital Spark

Inorganic Compounds:
Es. NH_3, H_2O
Definite Proportions

Organic World: Es. CH_4, C_2H_6, C_3H_8,
C_2H_4
C_2H_2
Similar properties but different proportions:
Vitalism!

1828: The End of Vitalism

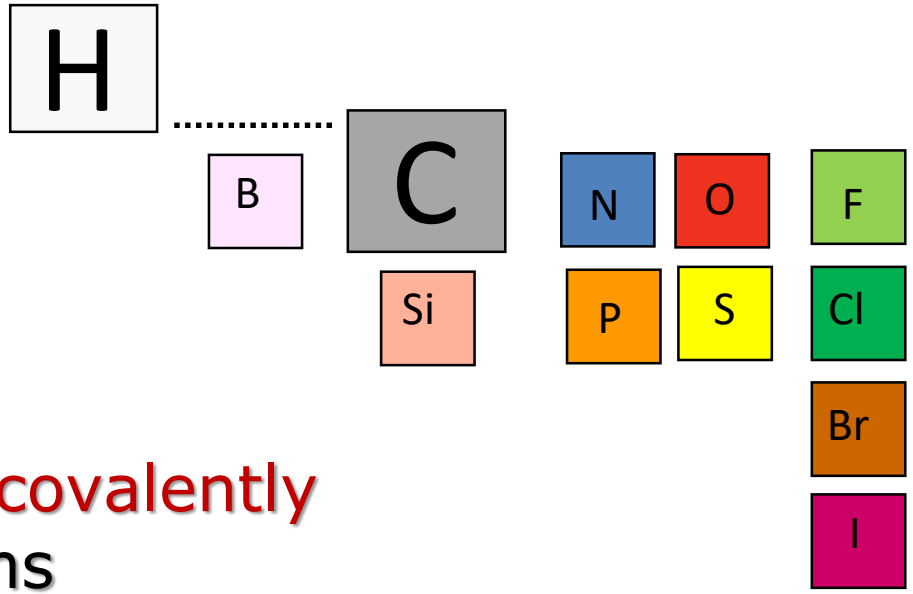
Friedrich Woehler
1800-1882



UREA

$$NH_4NCO \xrightarrow{\text{heat}} \mathbf{CO(NH_2)_2}$$

ORGANIC CHEMISTRY = Chemistry of Covalent Carbon Compounds



- Carbon Compounds covalently bonded to other atoms

H B N O Si P S F Cl Br I

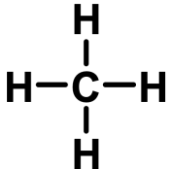
Heteroatoms

Organic Compounds are Ubiquitous

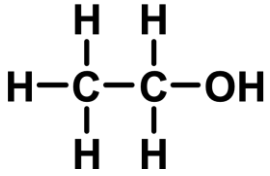
There are approximately 60.000.000 organic molecules.

- Biomolecules: c*arbohydrates, lipids, proteins and nucleic acids*.
- Materials: c*otton*, *paper*, *wood, leather, silk, wool, benzin, mineral oils.*
- Synthetic molecules and materials: *drugs, plastics, paints, dyes, artificial fibres, fertilizers, aromas, cosmetics, detergents, parfumes, sweeteners,* etc.

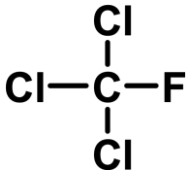
Organic Compounds



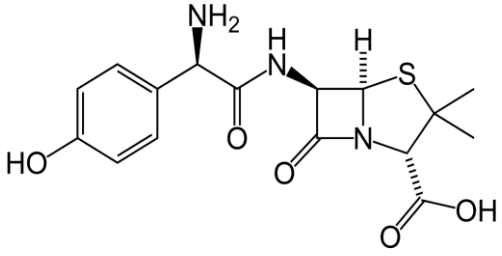
Methane



Ethanol

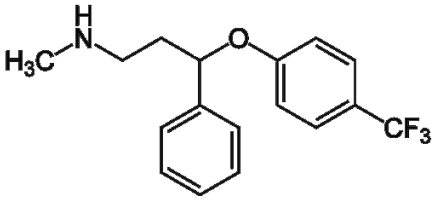


Trichlorofluoromethane



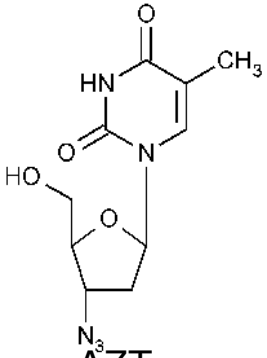
Amoxycillin

(2*S*,5*R*,6*R*)-6-(2-amino-2-(4-hidroxyphenyl)acetamido)-3,3-dimehyl-7-oxo-4-thia-1-azabiciclo[3.2.0]heptane-2-carboxylic acid



Fluoxetin
Prozac

N-methyl-3-phenyl-3-[4-(trifluoromethyl)phenoxy]propan-1-amine



AZT

3'-azido-3'-deoxythymidine

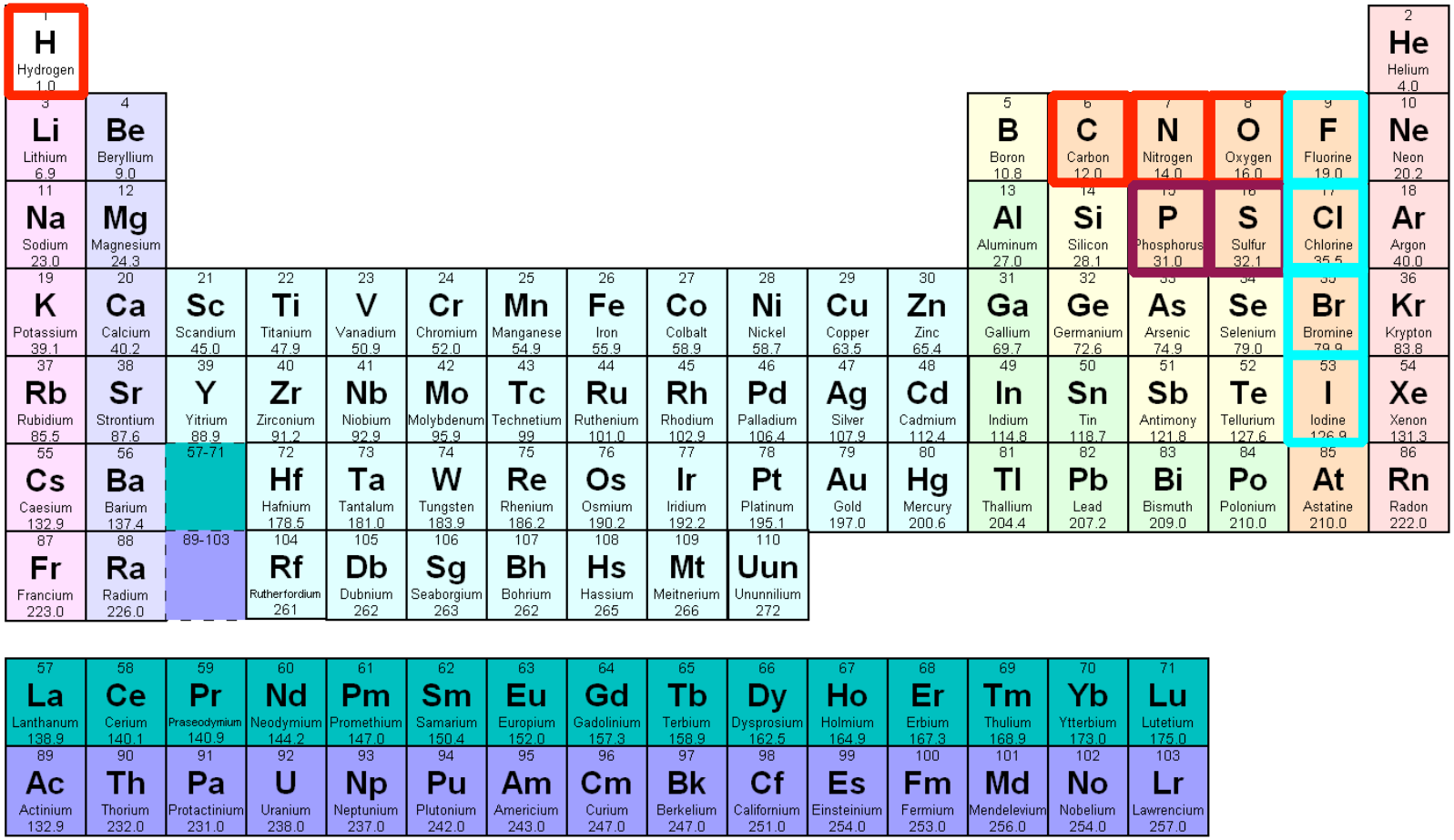
The Carbon Atom

- Atomic Number: 6
- 2 Isotopes

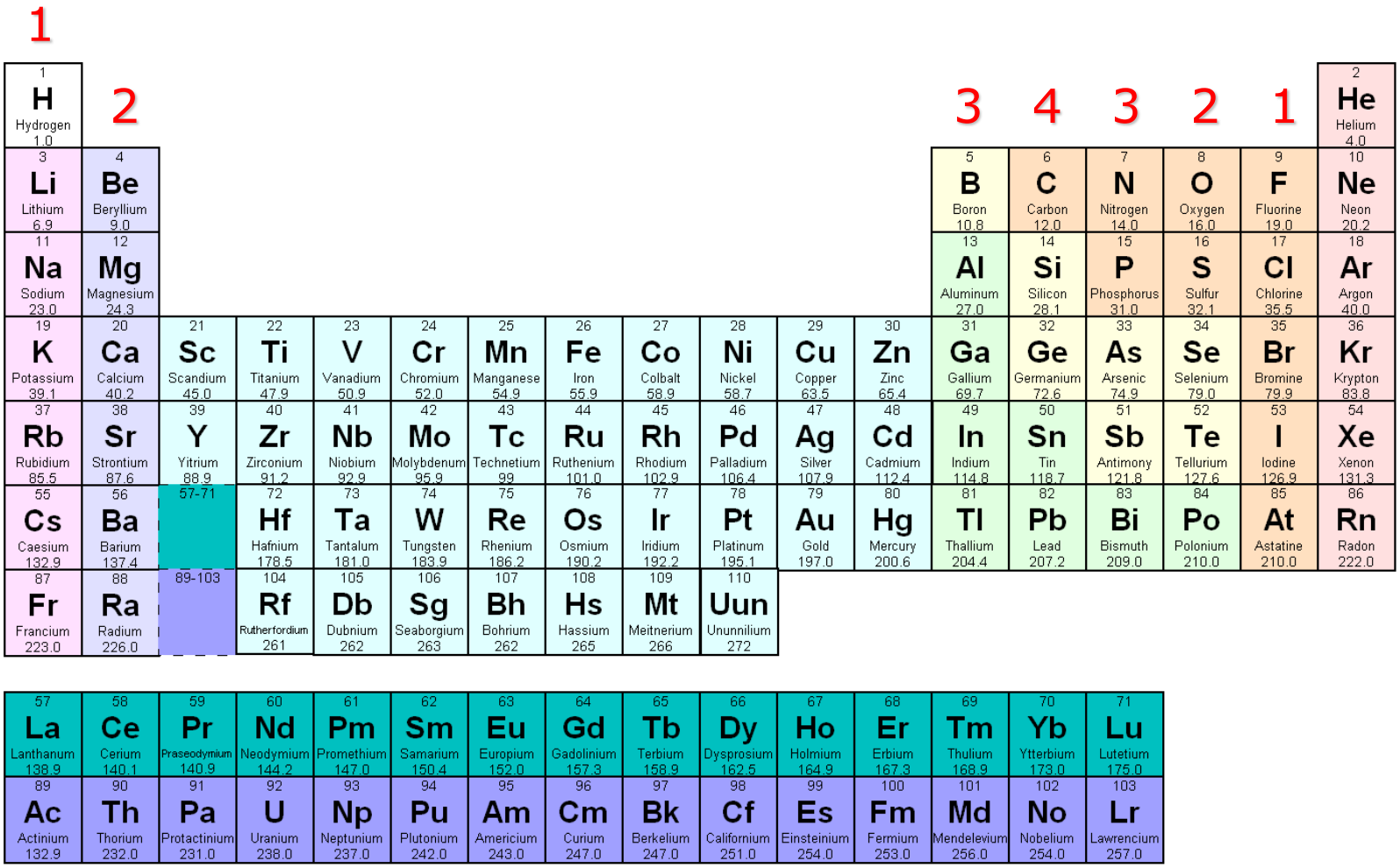
  ^{12}C (98,9%): 6 protons, 6 neutrons

  ^{13}C (1,1%): 6 protons, 7 neutrons
- Electron Configuration: $1s^2\ 2s^2\ 2p^2$

1. Carbon Forms Covalent Bonds With Many Other Elements



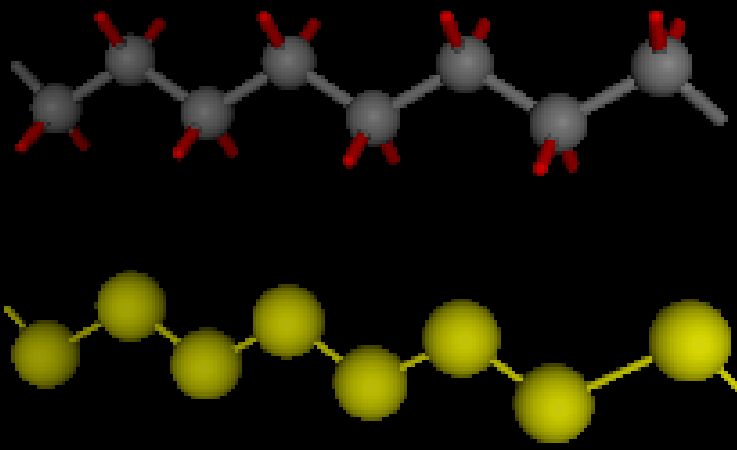
2. Carbon Is Tetravalent



3. Carbon Forms Very Strong Bonds

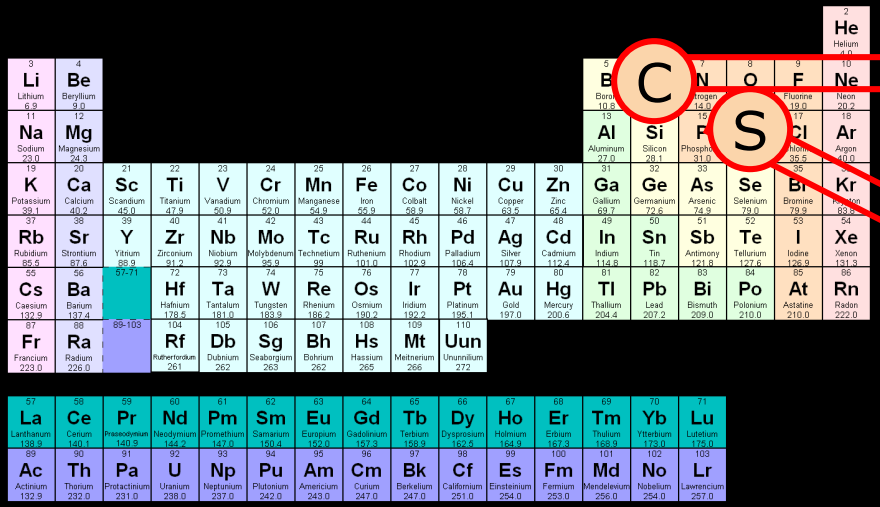
Bond	Bond Dissociation Energy (kJ/M)
C—C	360
C—H	400-550
C—O	350-400
C—N	360
N—N	250
O—O	180

4 Carbon forms chains



Energy (kJ/mol)

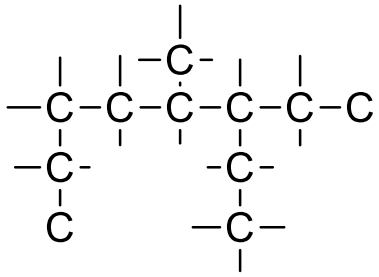
C-C	360
N-N	230-280
O-O	160-200

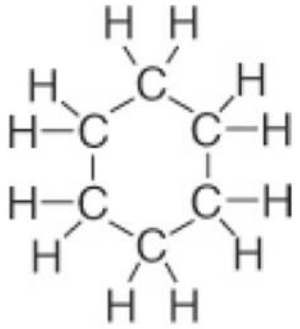


$2s^2 2p^2$

$3s^2 3p^4$

3. Carbon Forms Branched Chains and Cyclic Structures





5. Carbon Forms Multiple Bonds

Bond	Bond Dissociation Energy (kJ/M)
C—C	360
C=C	700
C≡C	950
C—O	400
C=O	750
C—N	360
C=N	700
C≡N	950

Organic Chemistry

- Structure
- Reactivity
- *Structure* and *reactivity* are correlated.

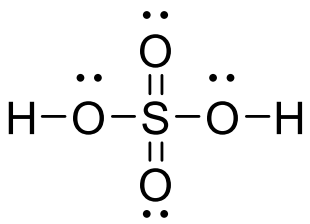
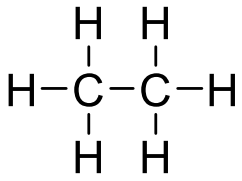
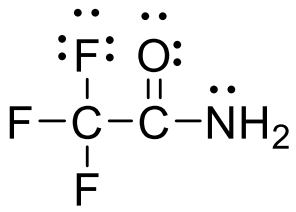
STRUCTURE  REACTIVITY

Goals

- Assign Structure and Name to Organic Compounds.
- Predict:
  - The tridimensional structure
  - The effects on reactivity (reaction rates and equilibrium constants)
- Design simple synthetic pathways
- Communicate with an appropriate language

Drawing molecules

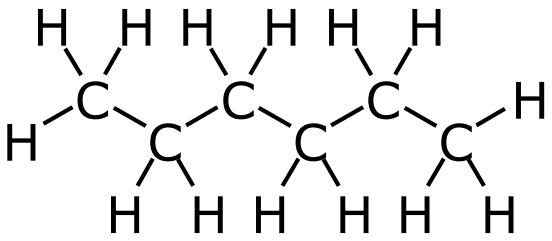
Molecular Formula

structural	empirical	
	H_2SO_4	Sulfuric acid
	C_2H_6	Ethane
	$C_2H_2F_3NO$	Trifluoroacetamide

General empirical formula of organic compounds: $C_CH_HBr_{Br}Cl_{Cl}F_FI_IN_NO_O$

Condensed Formula

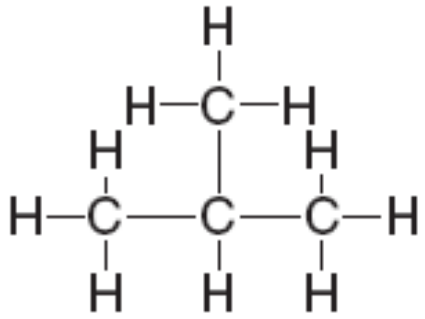
- Different degrees of condensation

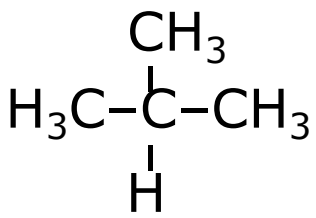


$CH_3\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_3$

$CH_3CH_2CH_2CH_2CH_2CH_3$

$CH_3(CH_2)_4CH_3$

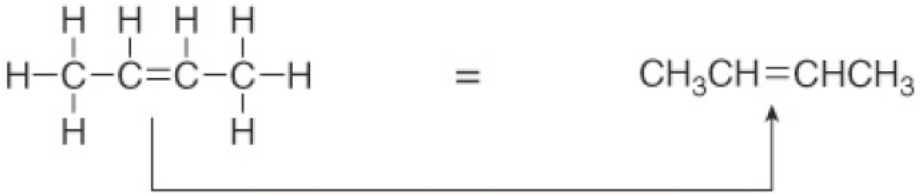




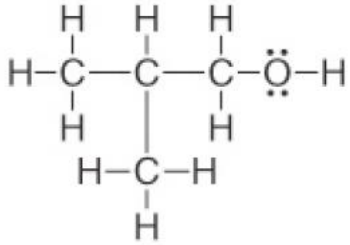
Certain bonds are maintained

$CH(CH_3)_3$ or $(CH_3)_3CH$

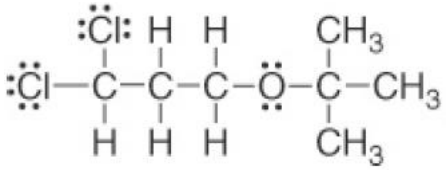
Condensed Formula



The double bond is maintained

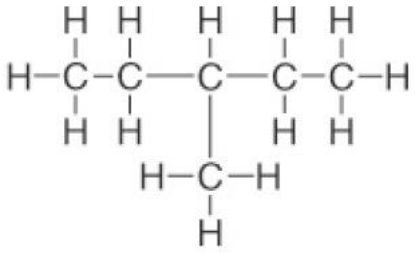


lone pairs are omitted



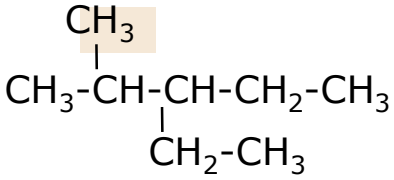
Condensed Formula

- Complex structures can be written on a single line using parentheses.



= $CH_3CH_2CHCH_2CH_3$ (with CH_3 branch) or $CH_3CH_2CH(CH_3)CH_2CH_3$

The middle CH_3 group is bonded outside the chain



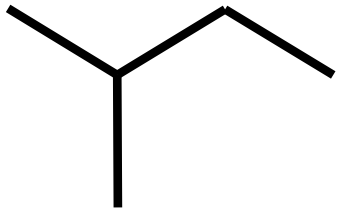
= $CH_3CH(CH_3)CH(CH_2CH_3)CH_2CH_3$

Branched alkanes

Skeletal (Linear) Formula

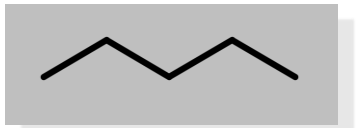
Minimal, non ambiguous, information

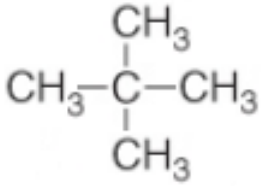
- Carbon atoms are omitted and lie on interceptions between bonds and at the end of the chain.
- Hydrogen atoms are omitted. Each carbon atom free valence is saturated with hydrogens.
- Atoms other than C and H (heteroatoms) are not omitted.

