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

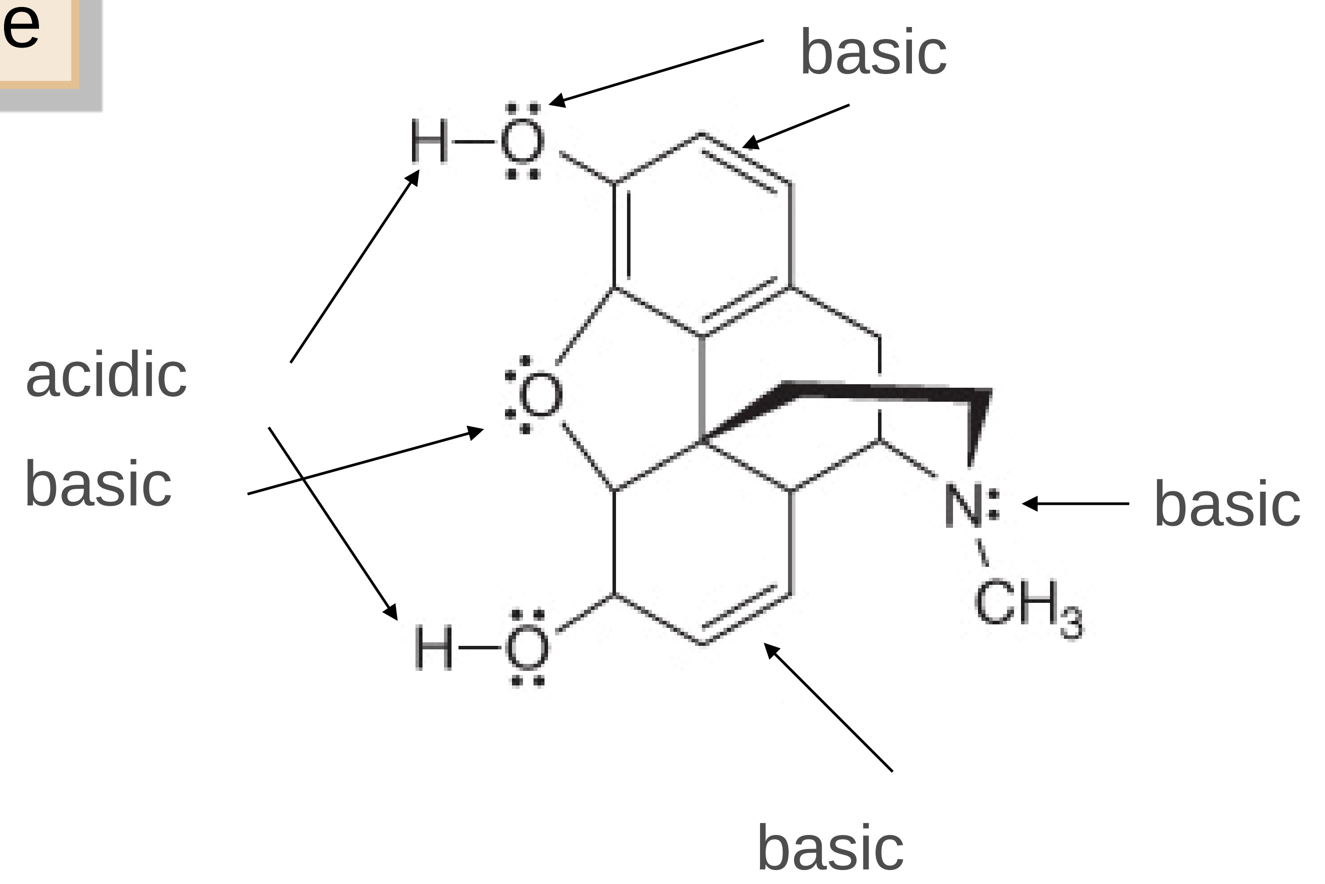
  All Brønsted-Lowry bases contain a lone pair or a π bond.