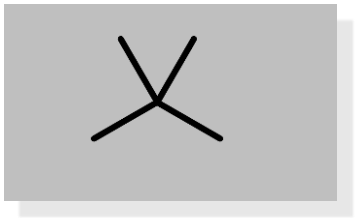


Skeletal (Linear) Formula

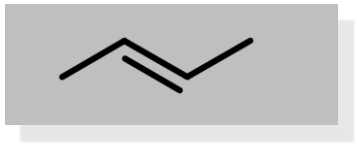
$CH_3CH_2CH_2CH_2CH_3$



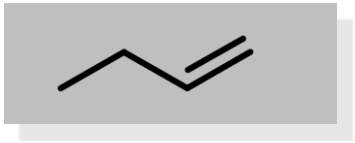




$CH_3CH{=}CHCH_3$

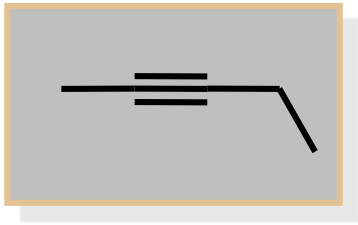


$CH_3CH_2CH{=}CH_2$

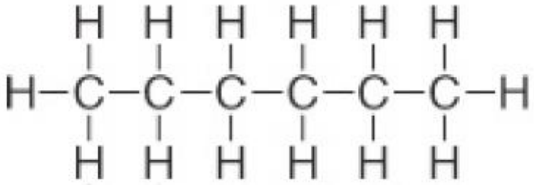


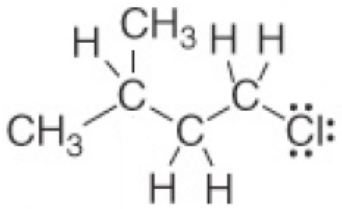
$H{-}C{\equiv}C{-}CH_3$

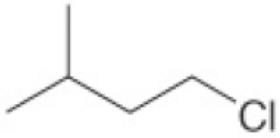
$CH_3{-}C{\equiv}C{-}CH_2CH_3$

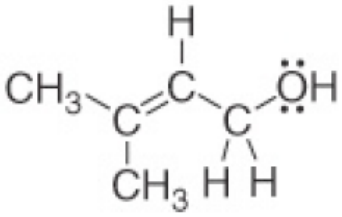


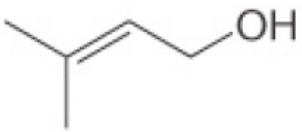
Examples

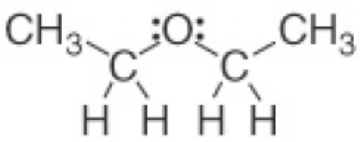


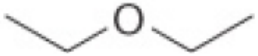


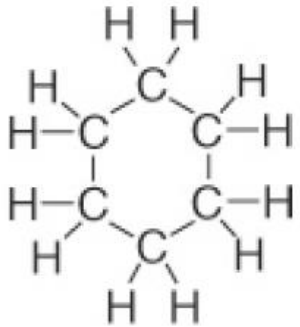




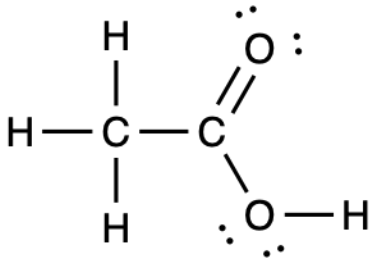




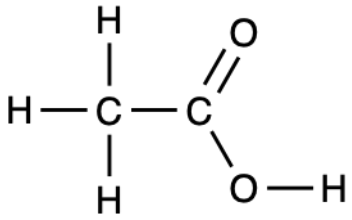




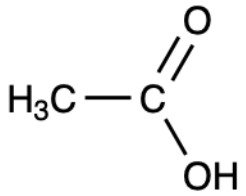
Acetic Acid



Lewis structure



Structural Formula

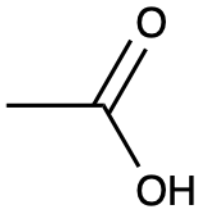


Condensed Formula

CH_3COOH

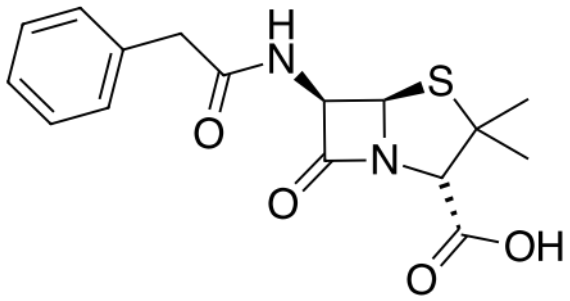
$C_2H_4O_2$

Empirical Formula

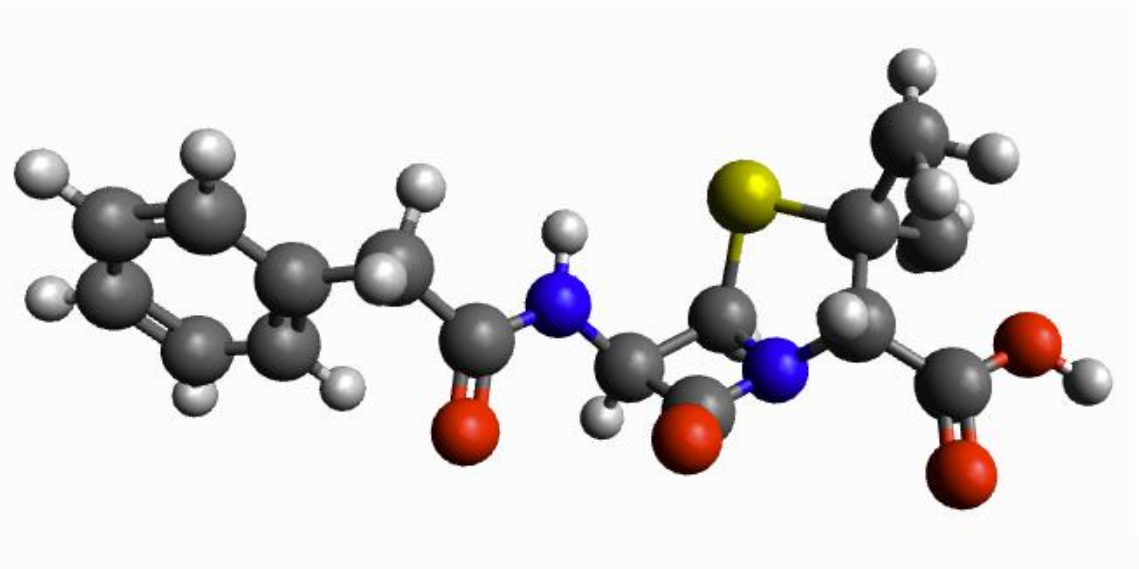


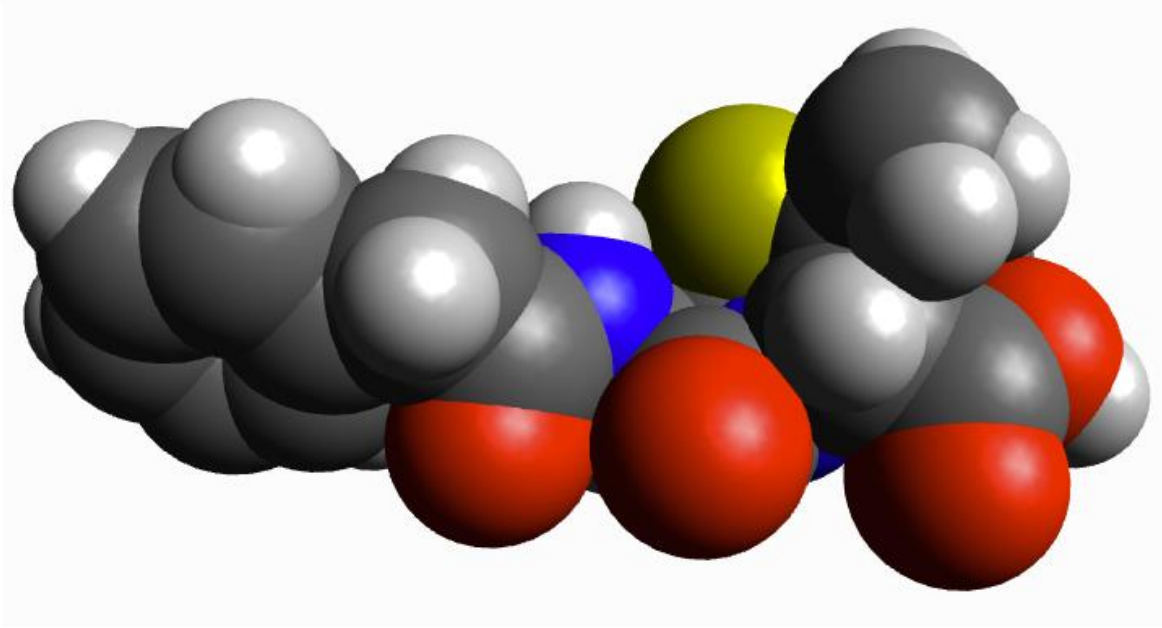
Skeletal Formula

Molecular Models

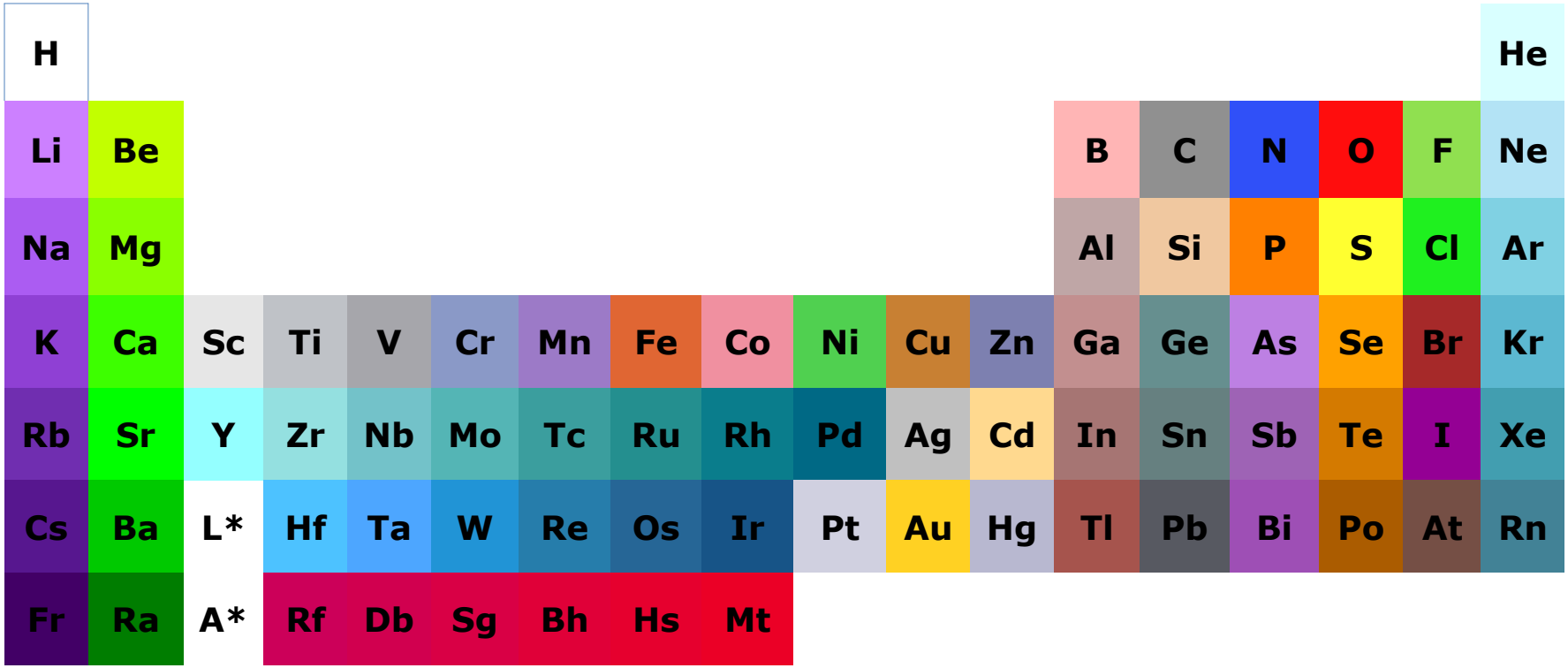


Benzylpenicillin
(penicillin G)





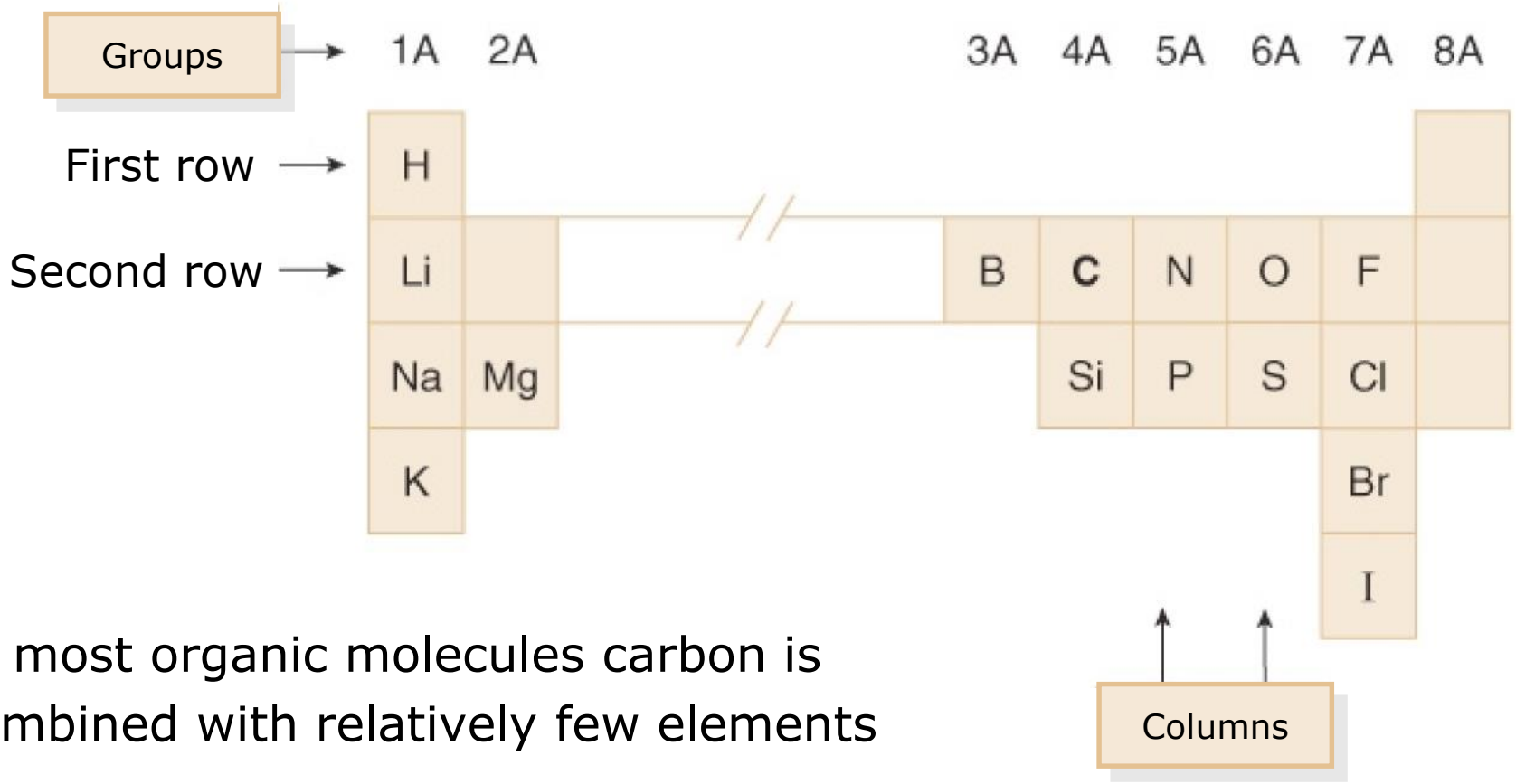
Element Coloring Scheme



Atomic Structure and Bonding

Chapter 1
Organic Chemistry, *8th Edition*
John McMurry

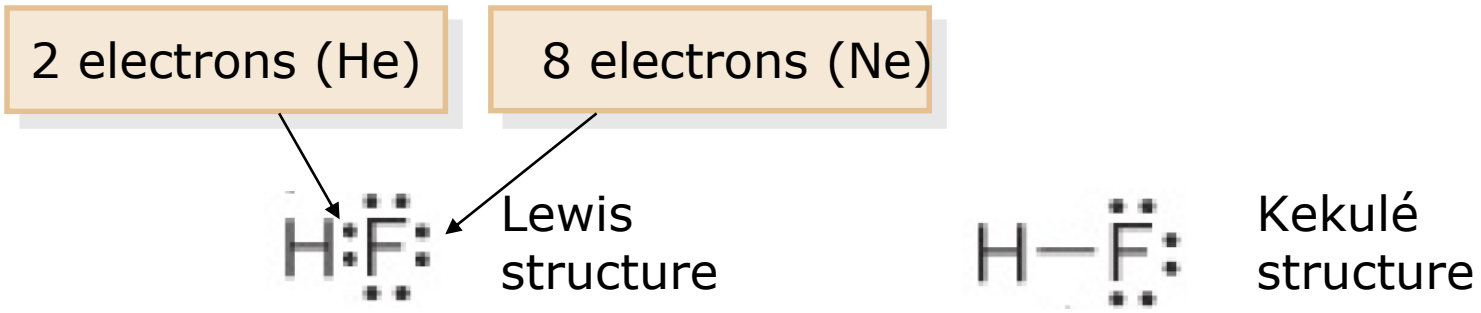
Common Elements



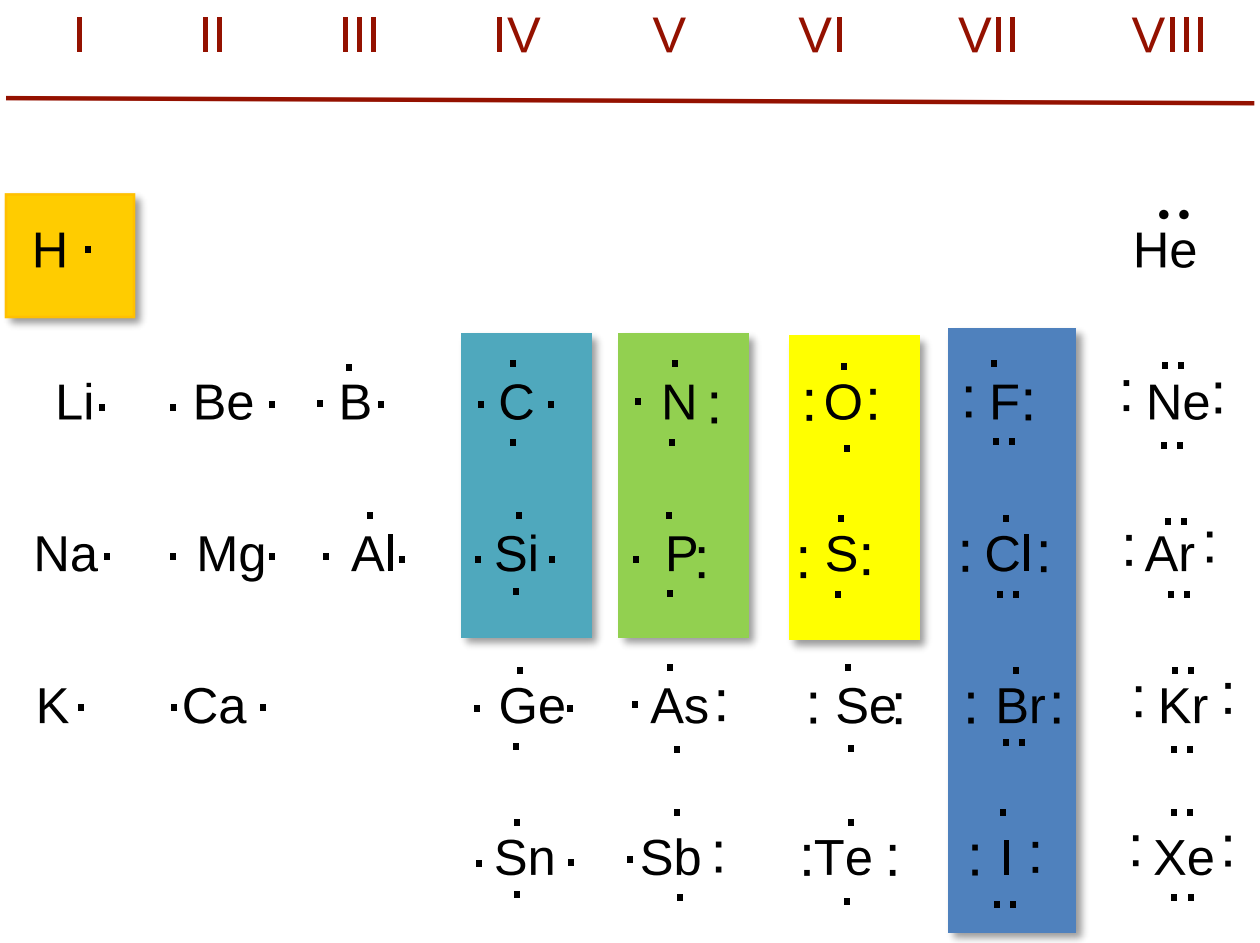
In most organic molecules carbon is combined with relatively few elements

Lewis Model

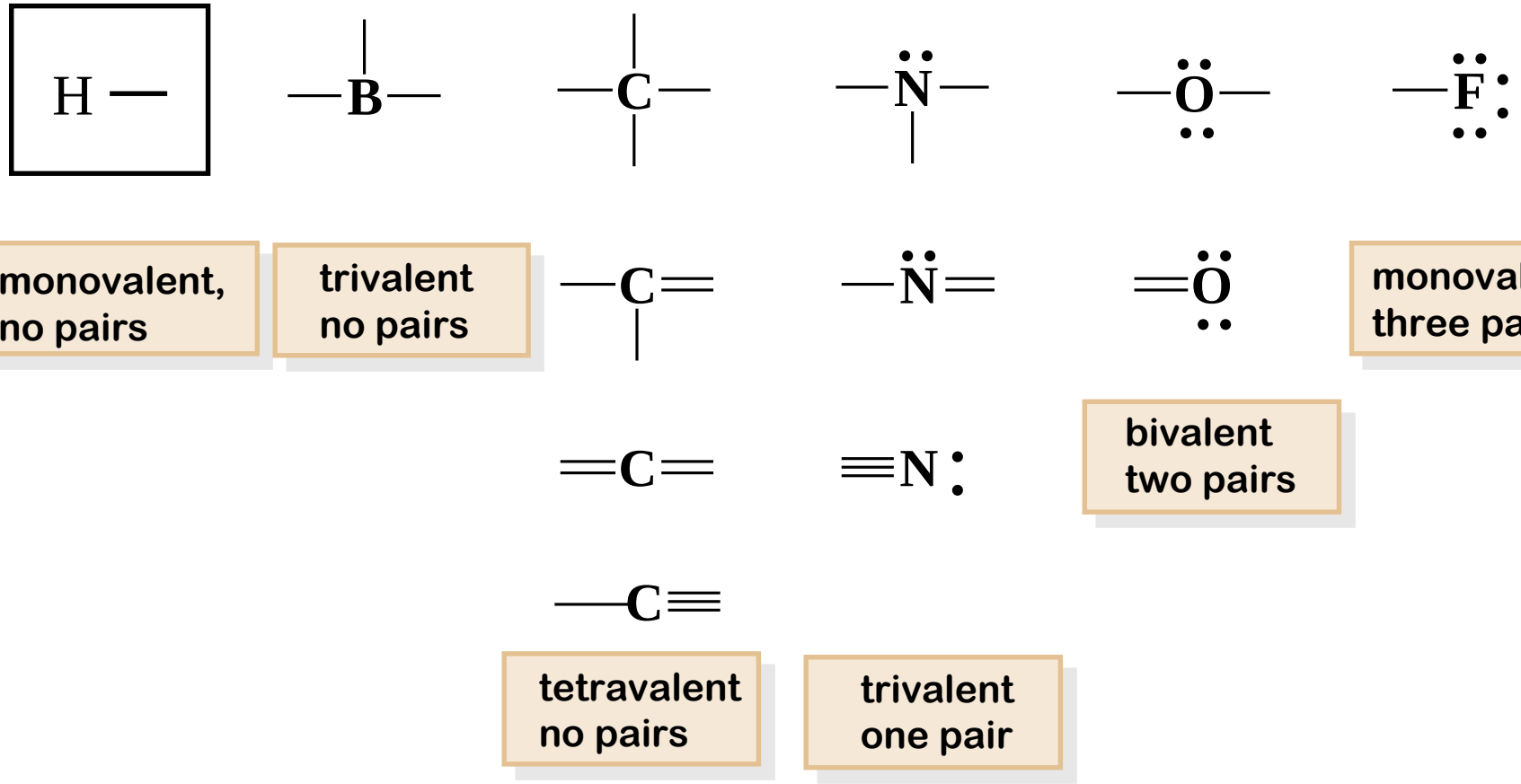
- Bonds are made by localised electron pairs.
- In Lewis structures electrons are represented as dots.
- Three general rules.
  - Include only valence electrons.
  - If possible, every 2nd raw element should have 8 electrons.
  - Every H atom has 2 electrons.



Lewis Symbols for elements

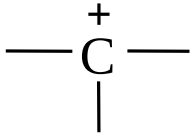


Bonding patterns for common neutral elements

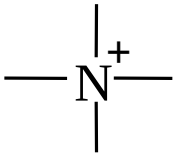


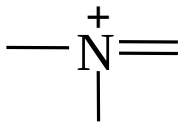
Bonding Patterns for ions

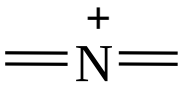
CATIONS

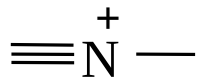


trivalent
no pairs

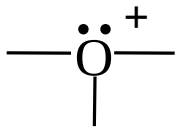


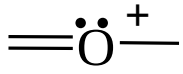






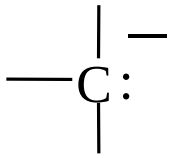
tetravalent
no pairs



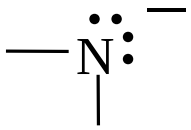


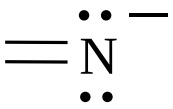
trivalent
one pair

ANIONS

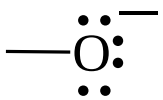


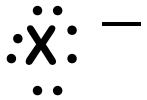
trivalent
one pair





bivalent
two pairs





monovalent
one pair

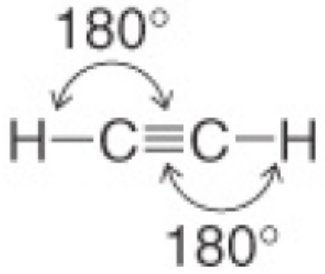
Geometry – VSEPR Theory

- The number of *Valence Shell Electron Pairs* (groups) around an atom defines the geometry of that atom.
- A group is an atom or a non bonding pair of electrons.
- Groups will tend to be as far apart as possible.

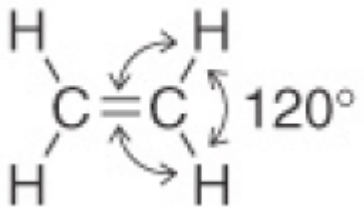
Number of groups	Geometry	Angle
2	linear	180°
3	trigonal planar	120°
4	tetrahedral	109.5°

Geometry – VSEPR Theory

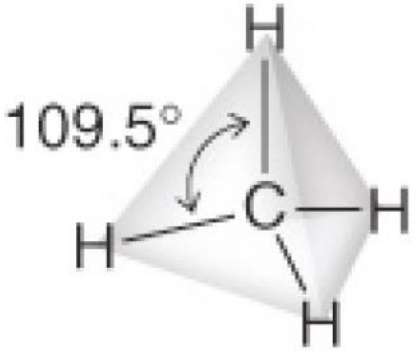
Number of groups	Geometry	Angle
2	linear	180°
3	trigonal planar	120°
4	tetrahedral	109.5°



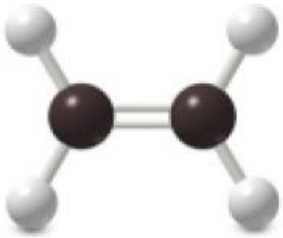
acetylene

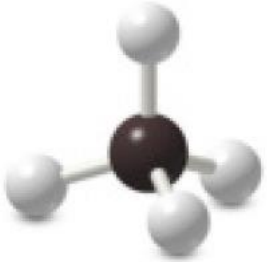


ethylene



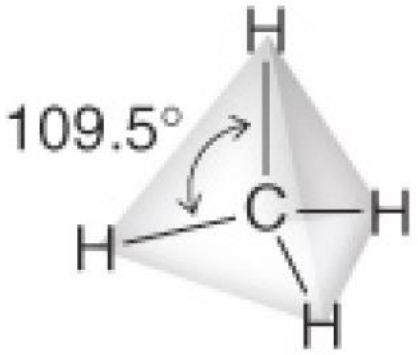
methane

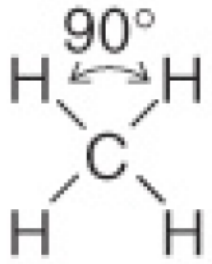




4 groups: CH_4

Tetrahedral	Square planar

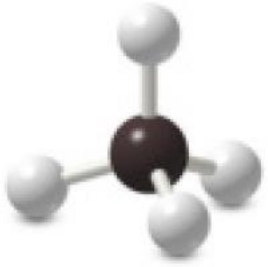


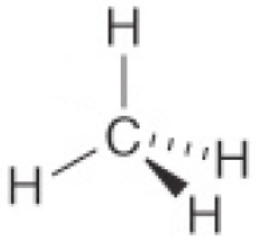


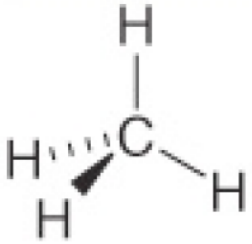
Preferred

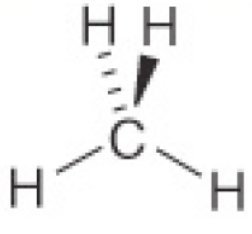
Not observed

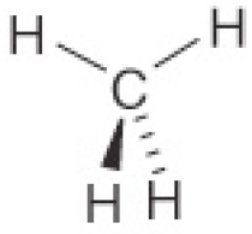
Tridimensional representations of methane





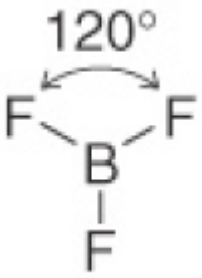






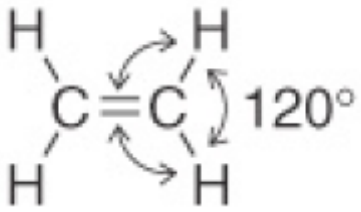
3 groups: BF_3 and C_2H_4

2 trigonal molecules



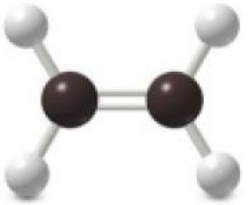
3 atoms around B

All 3 atoms are in the plane

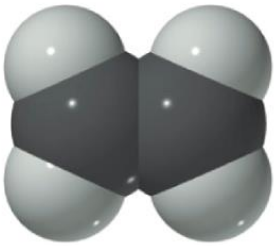


3 atoms around each C

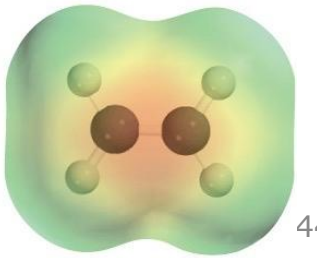
All 6 atoms are in the plane



ball-and-stick model

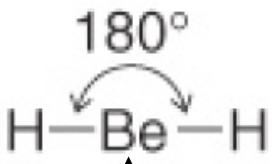


space-filling model

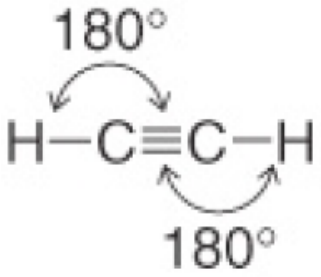


2 groups: BeH_2 and C_2H_2

2 linear molecules



2 atoms around Be



2 atoms around each C

≡

Energies of Multiple Bonds

Bond	Bond Dissociation Energy (kJ/M)
C—C	360
C=C	700
C≡C	950
C—O	400
C=O	750
C—N	360
C=N	700
C≡N	950

The Lewis model is not adequate!

Models for the Chemical Bond

- Valence Orbital theory.
  - Covalent bonds are formed by the overlap of two atomic orbitals and the electron pair is shared by both atoms.
  - A valence bond is localized between two atoms.

- Molecular Orbital theory.
  - n atomic orbitals are combined to give a new set of n molecular orbitals (bonding and antibonding).
  - Molecular orbitals are delocalized on the whole molecule.

Valence Orbitals

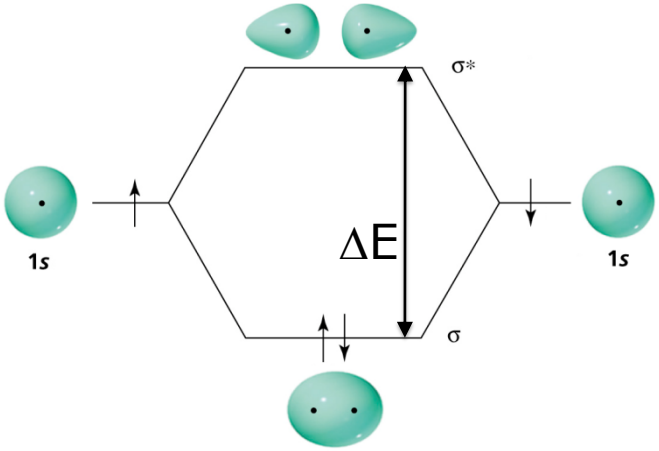
- Bonds are formed by the in-phase overlap of two atomic orbitals each contributing one electron.
- The electron pair is localized between two atoms and is shared by both atoms.
- Hydrogen uses the 1s orbital to form σ bonds.
- 2nd row atoms use hybrid orbitals (sp^3, sp^2, sp) to form σ bonds.
- 2nd row atoms use p orbitals to form π bonds that have a nodal plane.
- Atomic orbitals overlap better in σ bonds (co-linear) than in π bonds (parallel).

Molecular Orbitals

- Valence electrons occupy molecular orbitals delocalized on the whole molecule.
- The combination of *n* atomic orbitals gives *n* new molecular orbitals.
- Bonding orbitals have lower energies and antibonding orbitals have higher energies than the starting atomic orbitals

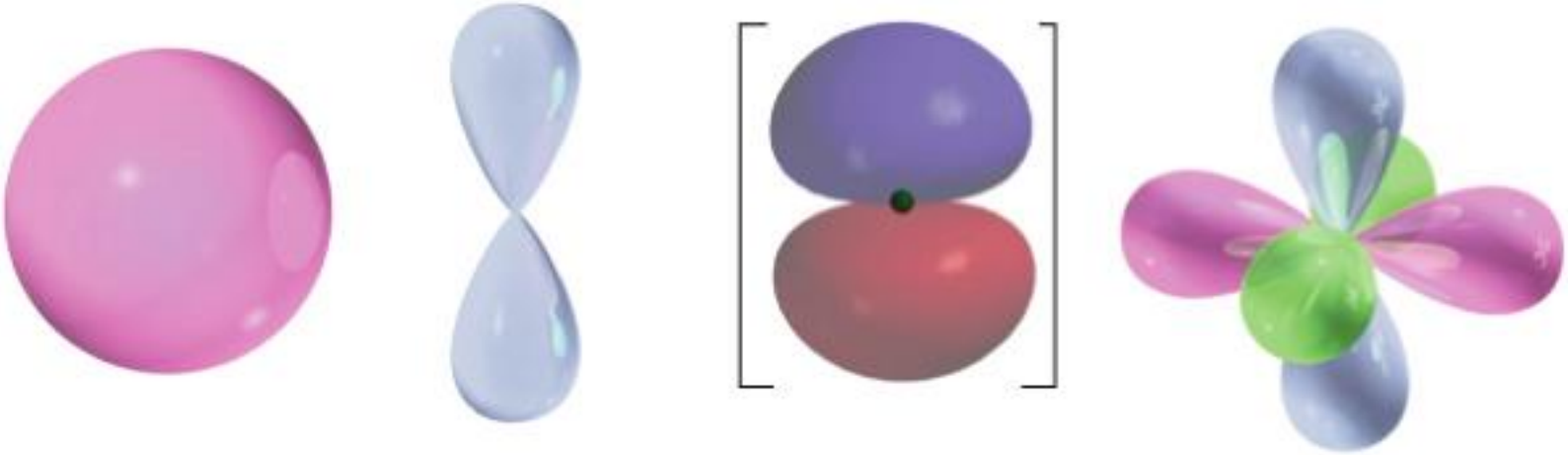
Robert Mulliken
(1896-1986)

The H_2 molecule:



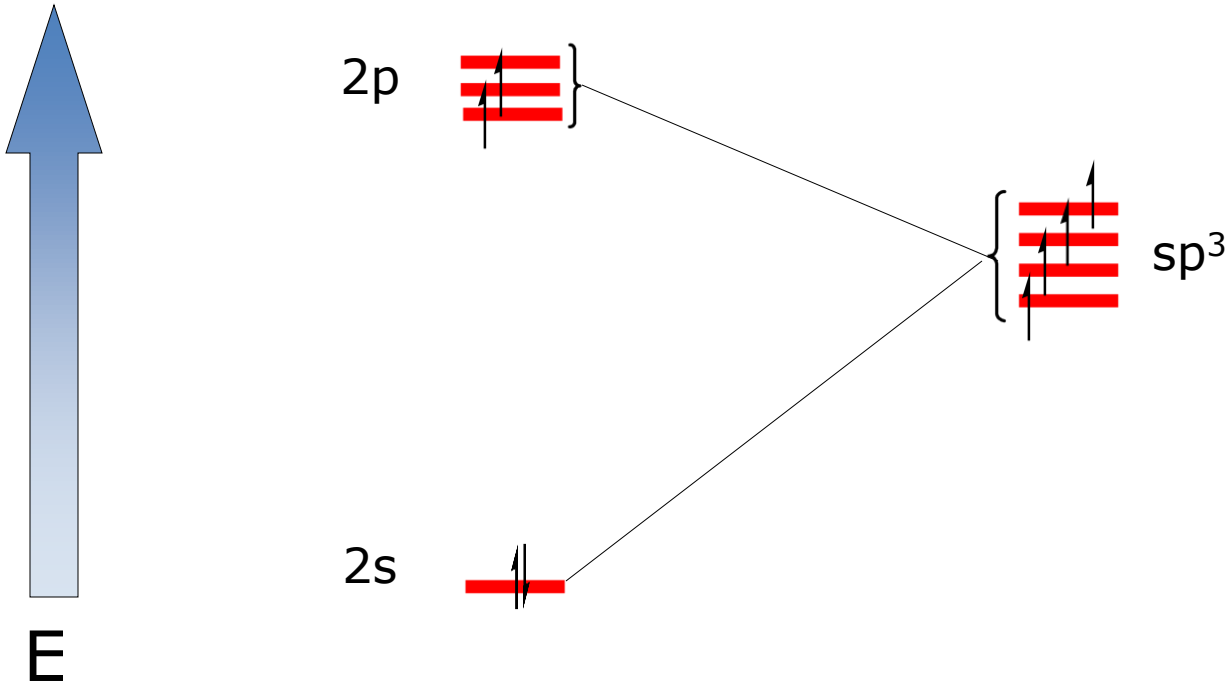
Atomic Orbitals of Carbon

$1s^2\ 2s^2\ 2p^2$



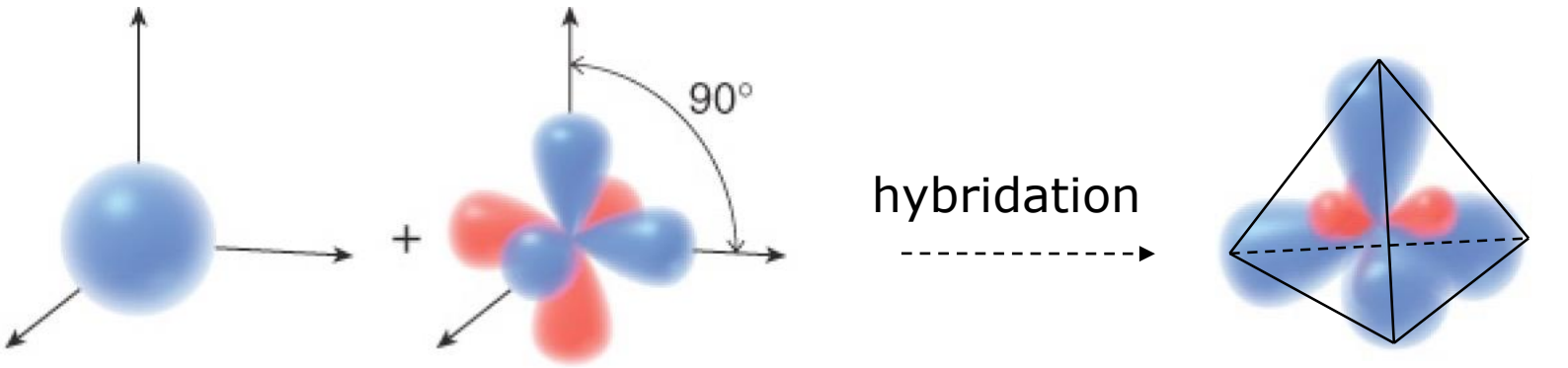
s p 2p 3 x 2p orbitals

sp^3 Hybrids

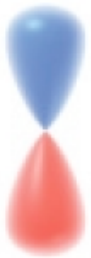


sp^3 Hybrids

- The mixing of a spherical 2*s* orbital and three 2*p* orbitals generates four sp^3 orbitals, each with a small and a large lobe.



2s 3 x 2p 4 x sp^3 orbitals

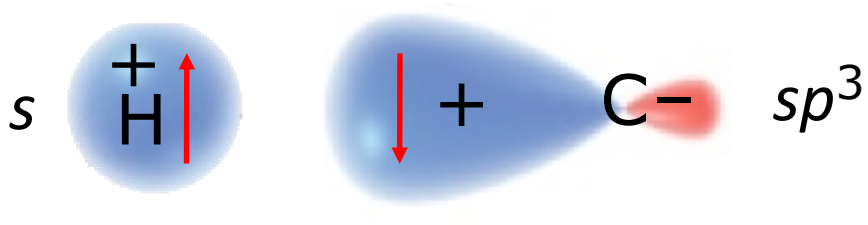


p

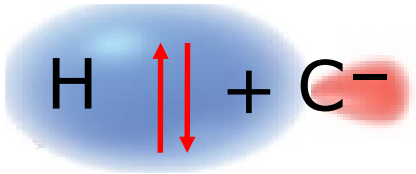
sp^3

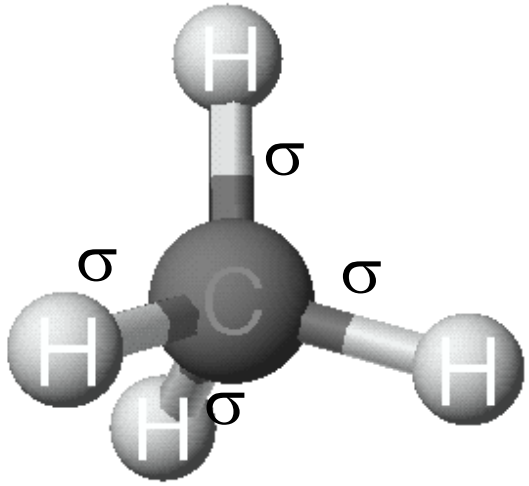
Methane

The overlap of a half-full *1s* orbital of hydrogen with a half-full sp^3 orbital of carbon bond gives a σ orbital.

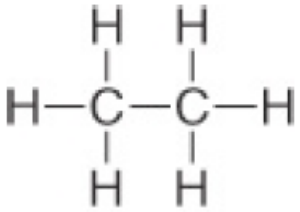


σ C–H

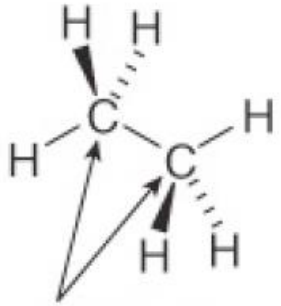




Ethane

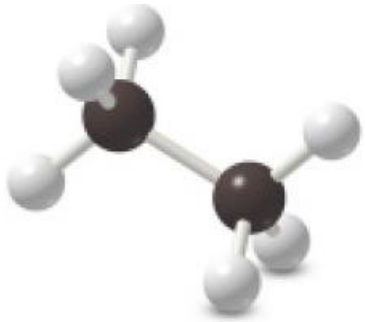


ethane

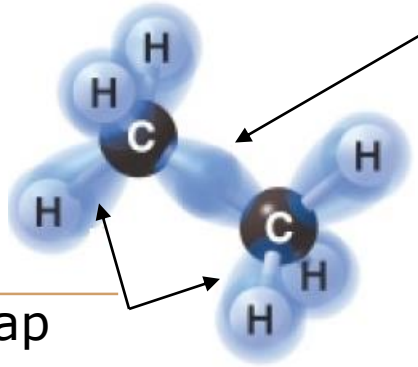


tetrahedral sp^3 C

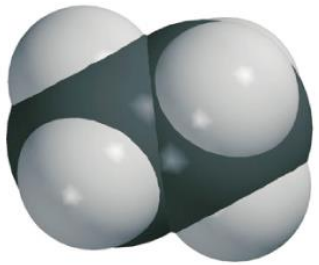
=

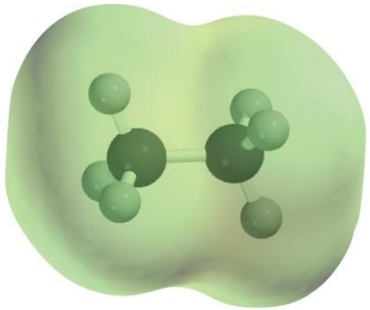


Two sp^3 hybrids overlap giving the C–C σ bond

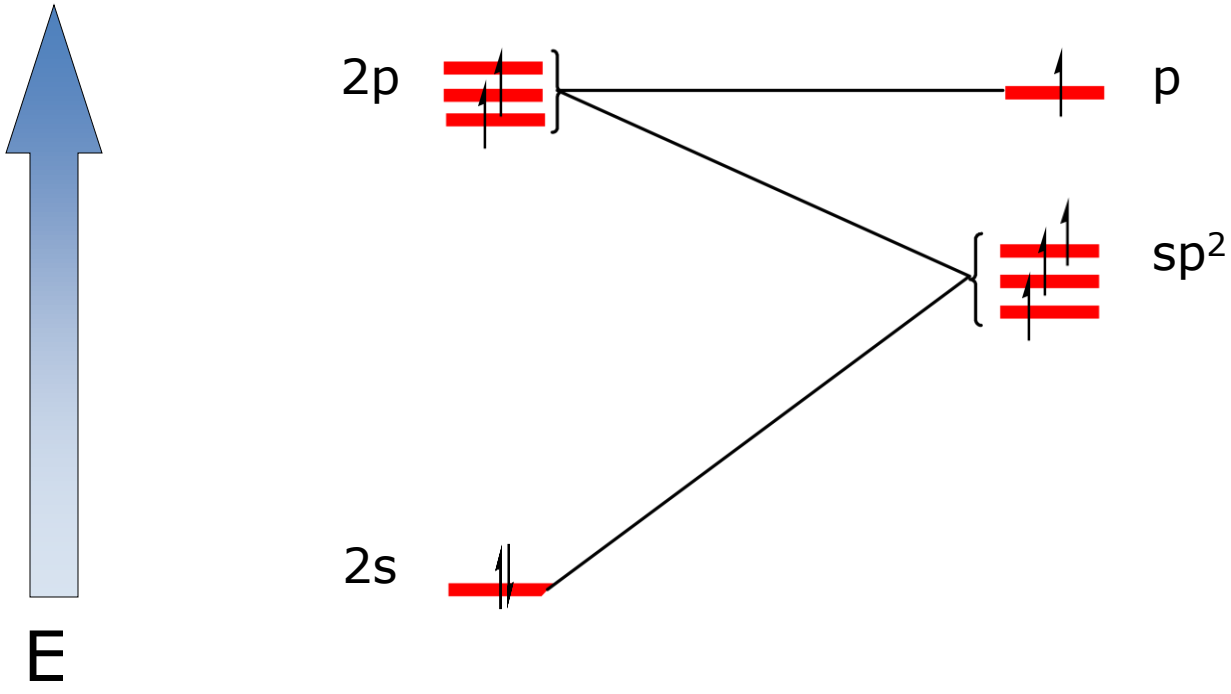


sp^3 hybrids on C overlap with *1s* orbitals on H giving the C-H σ bonds.

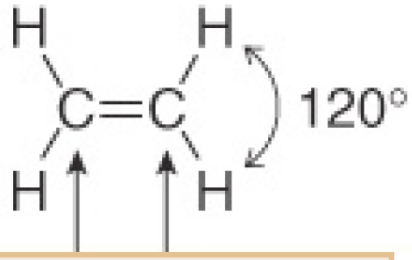




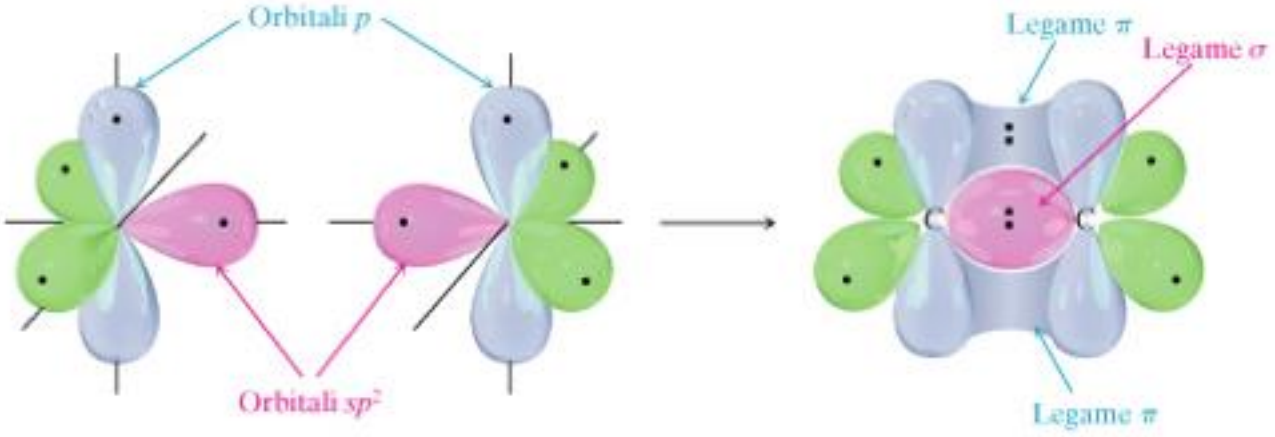
sp^2 Hybrids



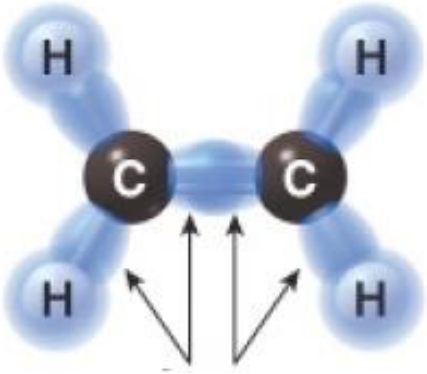
Ethylene C_2H_4



3 groups around C
C atoms are sp^2

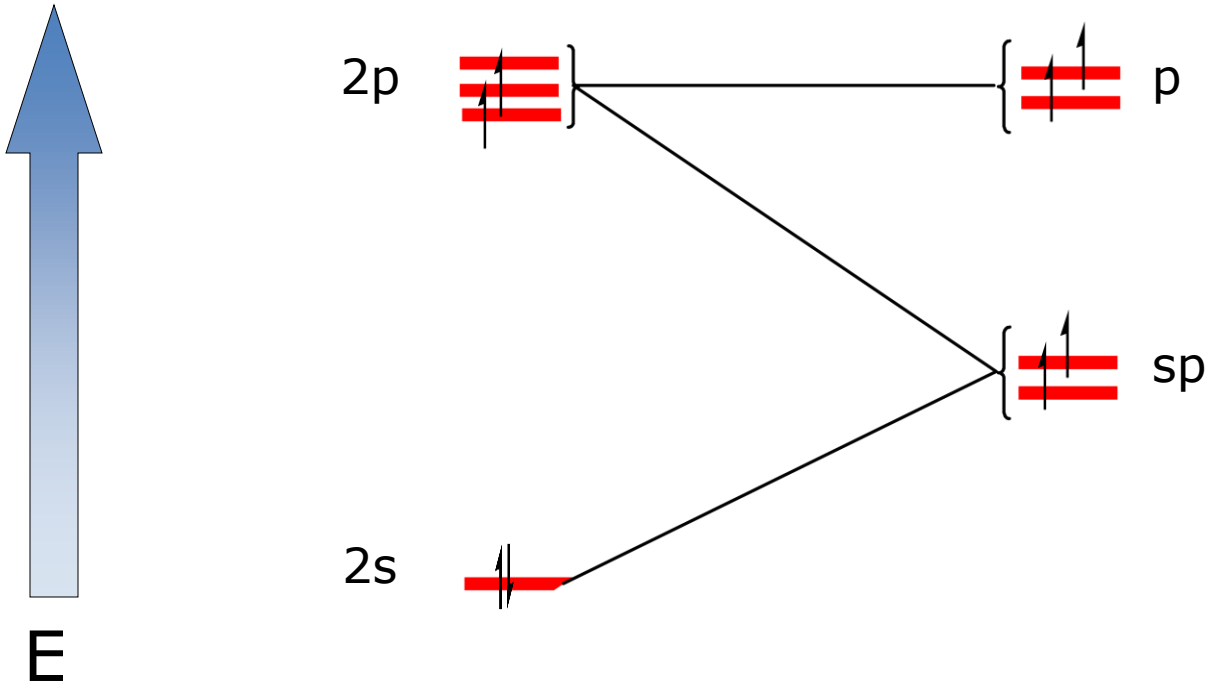


C-C double bond

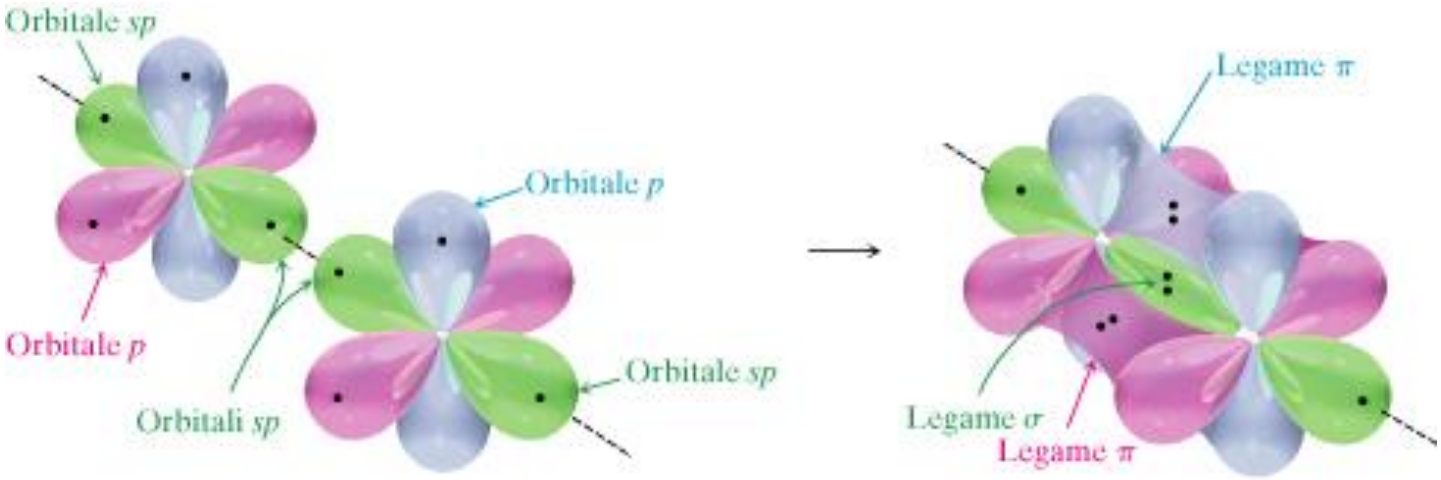


Sp^2 hybrids

sp Hybrids

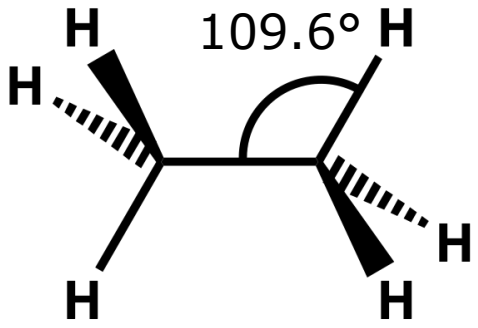


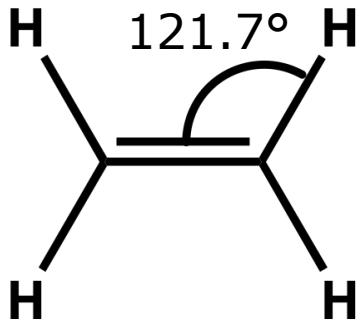
Acetylene C_2H_2

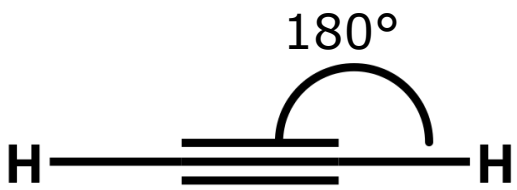


C-C triple bond

Structures of C_2H_6, C_2H_4, C_2H_2







$d_{C\text{-}C}$ (pm):	154	133	120
$d_{C\text{-}H}$ (pm):	110	107.6	106
$E_{C\text{-}C}$ (kJ/M):	376	611	835