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	$H_2\ddot{O}:$, $:NH_3$	$CH_3\ddot{N}H_2$ methylamine	$CH_3\ddot{O}:^-$ methoxide ion
	$HO_2CCH_2-C(OH)(COOH)-CH_2CO_2H$ citric acid	$^-:\ddot{O}H$, $^-:\ddot{N}H_2$	$(CH_3)_2C=\ddot{O}$ aceton	$CH_2=CH_2$ ethylene

Brønsted-Lowry Acids and Bases

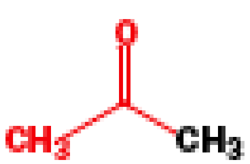
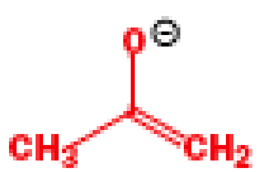
- Certain molecules can behave both as acids and bases.

Morphine



Some Reference pKa Values: Polarization and Electronegativity Effects

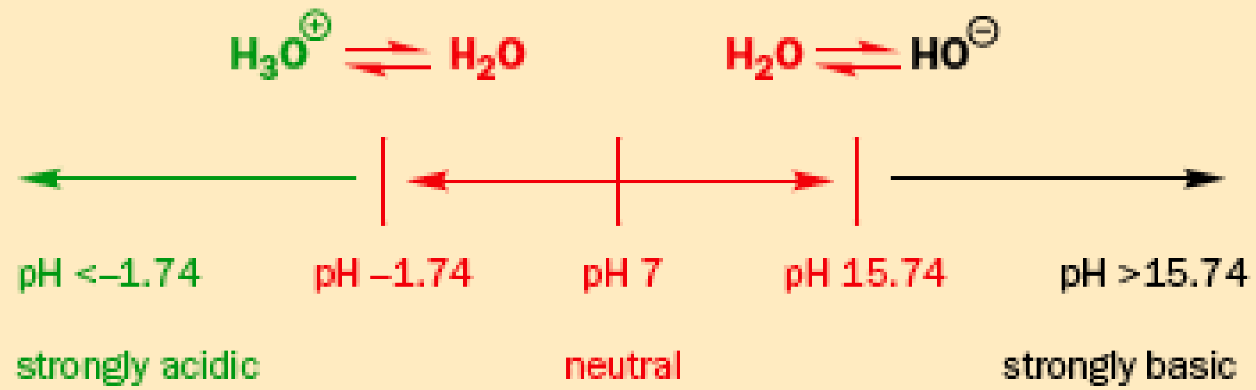
Table 8.1 The pK_a value of some compounds

Acid	pK_a	Conjugate base
HI	ca. –10	I^-
HCl	ca. –7	Cl^-
H_2SO_4	ca. –3	HSO_4^-
HSO_4^-	2.0	SO_4^{2-}
CH_3COOH	4.8	CH_3COO^-
H_2S	7.0	HS^-
NH_4^+	9.2	NH_3
C_6H_5OH	10.0	$C_6H_5O^-$
CH_3OH	15.5	CH_3O^-
	20.0	
$CH{\equiv}C{-}H$	25	$CH{\equiv}C^{\ominus}$
NH_3	33	NH_2^-
C_6H_6	ca. 43	$C_6H_5^-$
CH_4	ca. 48	CH_3^-

- The strongest base in aqueous solution is OH^- and the strongest acid in aqueous solution is H_3O^+. Remember that:
  - Addition of stronger bases than OH^- just gives more OH^- by the deprotonation of water
  - Addition of stronger acids than H_3O^+ just gives more H_3O^+ by protonation of water