Polar Bonds
Intermolecular Interactions
Delocalised Bonds

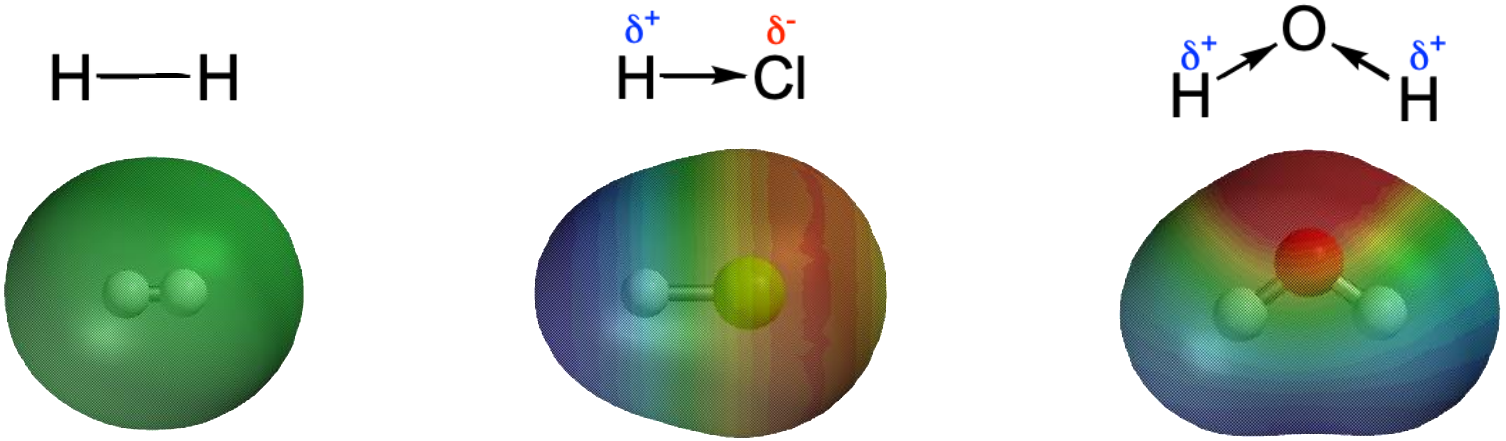
Chapter 2

Organic Chemistry, *8th Edition*

John E. McMurry

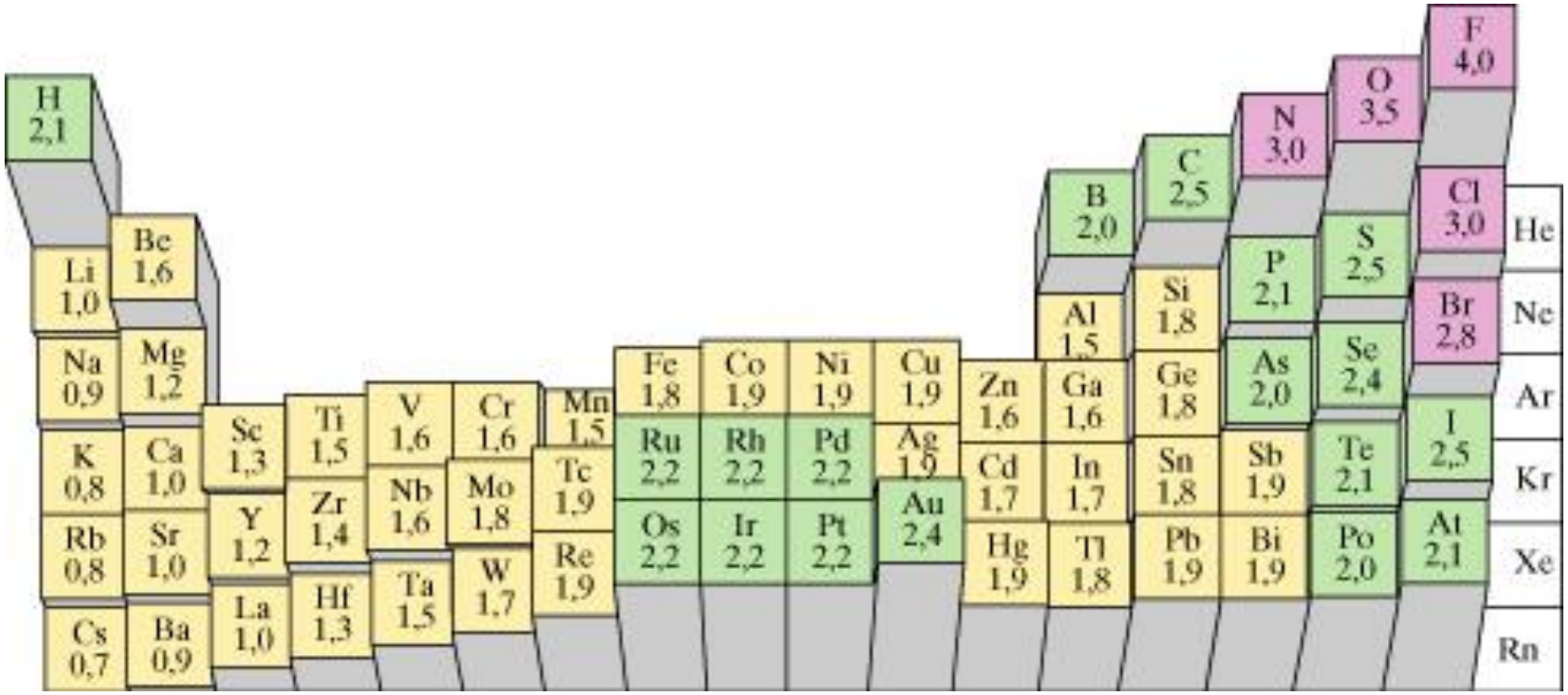
Polar Covalent Bonds

- In polar bonds, bonding electrons are attracted towards the more electronegative atom.



- The higher the electronegativity difference, the higher the polar character of a covalent bond.
  - $\Delta X > 1.9 \Rightarrow$ ionic bond
  - $\Delta X < 0.5 \Rightarrow$ apolar covalent bond : C-C, C-H
  - $\Delta X = 0.5 - 1.9 \Rightarrow$ polar covalent bond : H-F, H-Cl, O-H, N-H, C-N, C-O, C-F, C-Cl C-Li, C-Mg

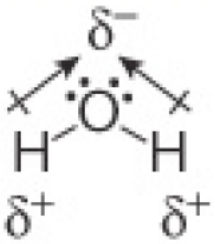
Pauling's Electronegativities

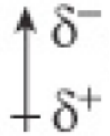


Dipole Moments

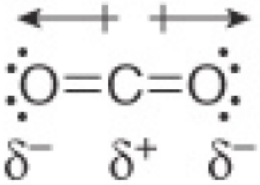
- Polar molecules have one or more polar bonds.

Es. H_2O

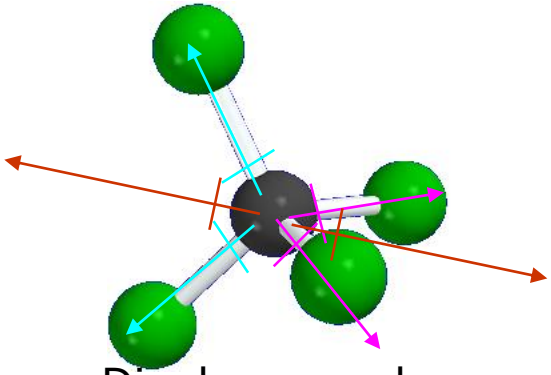




- Apolar molecules either do not have polar bonds or have polar bonds whose dipoles cancell each other. E.g. CO_2

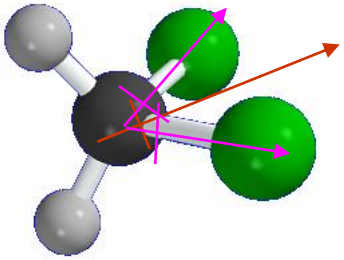


CCl_4 μ = 0 D



Dipoles cancel

CH_2Cl_2 μ = 1.62 D



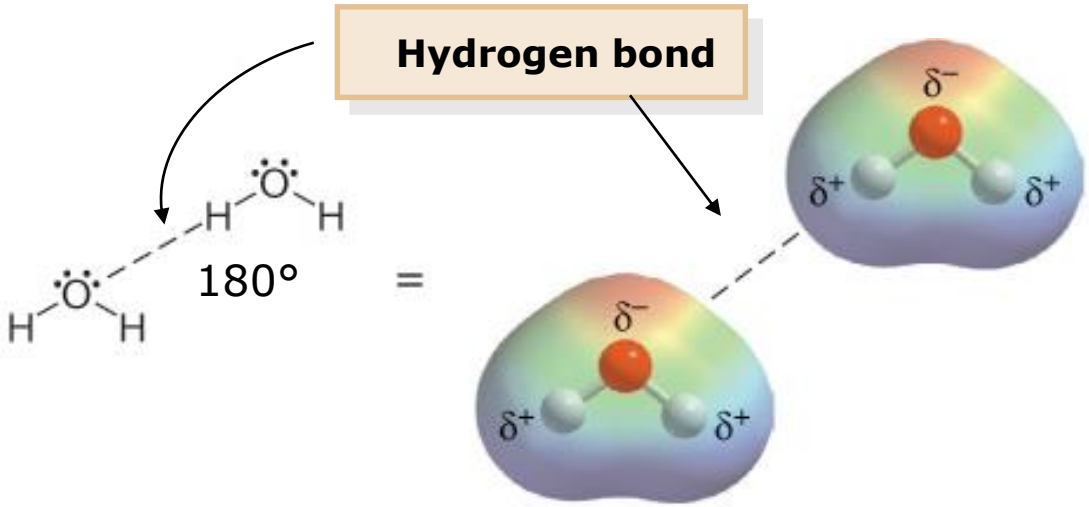
Dipoles add

Intermolecular interactions

- Intermolecular interactions are also called non-covalent or non-bonded interactions.
- Intermolecular interactions depend on the type and number of functional groups.
- In neutral molecules there are three main types of intermolecular interactions.
  - Vand der Waals interactions (London dispersion forces) – VDW
  - Dipole-dipole interactions – DD
  - Hydrogen bonds– HB

The Hydrogen Bond

- The hydrogen bond is an electrostatic interaction betweeen a O-H or N-H group and a lone pair on O or N.

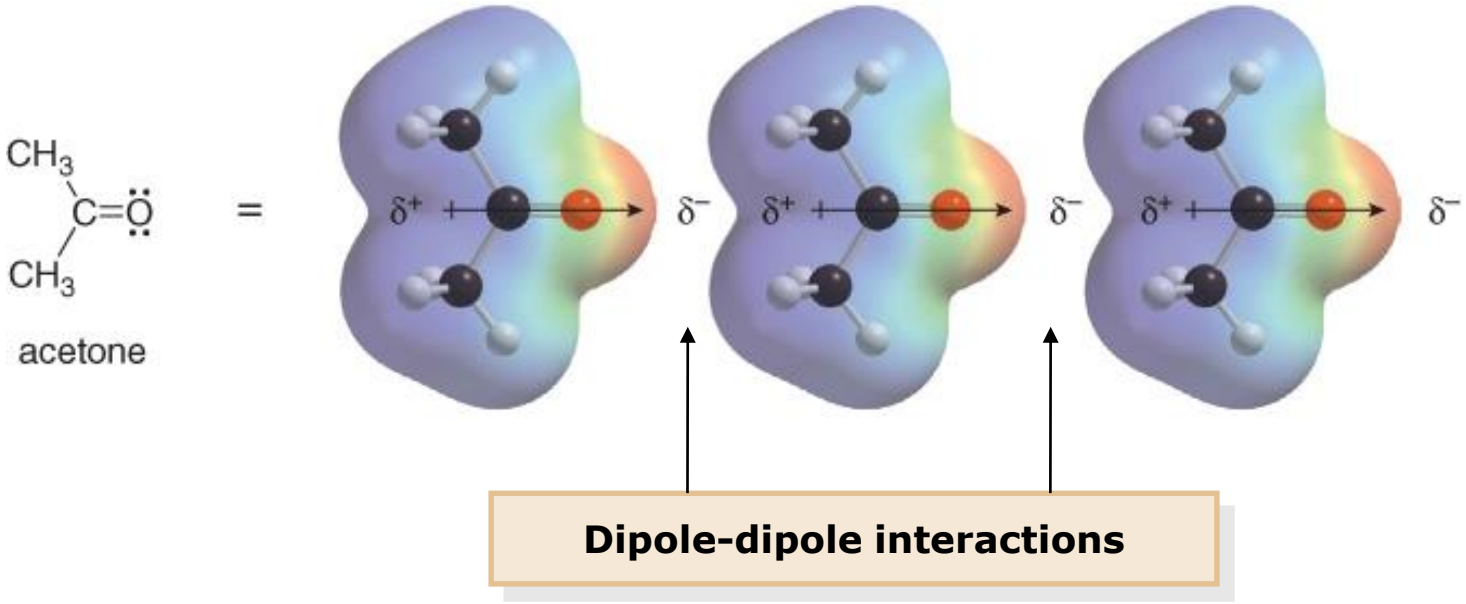


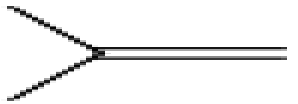
The Hydrogen Bond

	MW	*b.p. (°C)*	*H-bond*
H_3C-CH_3	***30***	***-89***	***none***
H_3C-NH_2	***31***	***-6***	***weak***
H_3C-OH	***32***	***65***	***strong***

Dipole-Dipole Interactions

- Dipole-dipole interactions are attraction forces between the permanent dipoles of two molecules.

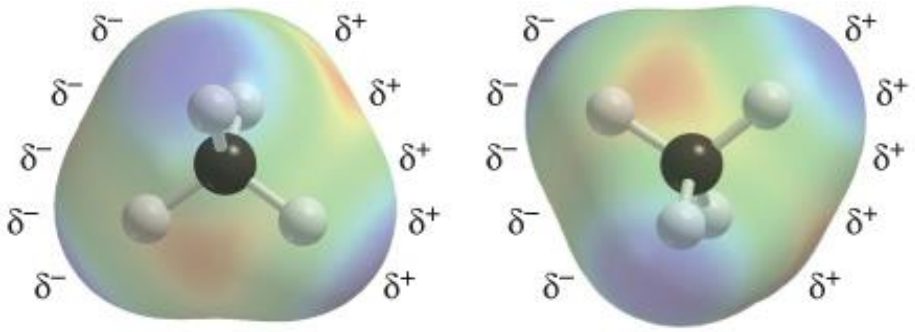


	MW	*b.p. (°C)*
	***56***	***-5***
	***58***	***56***

Van der Waals (London) Forces

- VdW forces are weak interactions originating from temporary variations of the molecule's electron density distribution.
- They are the only attractive forces in apolar molecules.

Van der Waals interactions between two CH_4 molecules

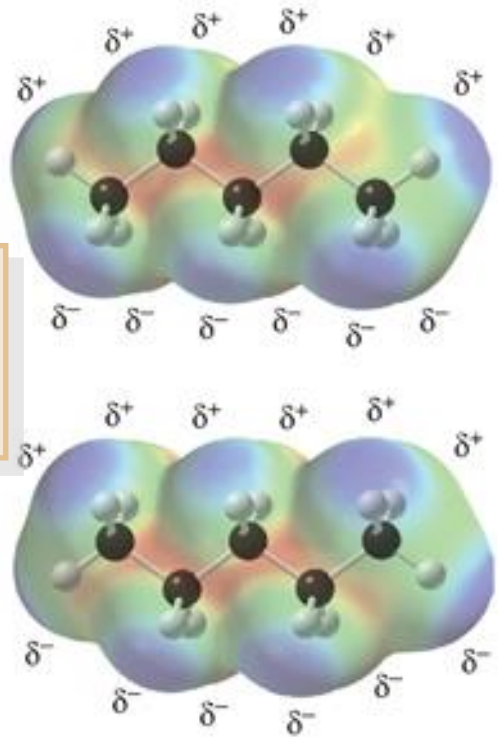


Dipoles generated by a temporay asymmetry in the electron density

Van der Waals (London) Forces

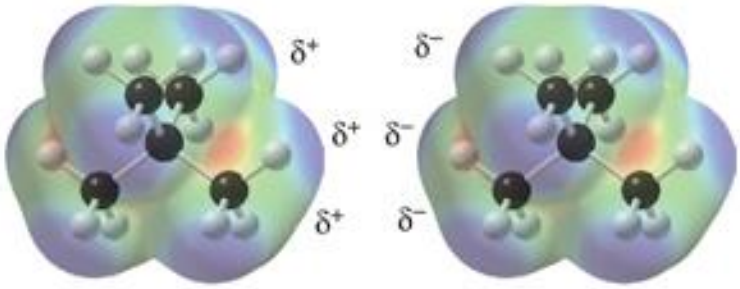
- Van der Waals interactions are present in all molecules.
- The larger the surface area, the larger the attractive force between two molecules, and the stronger the intermolecular forces.

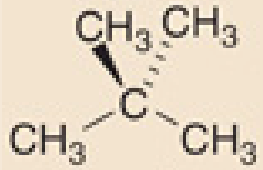
Long, cylindrical molecules:
stronger interactions



$CH_3CH_2CH_2CH_2CH_3$
n-pentane
b.p. 36 °C

Compact, spherical molecules:
weaker interactions





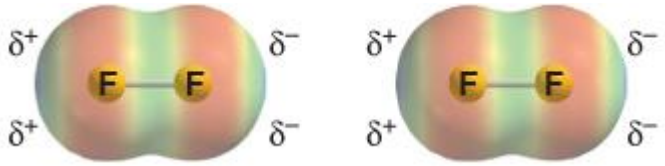
neopentane
b.p. 10 °C

Van der Waals (London) Forces

- VdW forces depend on polarizability.
- Larger atoms, like iodine, which have more loosely held valence electrons, are more polarizable than smaller atoms like fluorine, which have more tightly held electrons

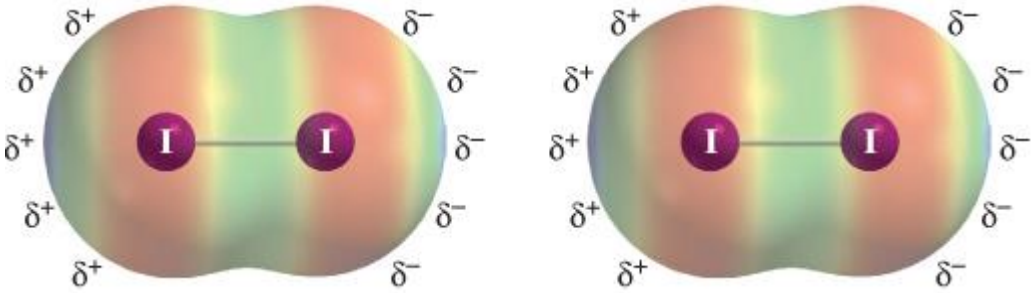
Small atoms: lower polarizability

Weak interaction



Large atoms: higher polarizability

Stronger interaction



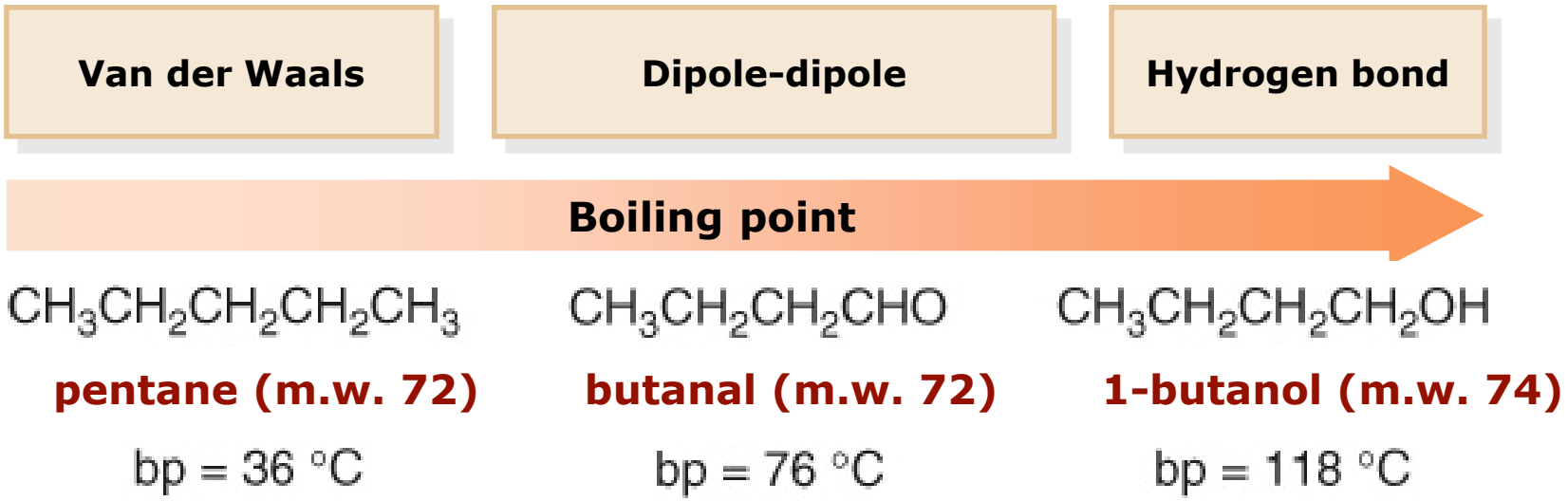
Summary

Interaction	Relative strength	Present in	Examples
Van der Waals VDW	Very weak	All molecules	$CH_3CH_2CH_2CH_2CH_3$ $CH_3CH_2CH_2CHO$ $CH_3CH_2CH_2CH_2OH$
Dipole-dipole DD	weak	Permanent dipoles	$CH_3CH_2CH_2CHO$ $CH_3CH_2CH_2CH_2OH$
Hydrogen bond HB	strong	Molecules with OH, NH, funct. groups	$CH_3CH_2CH_2CH_2OH$
ionic	Very strong	Ionic compounds	NaCl, LiF

Polar molecules interact strongly than apolar ones.

Boiling Point

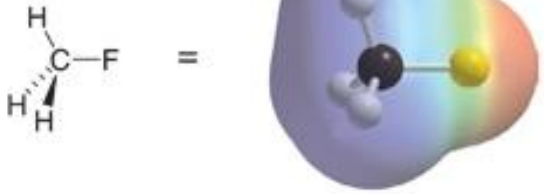
- The boiling point is the temperature at which the vapor pressure of a liquid is equal to the external pressure.
- Energy is required to break intermolecular interactions.
- The higher the intermolecular interactions, the higher the b.p..
- Compounds with similar M.W.:



Boiling Point

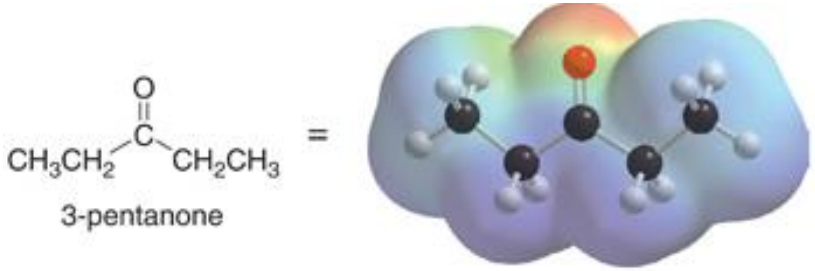
b.p. = 42 °C

I is more polarizable



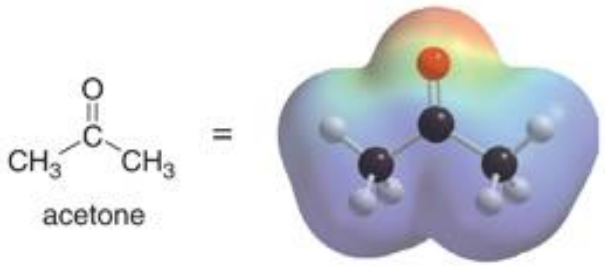
b.p. = –78 °C

Smaller F has a low polarizability



b.p. = 102 °C

Larger surface area



b.p. = 56 °C

Smaller surface area

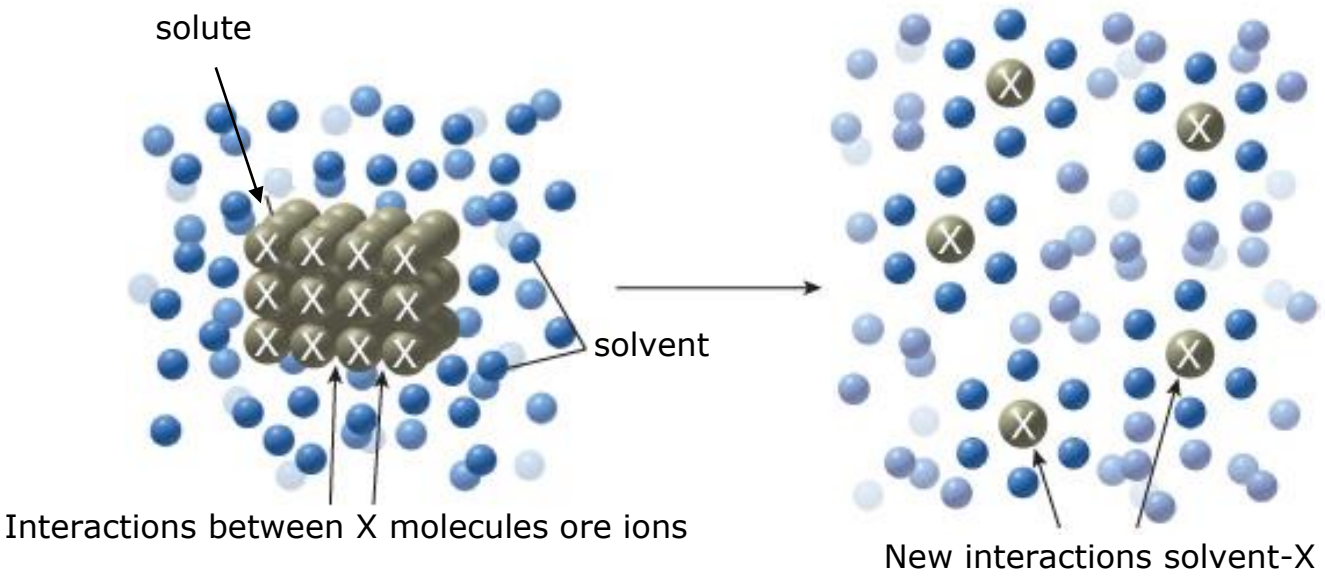
Melting Point

- M.p. and b.p. follow the same trend.

$CH_3CH_2CH_2CH_2CH_3$	$CH_3CH_2CH_2CHO$	$CH_3CH_2CH_2CH_2OH$
pentane	**butanal**	**1-butanol**
mp = –130 °C	mp = –96 °C	mp = –90 °C

Solubility

- Solubility is a measure of the degree to which a compound (solute) dissolves in a liquid (solvent).
- Interactions between ions or molecules are replaced by interactions with the solvent



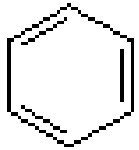
Solubility

- Compounds dissolve in sovents with which they can interact efficiently.
- “Like dissolves like.”
- Polar compounds dissolve in polar solvents. Apolar or weakly polar compounds dissolve in apolar/weakly polar solvents)
- Three physical quantities are related to polarity:
  - The dipole moment μ
  - The dielectric constant ε
  - The miscibility with water

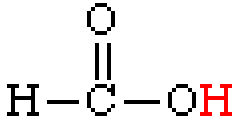
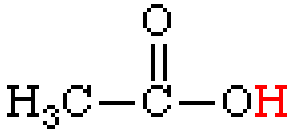
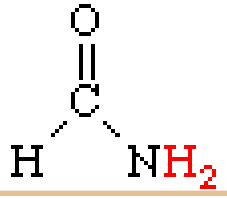
Solvents

- Solvents are generally classified in three cathegories.
  - *polar protic*: containing OH.
  - *(di)polar aprotic*: they have a high dipole moment but do not contain –OH groups
  - *apolar*: low dielectric constants; do not mix with water

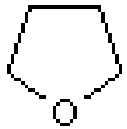
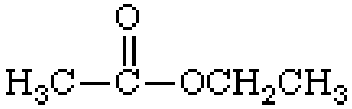
Apolar Solvents

Name	Structure	b.p., °C	dipole moment	dielectric constant
hexane	$CH_3(CH_2)_4\ CH_3$	69	----	2.02
benzene		80	0	2.28
carbon tetrachloride	CCl_4	76	0	2.24

Polar Protic Solvents

Name	Structure	b.p.., °C	Dipole moment	Dielectric constant
water	H-OH	100	1.85	80
methanol	CH_3-OH	68	1.70	33
ethanol	CH_3CH_2-OH	78	1.69	24.3
1-propanol	$CH_3CH_2CH_2$-OH	97	1.68	20.1
1-butanol	$CH_3CH_2CH_2CH_2$-OH	118	1.66	17.8
formic acid		100	1.41	58
acetic acid		118	1.74	6.15
formamide		210	3.73	109

Polar Aprotic Solvents

Name	Structure	b.p., °C	dipole moment	dielectric constant
acetone	$(CH_3)_2C{=}O$	56	2.88	20.7
tetrahydrofurane (THF)		66	1.63	7.52
diethyl ether	$CH_3CH_2OCH_2CH_3$	35	1.15	4.34
Ethyl acetate		78	1.78	6.02
acetonitrile	CH_3CN	81	3.92	36.6
N,N-dimetilformamide (DMF)	$(CH_3)_2NCHO$	153	3.82	38.3
dichloromethane	CH_2Cl_2	40	1.60	9.08
dimethyl sulfoxide (DMSO)	$(CH_3)_2S{=}O$	189	3.96	47.2

Delocalized Electrons and Bonds. Resonance

- The structure and properties of certain molecules can not be explained by the simple valence orbital model with localized electrons.
- In this case, a single Lewis structure is replaced by a set of Lewis structures called resonance structures.

Resonance

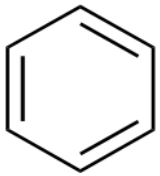
- Resonance structures have the same disposition of atoms but a different arrangement of electrons (π electrons and lone pairs).

- Bond lengths and angles do not change in resonance structures.

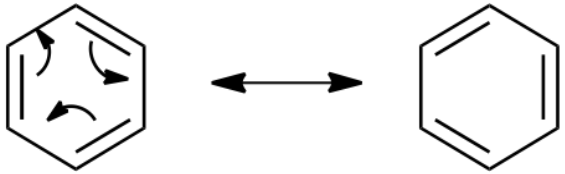
- Resonance is a simple theory to adapt conventional Lewis structures to the representation of molecules with delocalized electrons and bonds.

Resonance - Delocalized Bonds

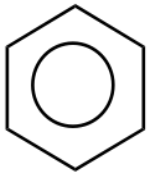
Benzene (C_6H_6)



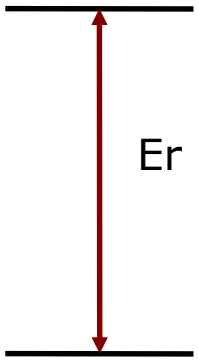
Very stabile
6 identical C-C bonds
139 pm

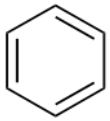


Resonance structures



Resonance hybrid





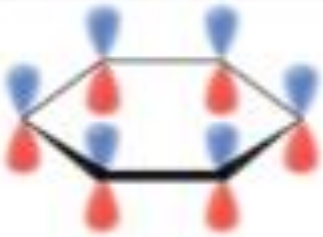
6 localized
π electrons

Er = 150.7 kJ/mol
(36 kcal/mol)

6 delocalized
π electrons

Resonance

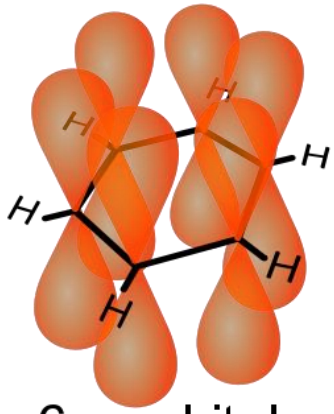
Cyclic compound



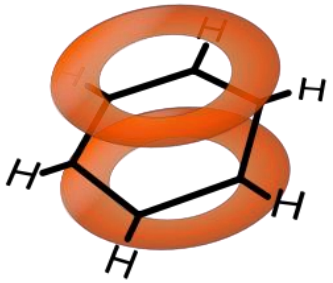
benzene

Every *p* orbital overlaps with two neighboring *p* orbitals.

aromatic



6 p-orbitals



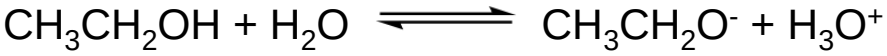
delocalized

Resonance

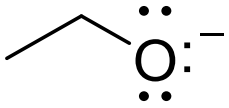
1. Resonance structures are not real. No single resonance structure can adequately represent the real structure of a species with delocalized electrons.
2. Resonance structures are not isomers. They only differ in the distribution of electrons not in the disposition of the nuclei.
3. Resonance structures are not in equilibrium.

Resonance

CH_3CH_2OH: pK_a 16

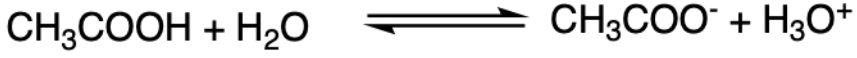


Ethoxide

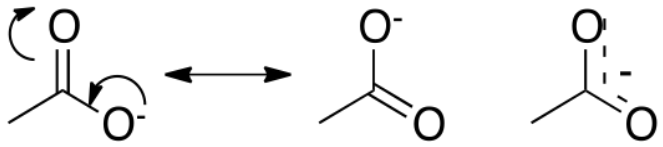


Localized
charge
less stabile

CH_3COOH: pK_a 4.75



Acetate



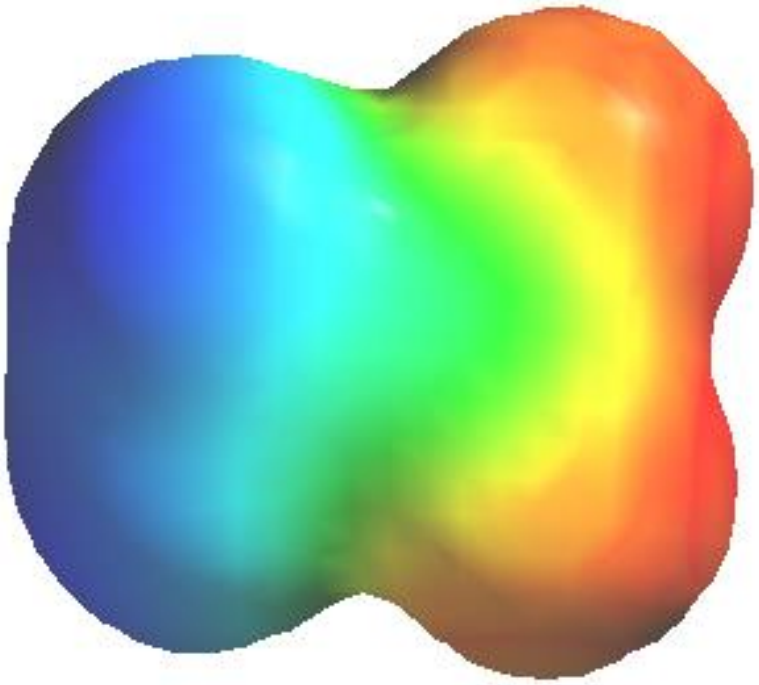
Resonance structures

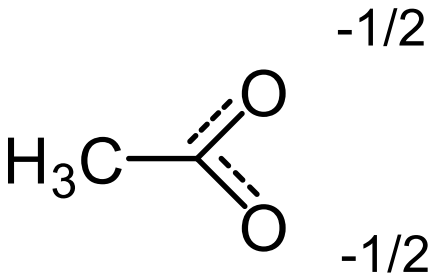
Resonance
hybrid

Delocalized
charge
more stabile

Acetate ion

(ab initio 3-21g calculation)





hybrid

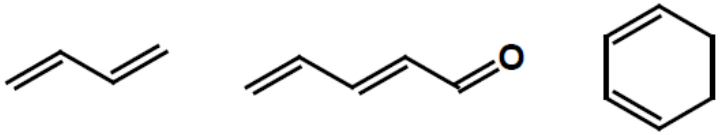
electrostatic potential mapped onto the Van der Waals surface

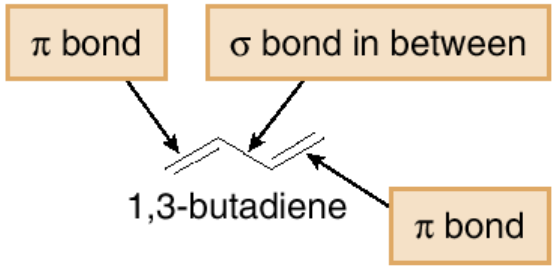
note symmetry

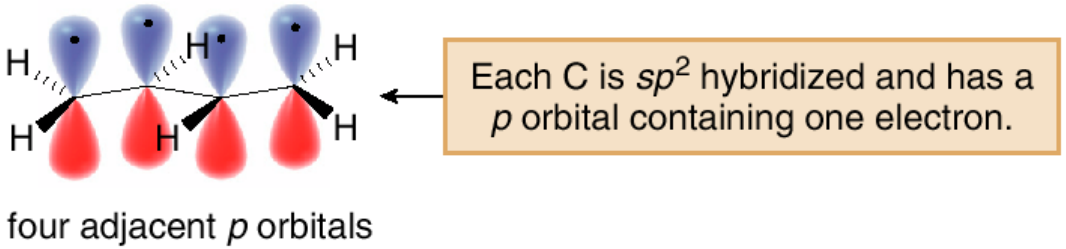
Conjugation and resonance

Delocalization occurs in conjugated systems
Conjugated systems have at least three adiacent and parallel p orbitals

Conjugated double bonds



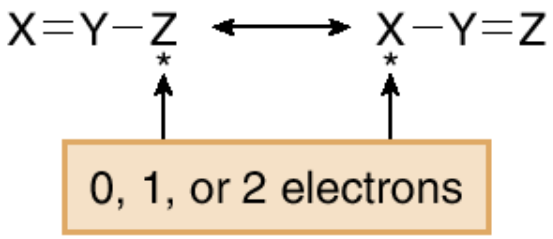




See chapter: Conjugated dienes

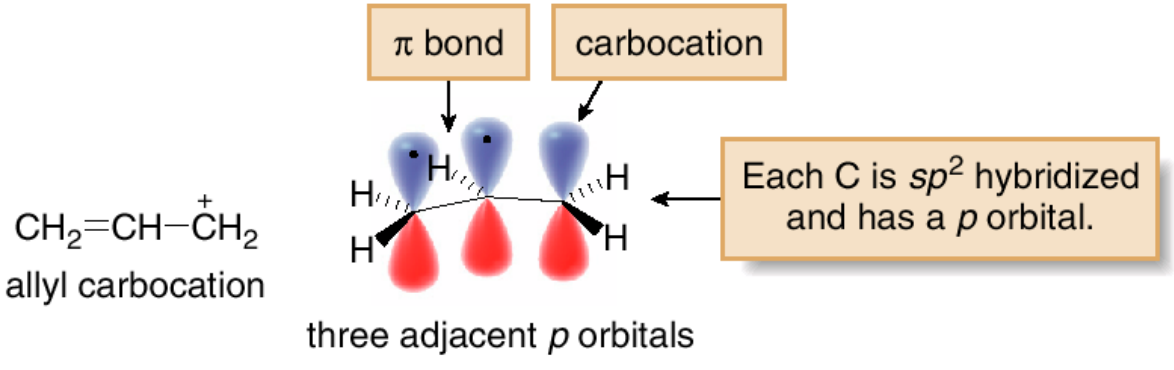
Conjugation and resonance

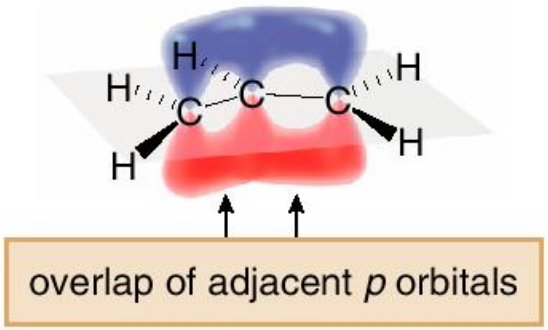
Allylic systems



Z = C, N, O

- Allylic carbocation is an example of conjugated system.

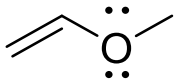


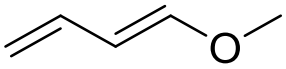


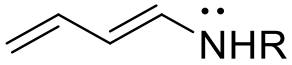
- Conjugation stabilizes allylic carbocation

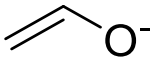
Conjugation and resonance

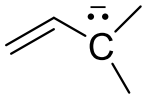
Allylic systems

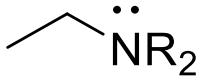




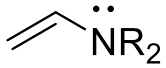




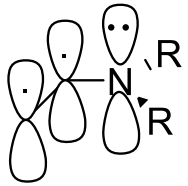




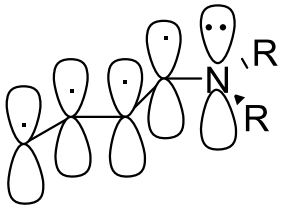
Localized pair
in sp3



Delocalized pair
in sp^2

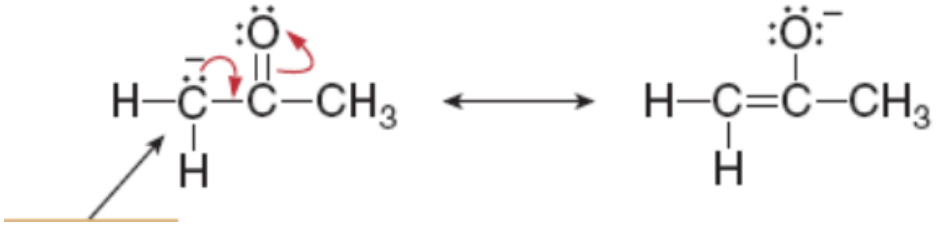


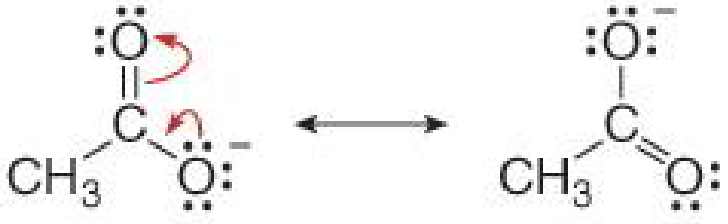
Trigonal sp^2 nitrogen



Writing resonance structures

1. Atom with lone pair adiacent to a π bond: anions

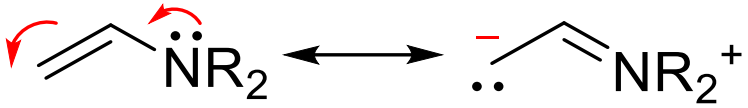


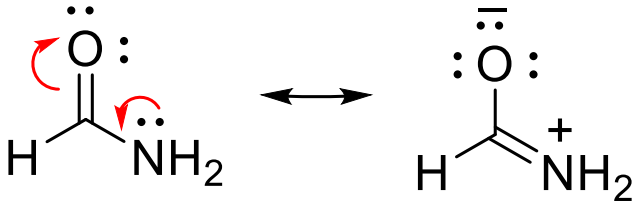


Exercise: write the resonance hybrid

Writing resonance structures

2. Atom with lone pair adiacent to a π bond: neutral molecules



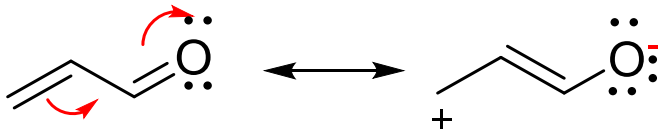


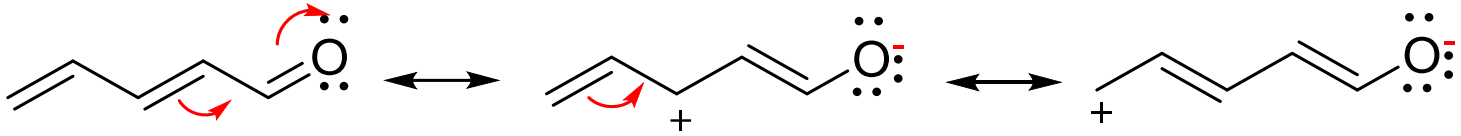
3. Carbocation adiacent to a π bond

Exercise: write the resonance hybrid

Writing resonance structures

4. Conjugated double bonds

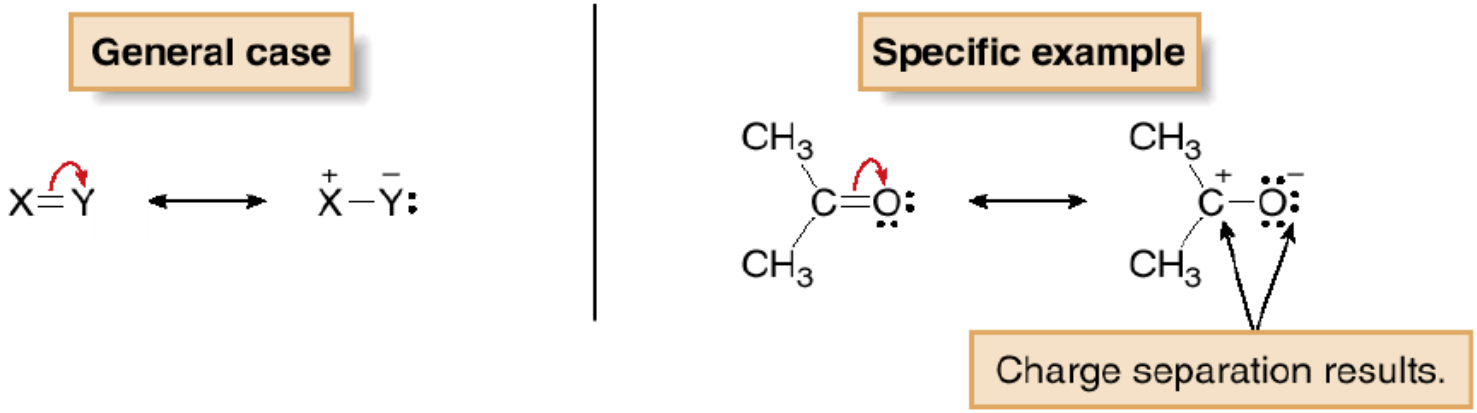




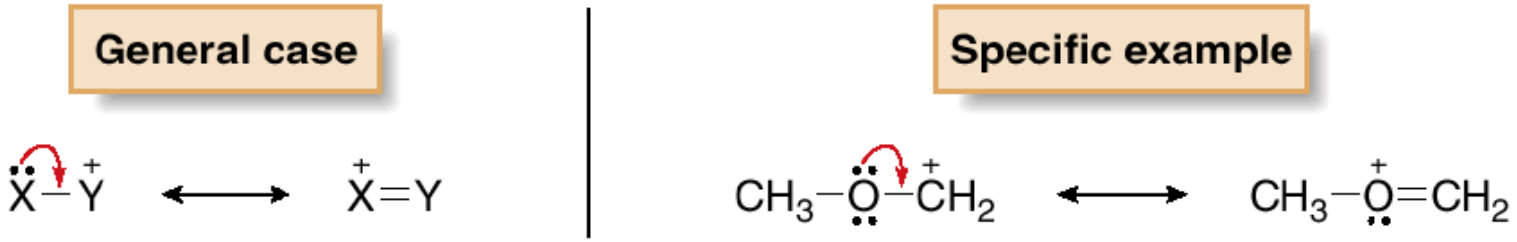
Exercise: write the resonance hybrid

Other systems described by resonance

3. Polar double bonds



4. Electron pair adiacent to a positive charge



Acids and Bases
Electrophiles and Nucleophiles
Organic Reaction Mechanisms

Chapters 2 & 6

Organic Chemistry, *8th Edition*

John McMurry

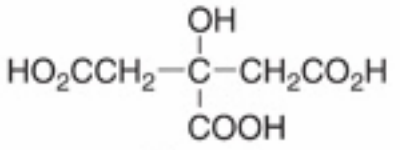
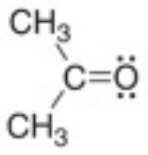
Brønsted-Lowry Acids and Bases

- Acids donate protons to an acceptor

  All Brønsted-Lowry acids contain a ionizable proton.

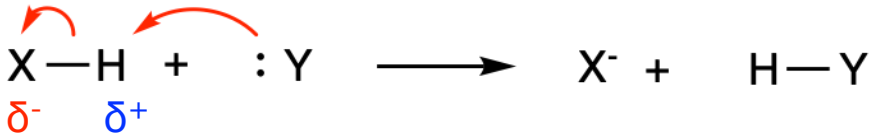
- Bases accept protons from a donor

  All Brønsted-Lowry bases contain a lone pair or a π bond.

Brønsted-Lowry acids HA		**Brønsted-Lowry bases B:**	
Inorganic	**Organic**	**Inorganic**	**Organic**
HCl H_2SO_4 HSO_4^- H_2O H_3O^+	CH_3CO_2H **acetic acid**  **citric acid**	$H_2\ddot{O}:$ $:NH_3$ $:\ddot{\underset{..}{O}}H^-$ $:\ddot{N}H_2^-$	$CH_3\ddot{N}H_2$ **methylamine** $CH_3\ddot{\underset{..}{O}}:^-$ **methoxide ion**  **aceton** $CH_2{=}CH_2$ **ethylene**

Brønsted-Lowry Acids and Bases

- An acid-base reaction is a proton transfer reaction



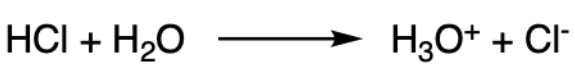
- Acids donate protons to an acceptor

  All Brønsted-Lowry acids contain a polar X-H bond.

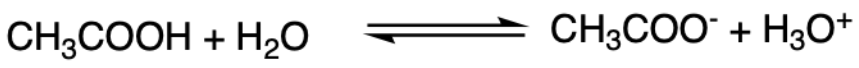
  (X=O, Halogens)

- Bases accept protons from a donor

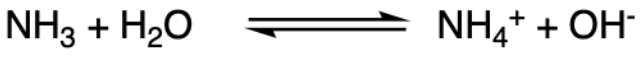
  All Brønsted-Lowry bases contain a lone pair.



strong acid



weak acid



weak base

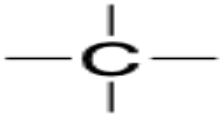
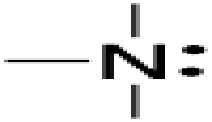
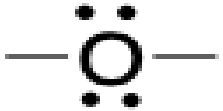
Organic Acids

Element	Electronegativity	Bond	Acidity
H	2.1		
C	2.5	C-H	NO
N	3.0	N-H	NO
O	3.5	O-H	YES

Formula	Name	K_a	pK_a	acidity
R-OH	alcohols	$<10^{-15}$	> 15	less than H_2O
Ar-OH	phenols	10^{-9}	9	slightly dissociated
R-COOH	carboxylic acids	$> 10^{-5}$	> 5	more dissociated

Ar = aromatic

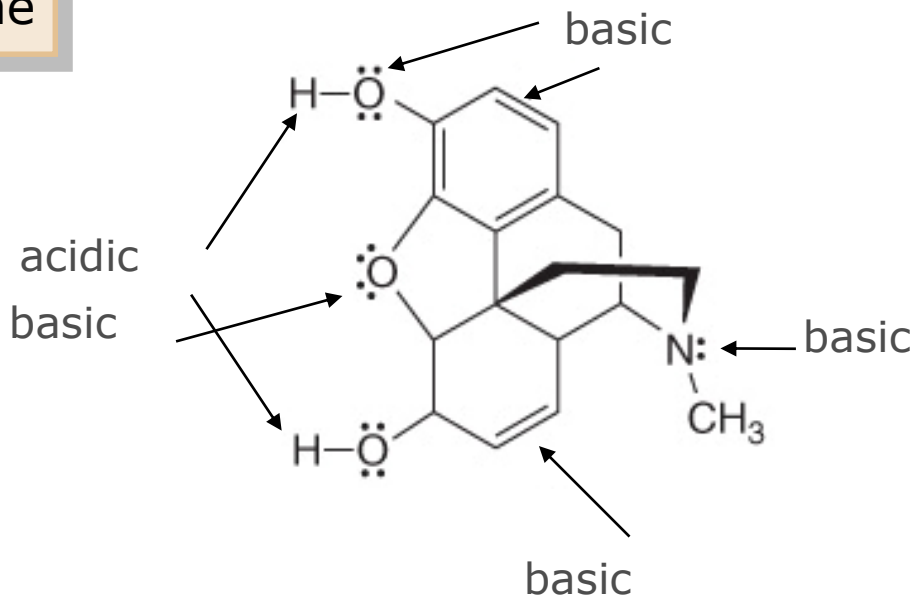
Organic Bases

Group	electron pairs	electronegativity	Basicity
	NO	-	NO
	1	3.0	YES
	2	3.5	WEAK

Brønsted-Lowry Acids and Bases

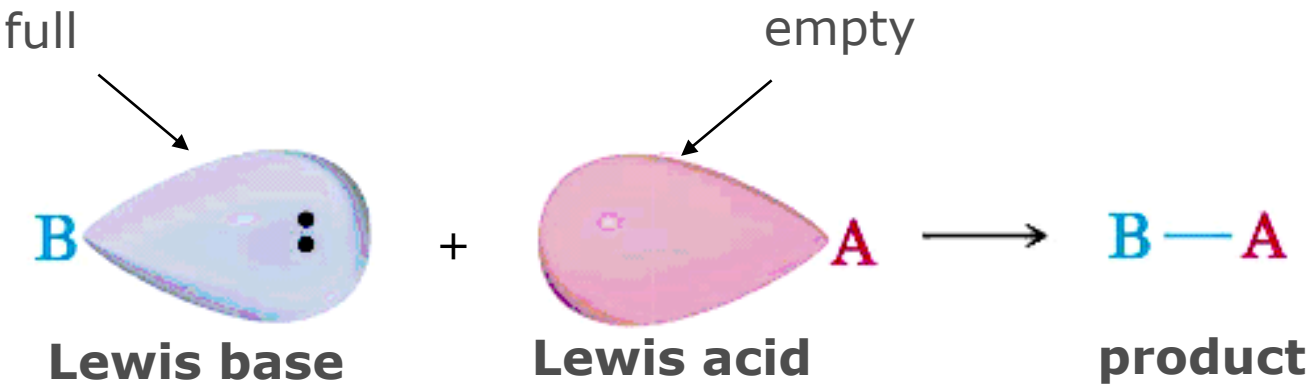
- Certain molecules can behave both as acids and bases.

Morphine



Lewis Acids and Bases

- A Lewis acid accepts an electron pair from a donor. Lewis acids have a low energy empty orbital.
- A Lewis base donates an electron pair to an acceptor. Lewis bases have a high energy full orbital (lone pair or π bonds).



Lewis Acids and Bases

- All Brønsted-Lowry acids are Lewis acids. Not all Lewis acids are Brønsted-Lowry acids.
- Only species with ionizable protons are Brønsted-Lowry acids. Any electron acceptor is a L.A.

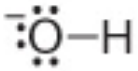
H_2O CH_3OH

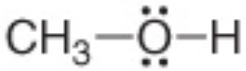
Brønsted-Lowry and Lewis acids

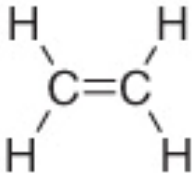
BF_3 $AlCl_3$

Lewis acids

- All Brønsted-Lowry bases are also Lewis bases. They must have either a lone pair or a π bond.

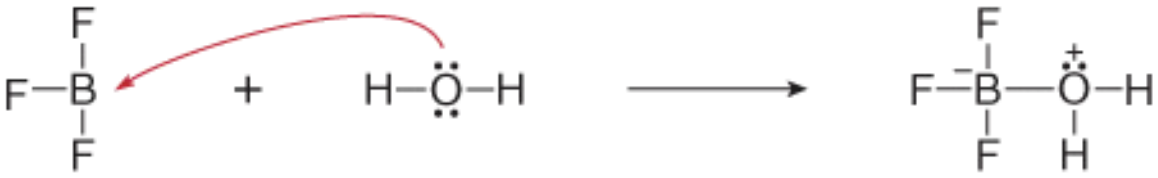






Reactions Between Lewis Acids and Bases

- Organic reactions can in most cases be described as reactions between electron poor species (Lewis acids) and electron rich species (Lewis bases).
- The electron poor species (Lewis acid) is called electrophile.
- The electron rich species (Lewis base) is called nucleophile.
- The movement of electrons is indicated with curved arrows.

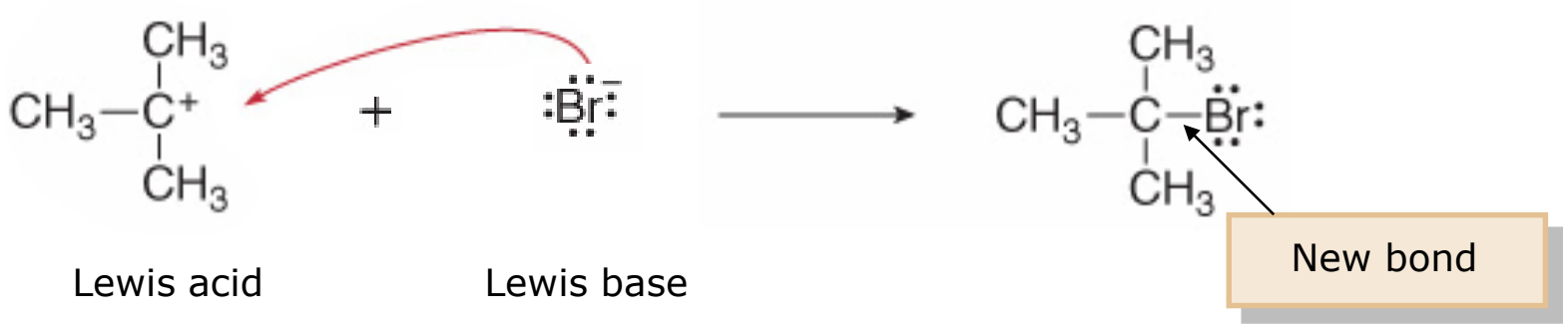


Lewis acid — Lewis base

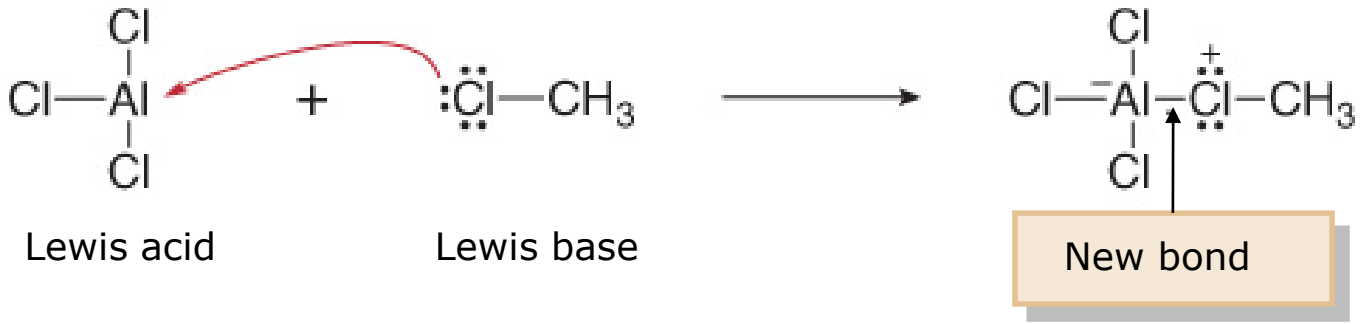
electrophile — nucleophile

Electrophiles and Nucleophiles

electrophile nucleophile



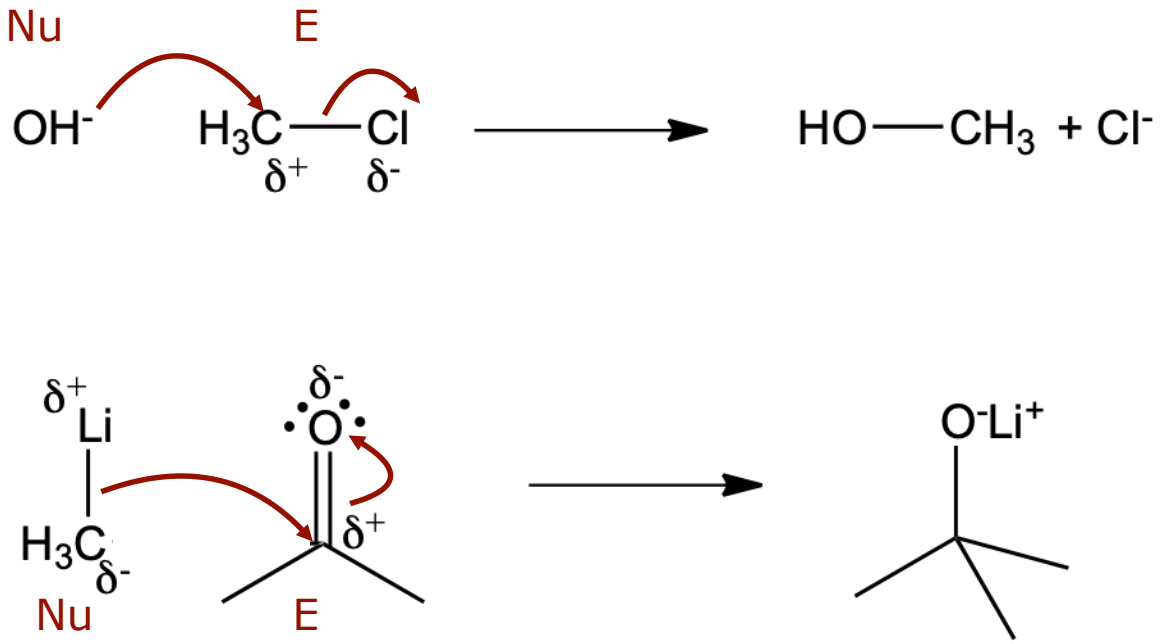
Lewis acid Lewis base



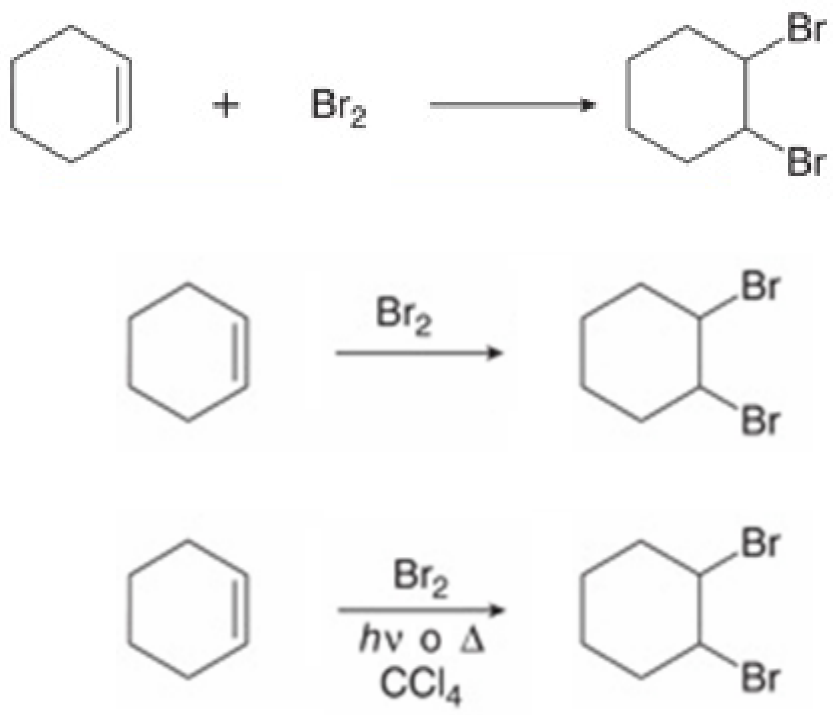
Lewis acid Lewis base

Electrophiles and Nucleophiles

- Nucleophiles and electrophiles may also contain polar bonds

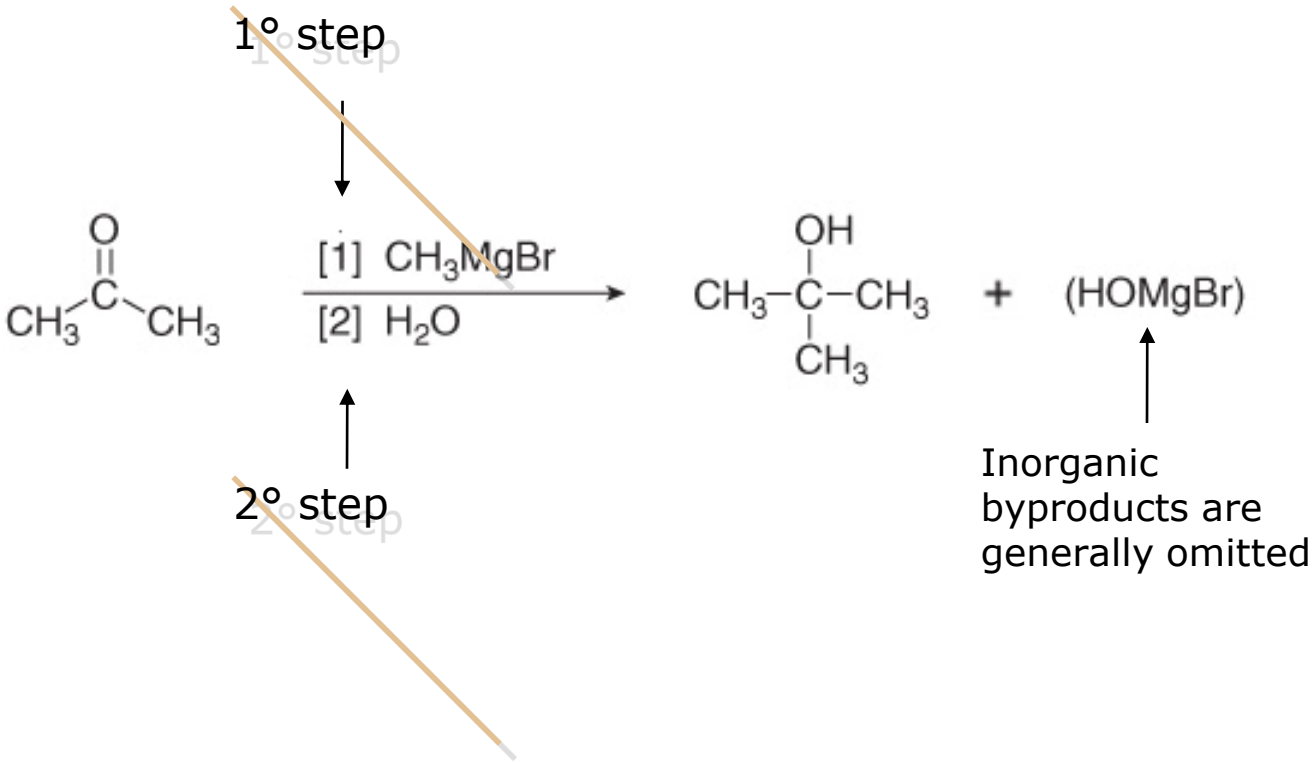


How to Write an Organic Reaction



How to Write an Organic Reaction

- In a sequence, the individual steps are numbered.

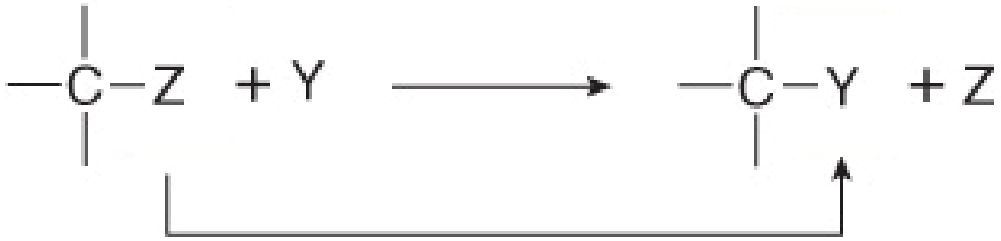


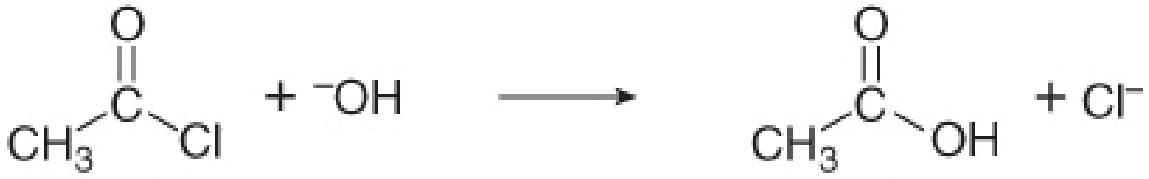
Organic Reactions

- Type of reaction (bond breaking/bond formation):
  - substitution
  - addition
  - elimination
  - rearrangement/transposition
- Mechanism = movement of electrons:
  - ionic (polar)
  - radicalic
  - pericyclic

Substitutions

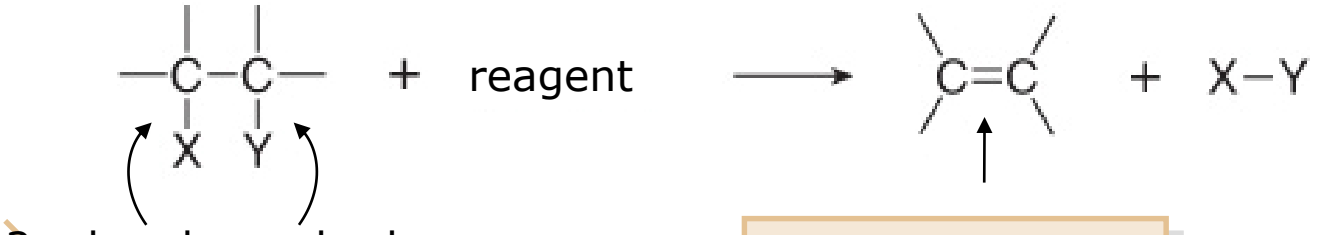
- In a general substitution reaction, an atom or group Y replaces an atom or group Z at carbon.
- Substitutions involve breaking and forming σ bonds.

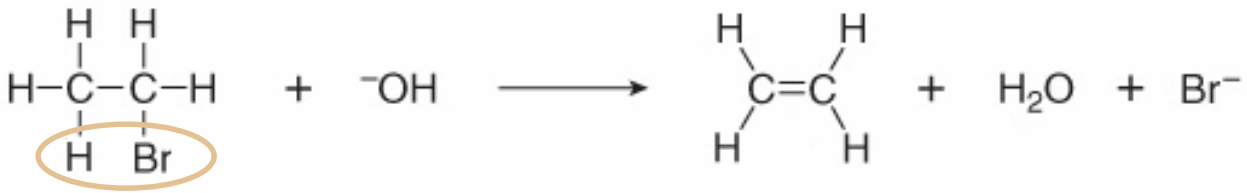


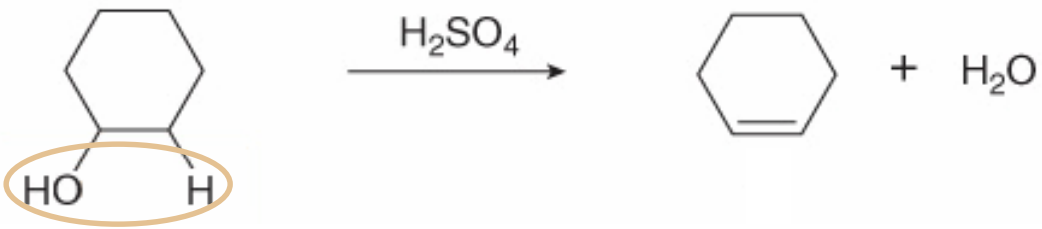


Eliminations

- In an elimination reaction two σ bonds are broken and one π bond is formed.

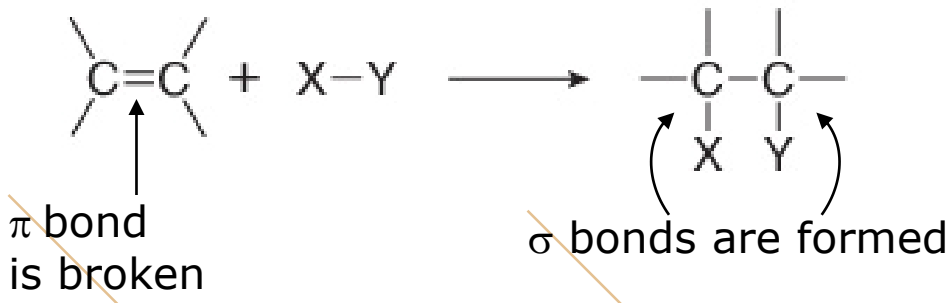


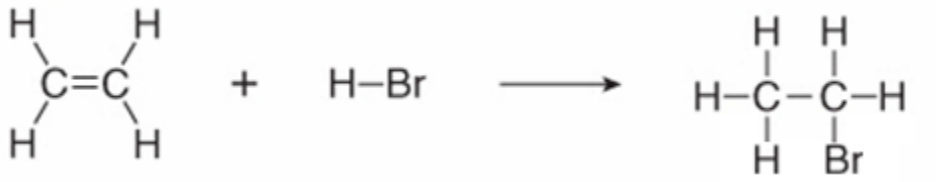


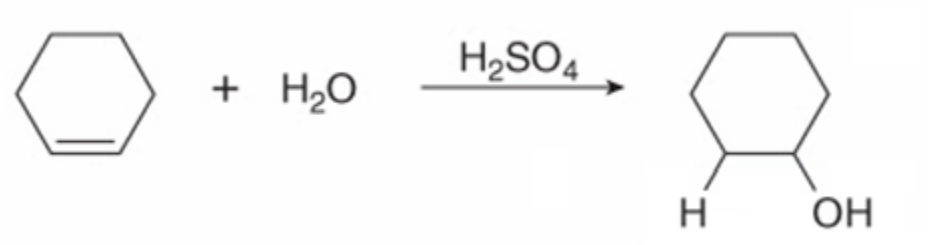


Additions

- In an addition reaction a π bond is broken and two new σ bond are formed.

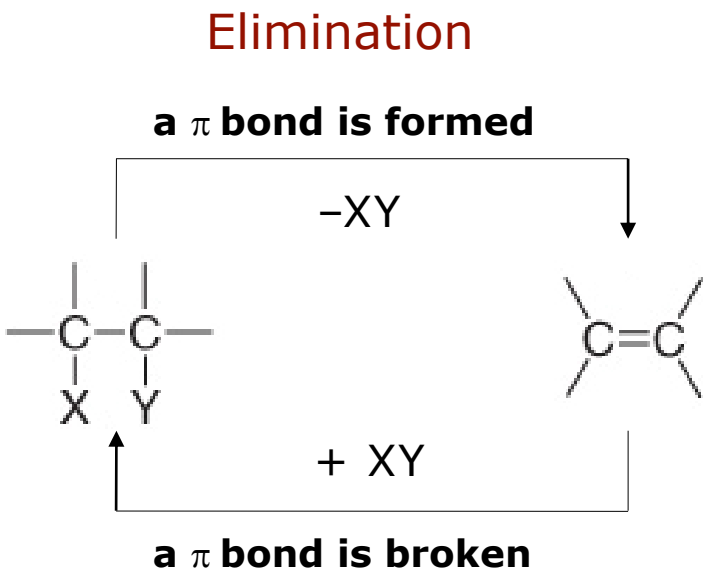






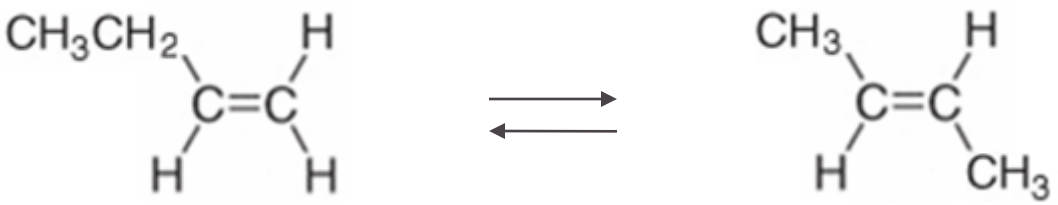
Additions and Eliminations

- Eliminations are the inverse of additions. A π bond is formed in eliminations and a π bond is broken in additions.



Rearrangements or Transpositions

- In a rearrangement or transposition the bonding pattern of a single reagent changes giving a constitutional isomer.



1-butene 2-butene

Bond Breaking

Omolysis

Radical

radicals are formed in *radical (omolitic) reactions*

Heterolysis

Carbocation

ions are formed or react in *polar (ionic) reactions*

Carbanion

Bond Formation

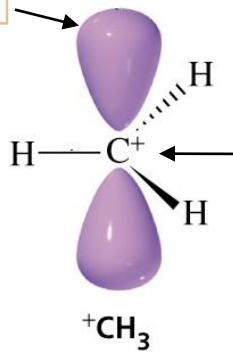
- A new bond can be formed in two ways:
  - From two radicals each contributing a single electron.

  - From a nucleophile contributing an electron pair and an electrophile accepting the electron pair. Nu and E may be ions or neutral molecules

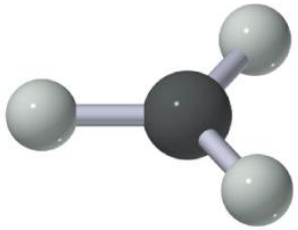
Energy is released in the formation of a bond

Carbocations, Carbanions, Radicals

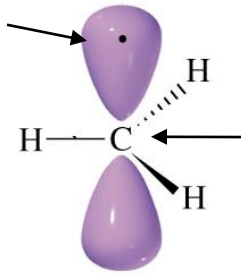
empty *p* orbital



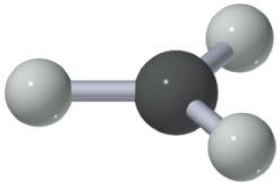
C *sp*² planar



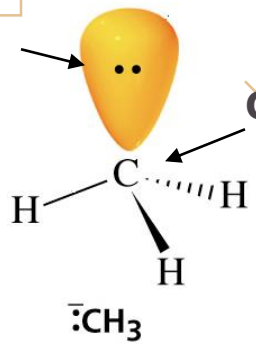
Singly occupied *p* orbital



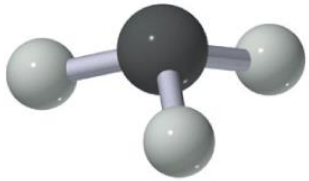
C *sp*² planar

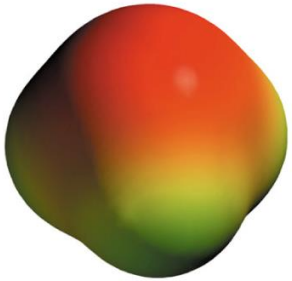


lone pair *sp*³



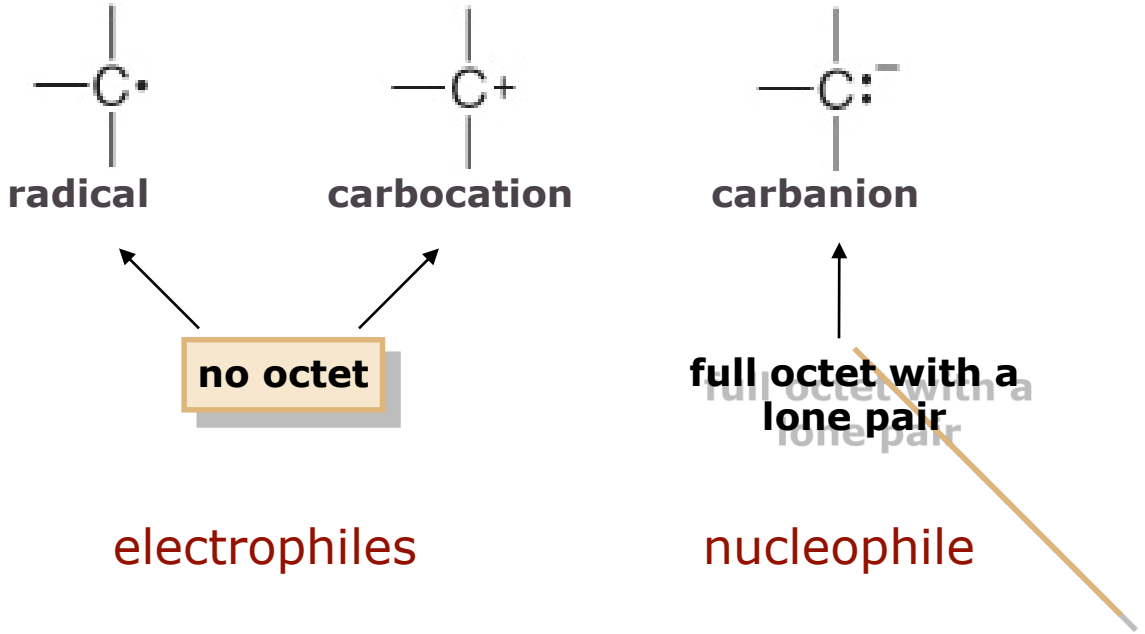
C *sp*³ tetrahedral





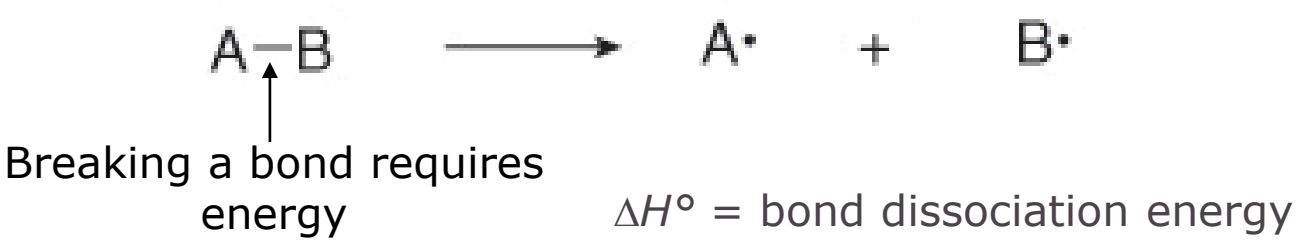
Carbocations, Carbanions, Radicals

- Radicals and carbocations are electrophiles because the carbon atom does not have a full octet.
- Carbanions are nucleophiles because the carbon atom has a lone pair.



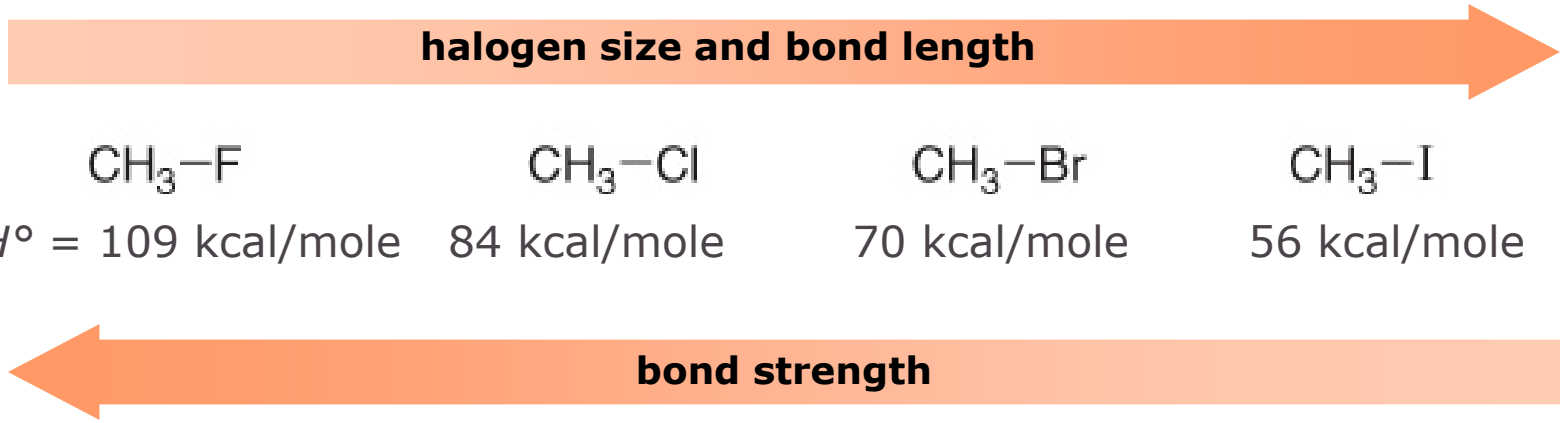
Bond Dissociation Energy

- Bond dissociation energy is the energy necessary to break a bond omolytically.



Bond Dissociation Energy

- The bond dissociation energy is a measure of the strength of the bond.
- The stronger the bond, the higher its dissociation energy.
- In general, shorter bonds are stronger.
- Bond dissociation energies decrease along a group.

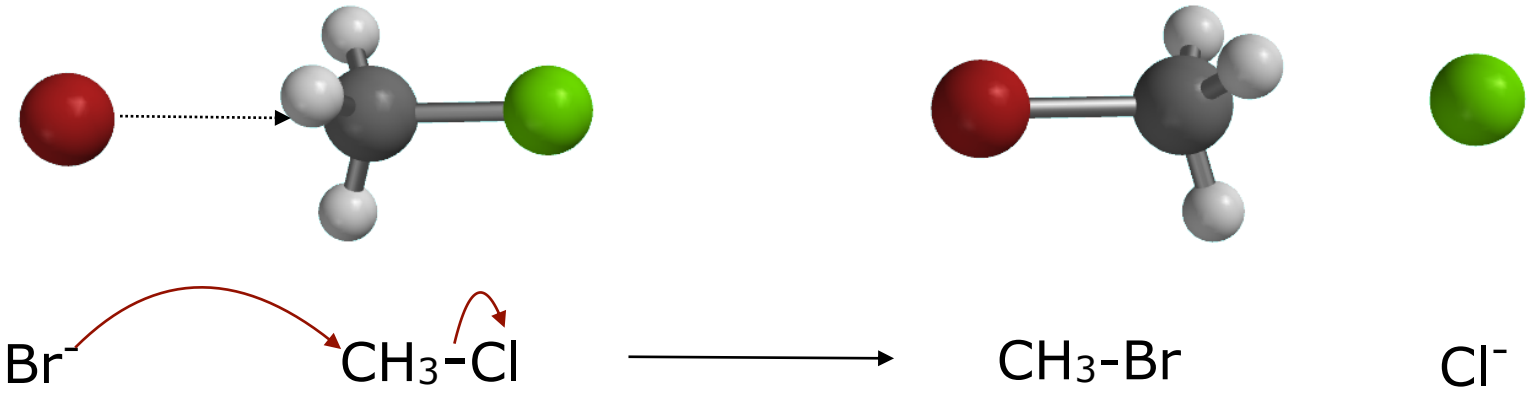


A Reaction Mechanism……

- Accounts for all reagents and products and their ratios.
- Describes in which order bonds are broken and formed and the rates of individual steps.
- In a *concerted reaction* reagents are directly converted into products in a single step.

- A multistep reaction involves the formation of one or more reactive intermediates.

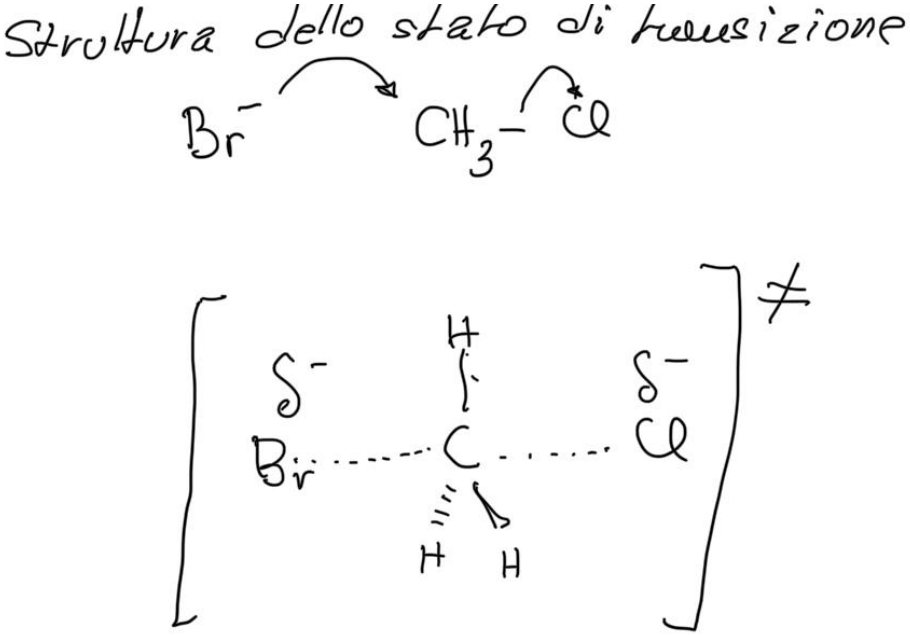
Transition State Theory and Collisional Theory

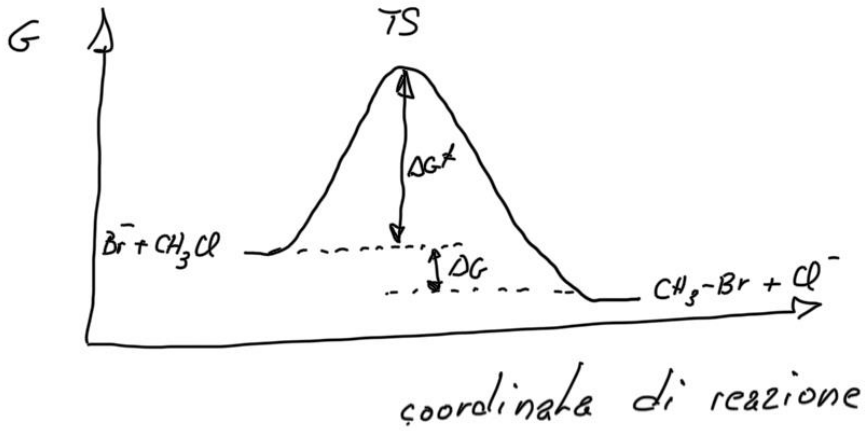


- Collisional theory: rigid collision between reacting species.

- Transition state theory: continuous deformation of reagent structure into product structure

Transition State





Transition State Theory - Energy Diagrams

- The activation energy $\Delta G^{\neq}$ is the energy required for a reaction to take place.
  - $\Delta G^{\neq} = \Delta H^{\neq} - T\Delta S^{\#}$
  - $\Delta G^{\neq}$ is correlated with the reaction's rate constant.

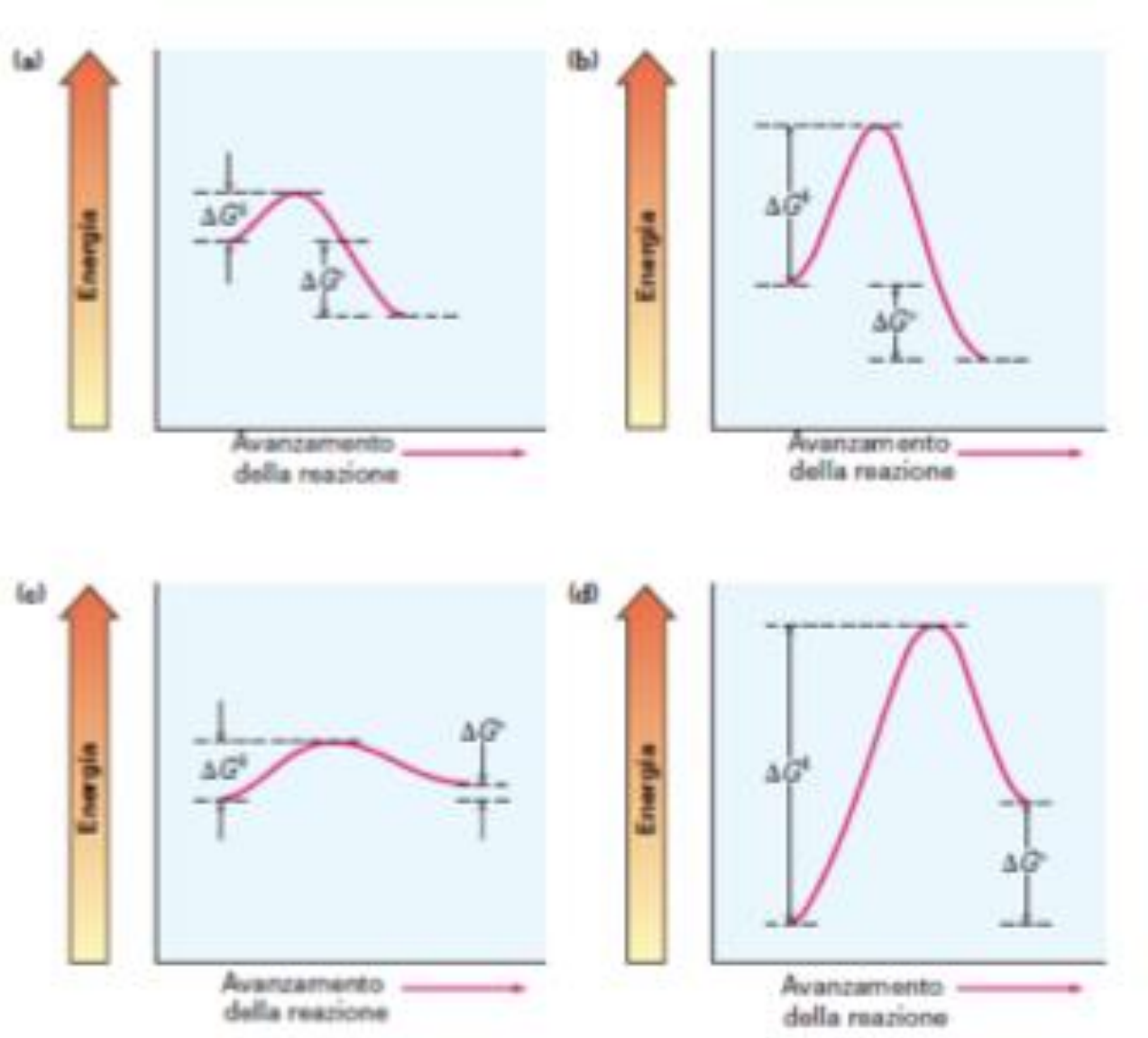
Eyring equation:

$$k = \frac{k_B T}{h} e^{-\frac{\Delta G^{\#}}{RT}}$$

- The transition state structure is intermediate between the structures of reagents and products. In the transition state there are partial bonds and partial charges (if the mechanism is ionic).
- Transition states are represented in brackets with the $^{\#}$ symbol.

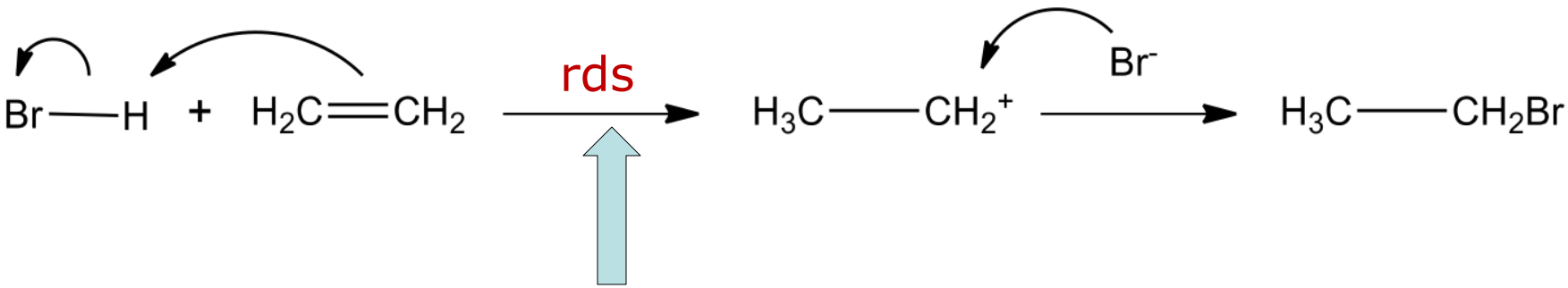
Energy Diagrams

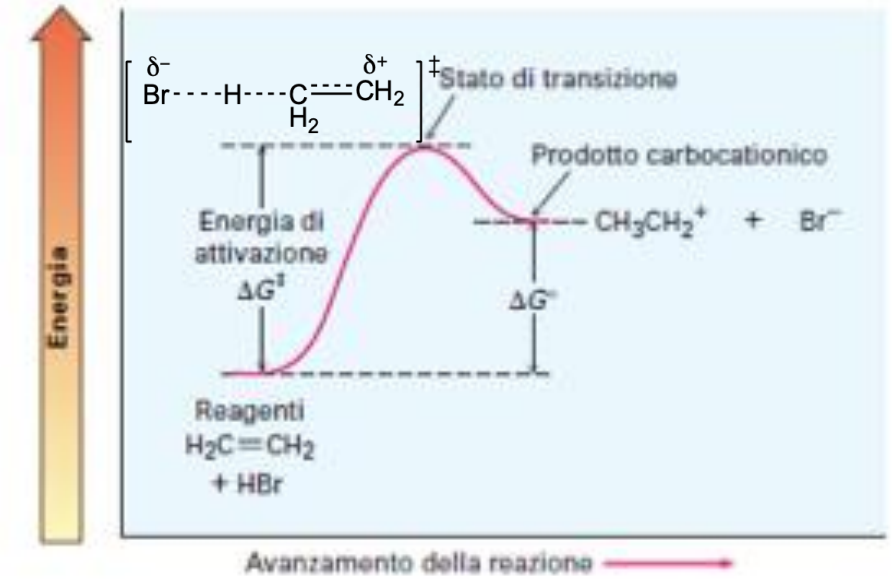
One step reaction



Energy Diagrams

Two-step reaction

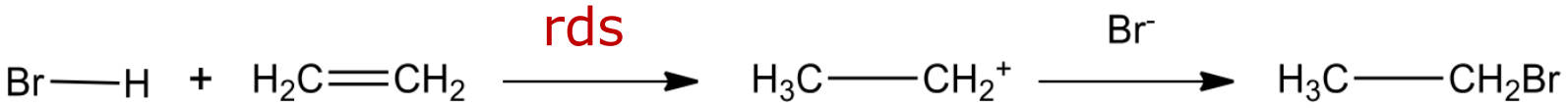


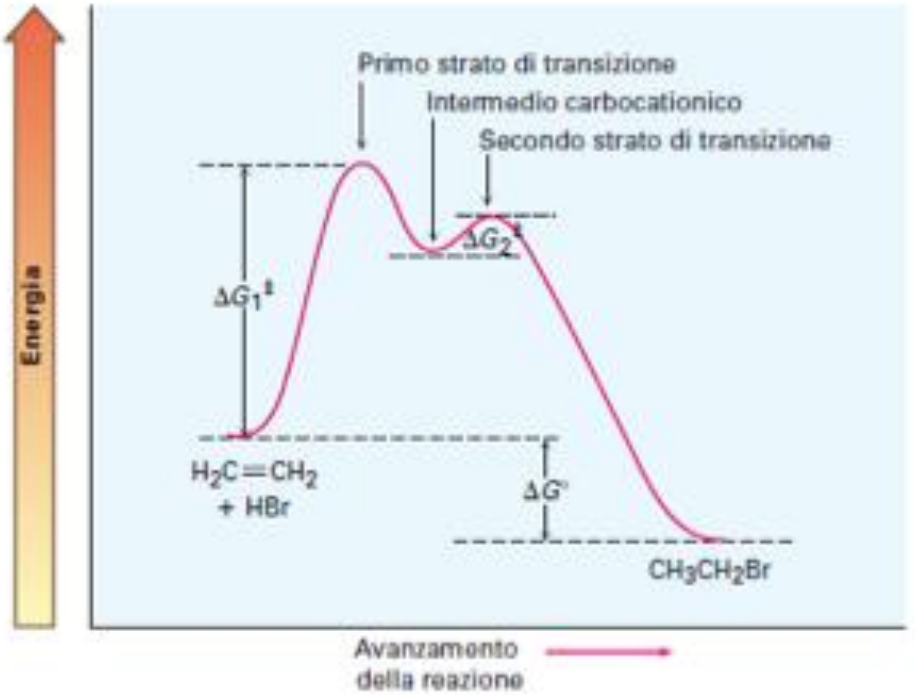


rds: rate determining step

Energy Diagrams

Complete energy diagram for the two-step reaction:

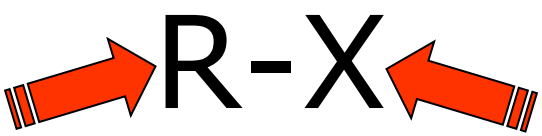




Functional Groups

Chapter 3.1
Organic Chemistry, *8th Edition*
J. McMurry

Functional Groups



Organic Residue (Radical)

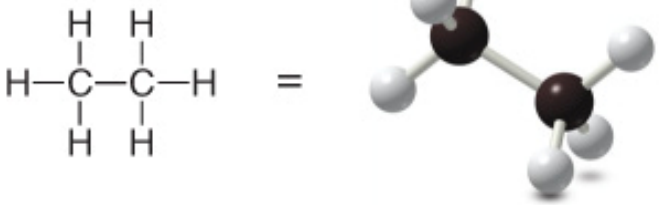
(from a hydrocarbon)

Functional Group

(heteroatom or group of atoms containing one ore or more heteroatoms)

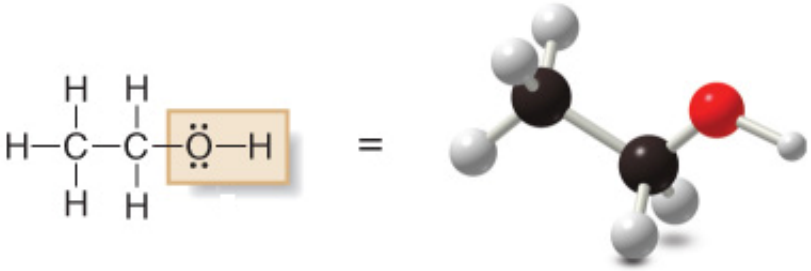
A functional group is an atom or a group of atoms all or in part # than C with specific and well defined physico-chemical properties.

Functional Groups



- Only C—C and C—H bonds
- No functional groups

- Does not posses polar bond or π bonds: very unreactive.
- Gas at NTP
- Insoluble in water



- OH functional groups

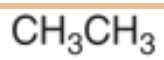
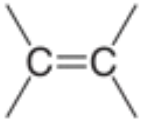
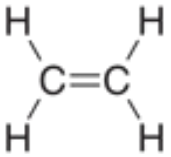
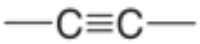
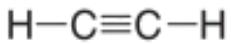
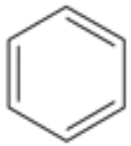
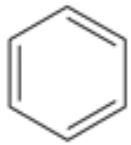
- Polar C-O and O-H bonds
- Lone pair on O
- Reacts with electrophiles
- Reacts with strong bases
- Liquid at NTP
- Soluble in water

Functional Groups

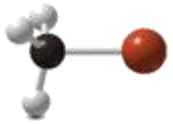
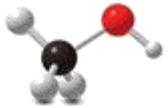
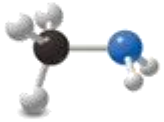
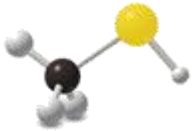
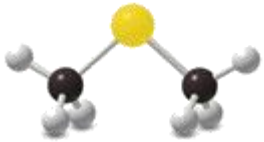
1. Define a class of compounds
   - Compounds belonging to the same class have similar properties and reactivity.
2. Are frequently the reaction site
   - Define the reactivity of a molecule
3. Determine the name
   - For example all ketones have the suffix –one:
     - » acetone
     - » cyclopropanone
     - » cortisone

Hydrocarbons

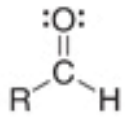
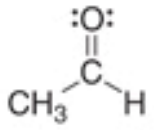
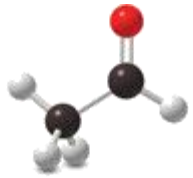
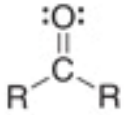
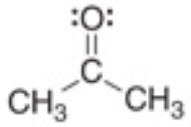
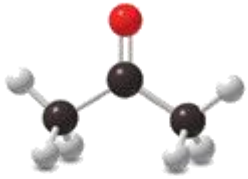
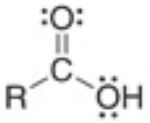
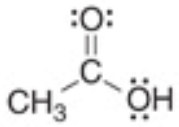
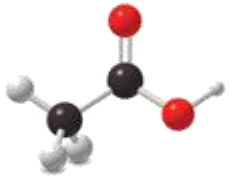
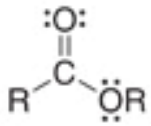
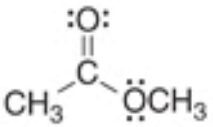
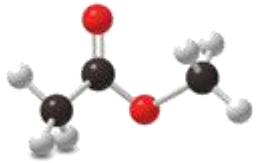
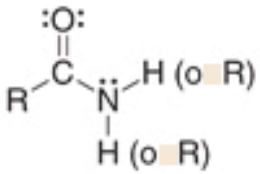
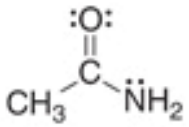
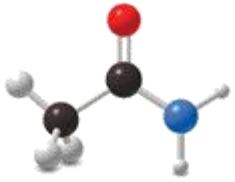
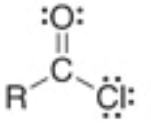
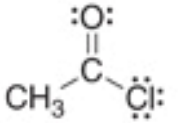
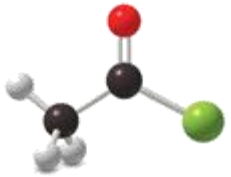
- Hydrocarbons possess only C–C e C–H bonds.
  - aliphatic (alkanes, alkenes, alkynes) and aromatic.

Hydrocarbon	General structure	Example	Functional Group
Alkanes			-----
Alkenes			Double bond
Alkynes			Triple bond
Aromatics			Aromatic ring

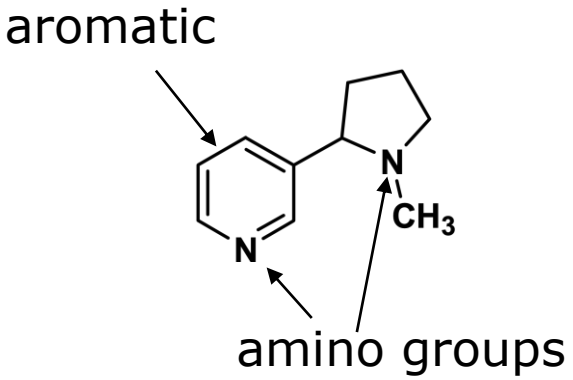
Functional Groups Containing C–Y σ bonds

Class Name	Structure	Example	3D Structure	Functional Group
Alkyl Halide	R–X: (X=F, Cl, Br, I)	CH_3–Br:		–X halo
Alcohol	R–OH	CH_3–OH		–OH hydroxy
Ether	R–O–R	CH_3–O–CH_3		–OR alcoxy
Amine	R–NH_2 o R_2NH or R_3N	CH_3–NH_2		–NH_2 amino
Thiol	R–SH	CH_3–SH		–SH mercapto
Sulfide	R–S–R	CH_3–S–CH_3		–SR alkylthio

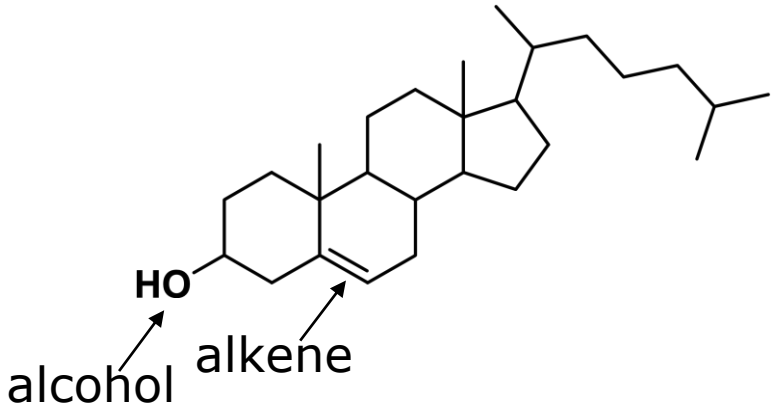
Functional Groups Containing The C=O Bond

Class Name	Structure	Example	3D Structure	Functional Group
Aldehyde				H–C=O formyl
Ketone				C=O carbonyl
Carboxylic Acid				–COOH carboxylate
Ester				–COOR
Amide				$–CONH_2$ –CONHR $–CONR_2$
Acid Chloride				–COCl

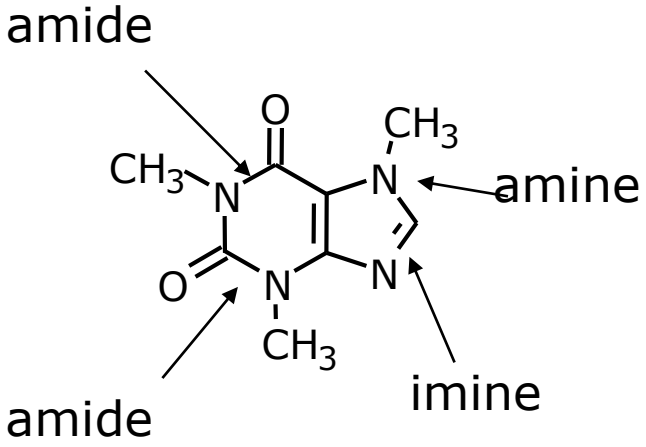
Polyfunctional Molecules



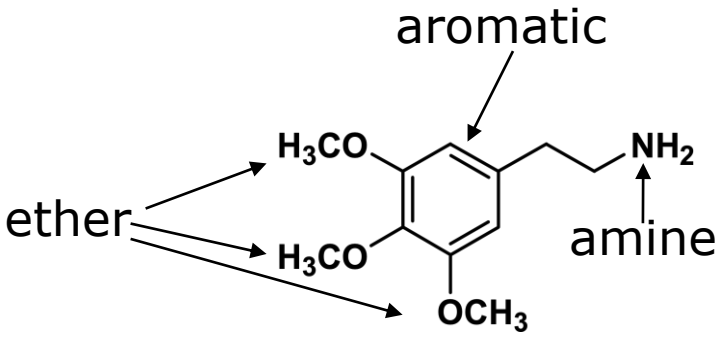
nicotine



cholesterol

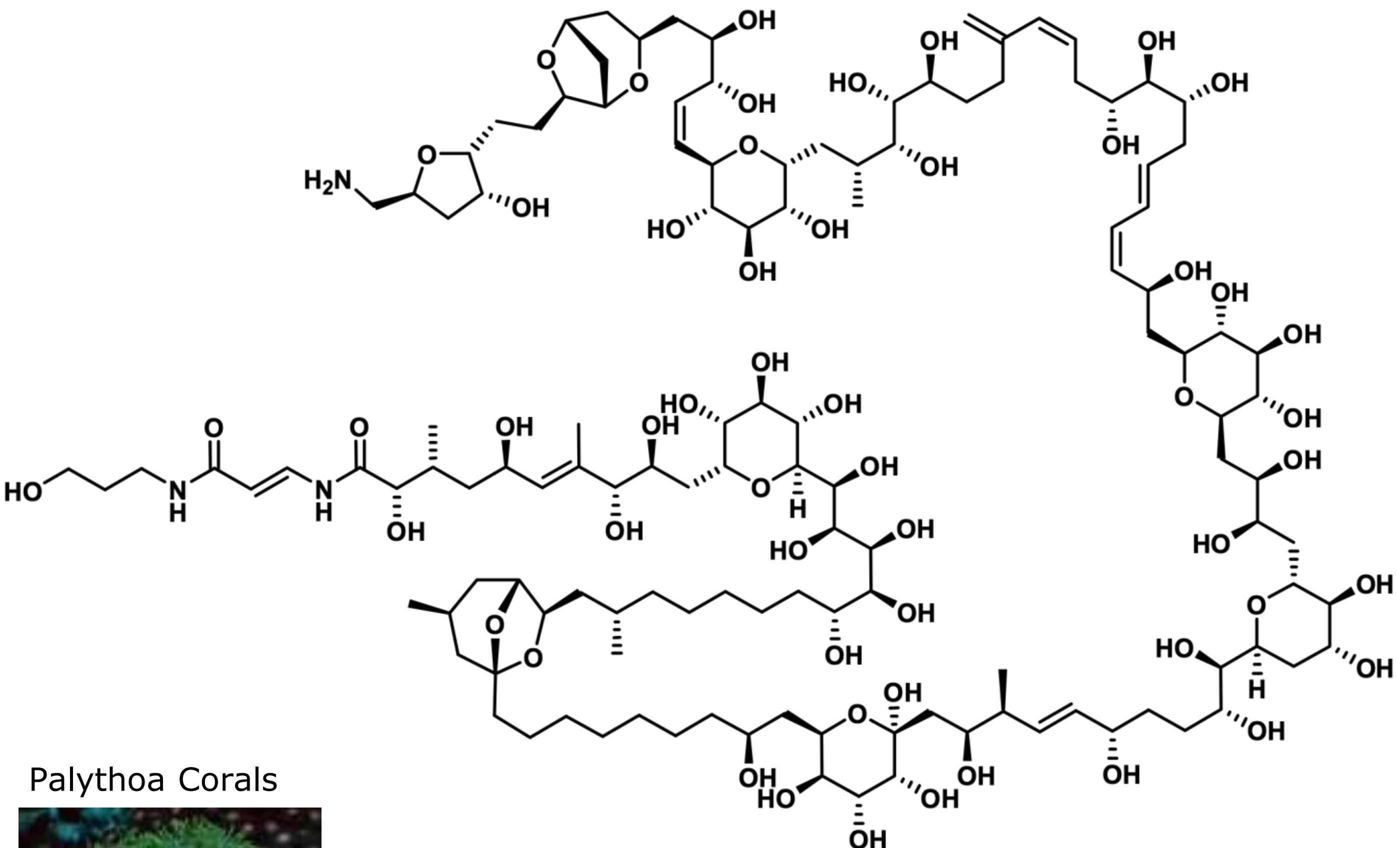


caffein



mescalin

Organic Compounds



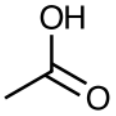
Palytoxin

Palythoa Corals

Lophozozymus pictor

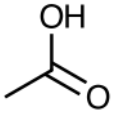
Line Notations

SMILES (**S**implified **M**olecular **I**nput **L**ine **E**ntry **S**ystem)



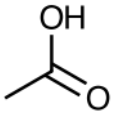
CC(=O)O

InChI (**In**ternational **Ch**emical **I**dentifier)

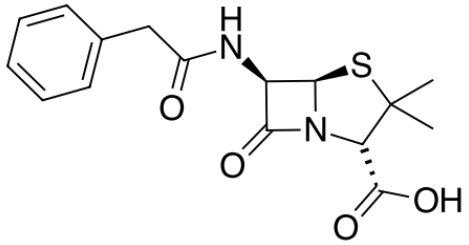


InChI=1S/C2H4O2/c1-2(3)4/h1H3,(H,3,4)

InChIKey (A hashed version of InChI)



QTBSBXVTEAMEQO-UHFFFAOYSA-N



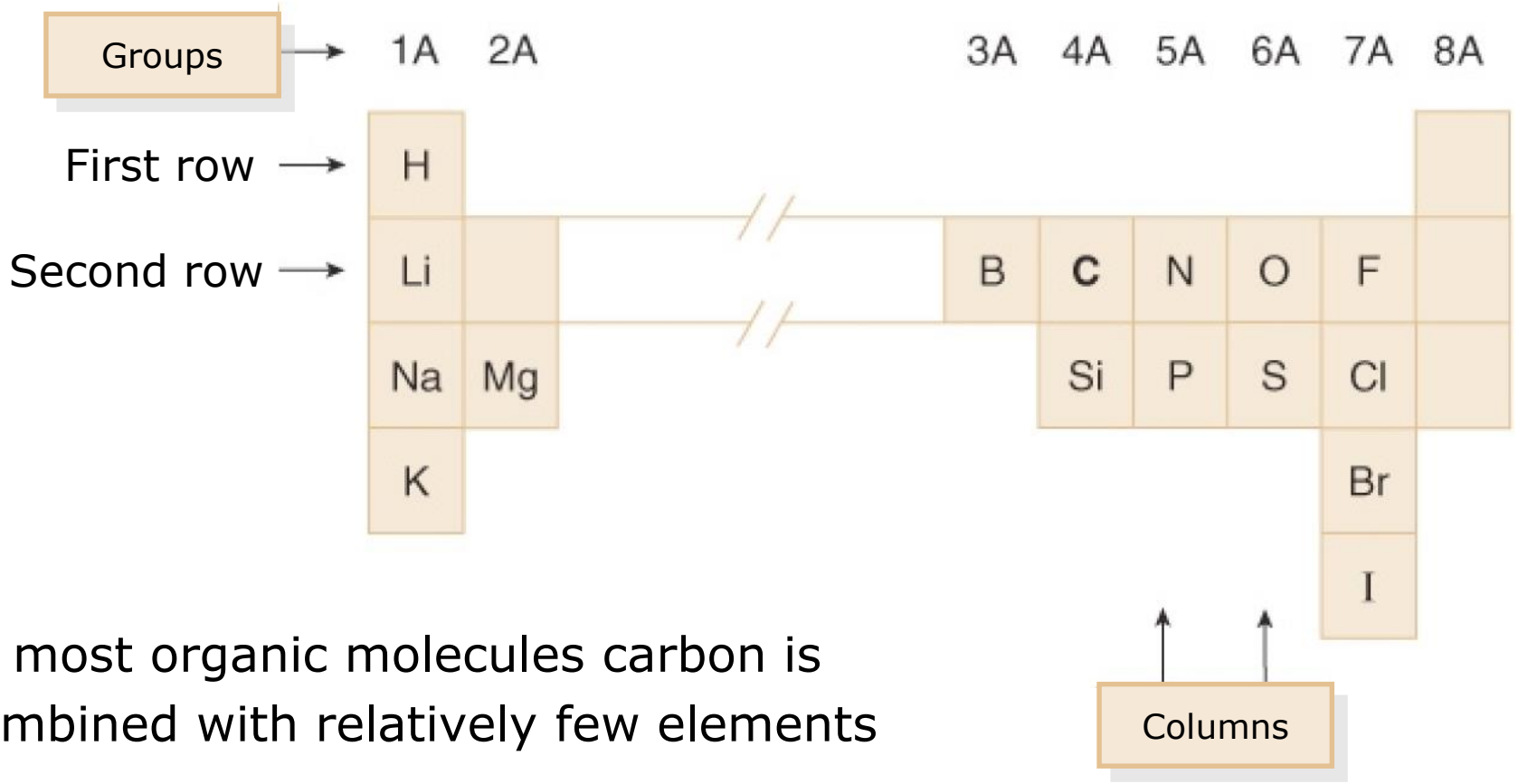
NIH molecular editor

SMILES: OC([C@@H]1N2C([C@@H](NC(CC3=CC=CC=C3)=O)[C@H]2SC1(C)C)=O)=O

InChI: InChI=1S/C16H18N2O4S/c1-16(2)12(15(21)22)18-13(20)11(14(18)23-16)17-10(19)8-9-6-4-3-5-7-9/h3-7,11-12,14H,8H2,1-2H3,(H,17,19)(H,21,22)/t11-,12+,14-/m1/s1

InChIKey: JGSARLDLIJGVTE-MBNYWOFBSA-N

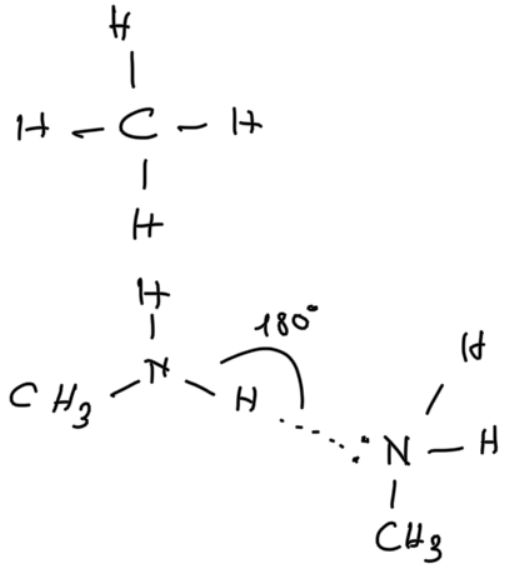
1. Carbon Forms Covalent Bonds With Many Other Elements



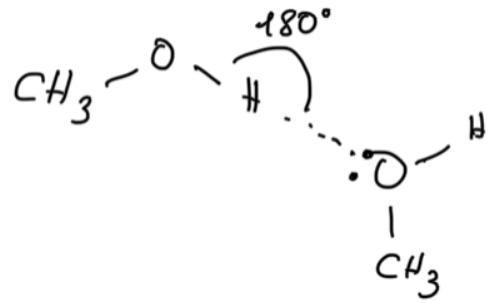
In most organic molecules carbon is combined with relatively few elements

The Hydrogen Bond

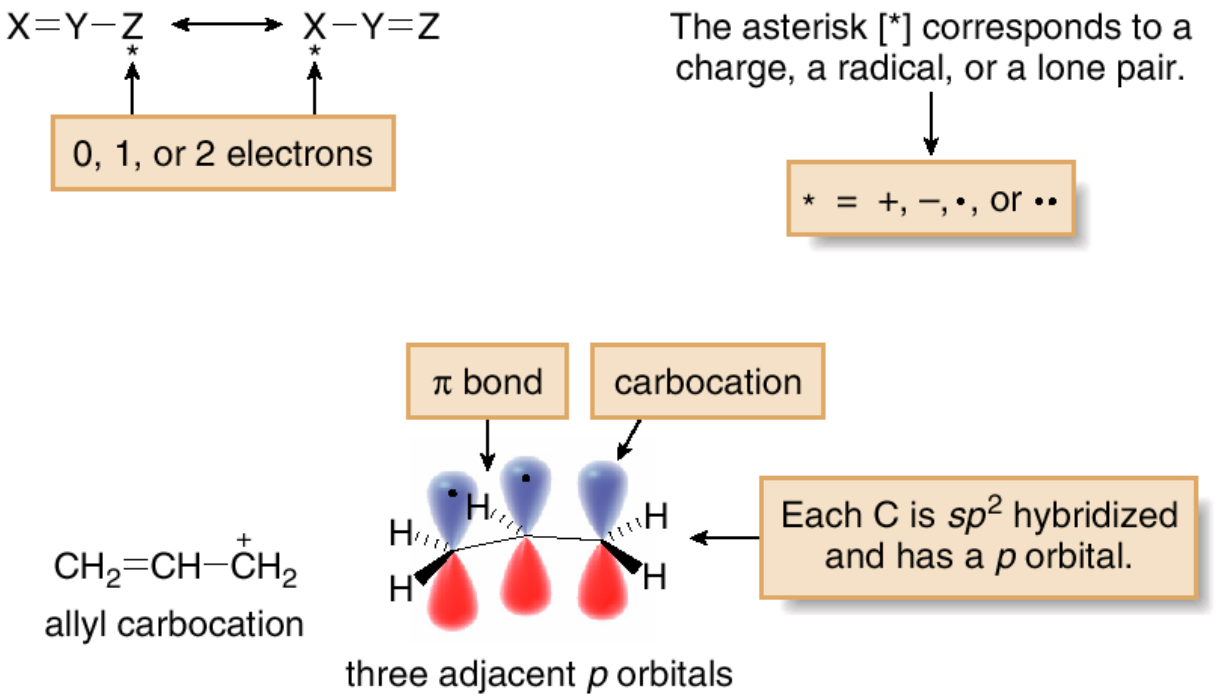
LE CAME IDROGENO



NO



- For any group of three atoms having a double bond X=Y and an atom Z that contains a *p* orbital with zero, one, or two electrons, two resonance structures are possible:



- Three *p* orbitals on three adjacent atoms, even if one of the *p* orbitals is empty, make the allyl carbocation conjugated.

Transition State