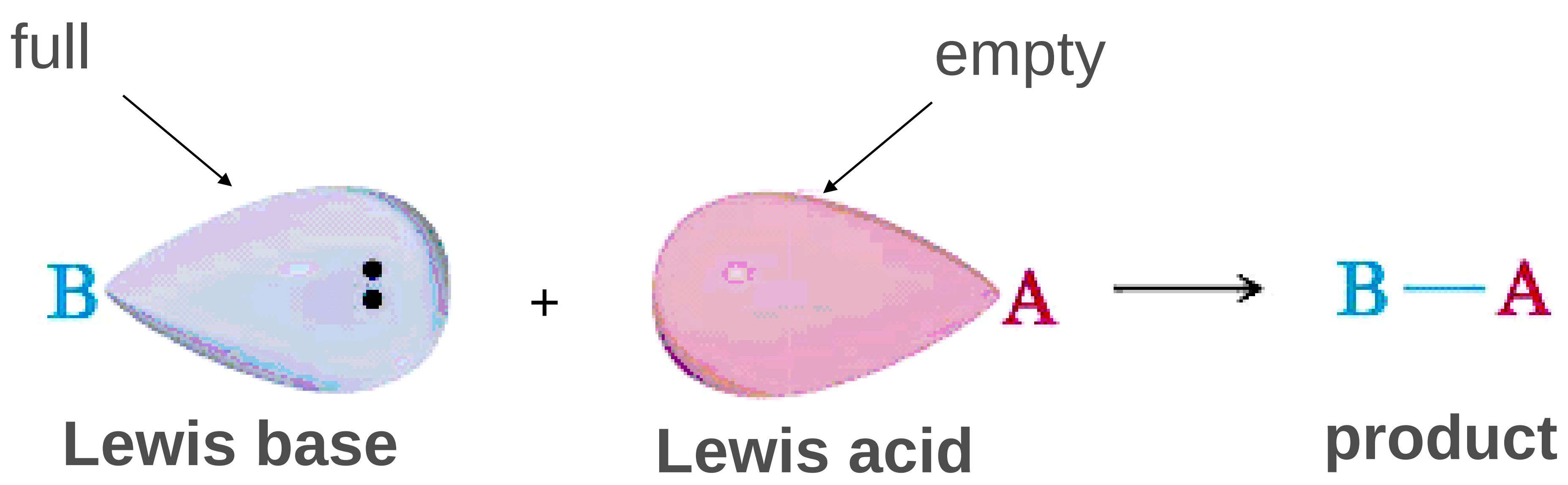
Also remember that:

- The pH of pure water at 25°C is 7.00 (not the pK_a)
- The pK_a of H_2O is 15.74
- The pK_a of H_3O+ is –1.74



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.

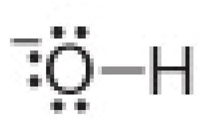
H_2O CH_3OH

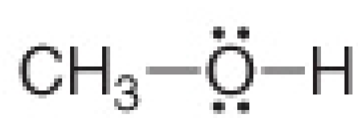
Brønsted-Lowry and Lewis acids

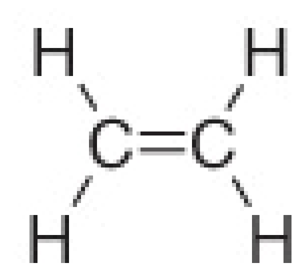
BF_3 $AlCl_3$

Lewis acids

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

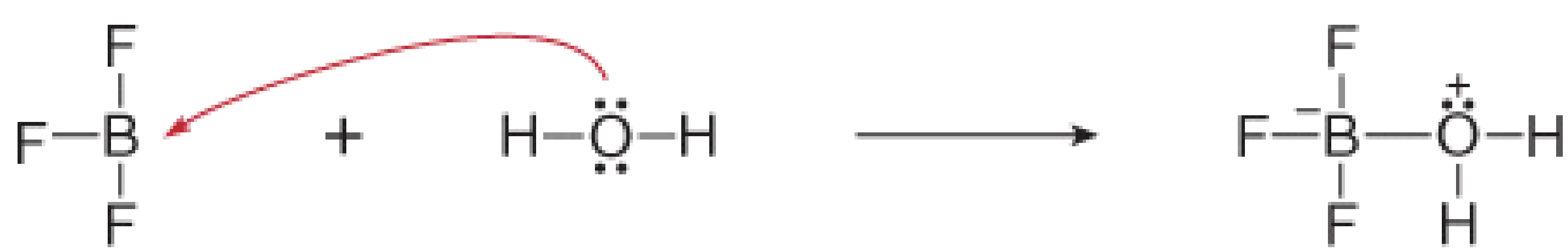






Reactions Between Lewis Acids and Bases

- 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.

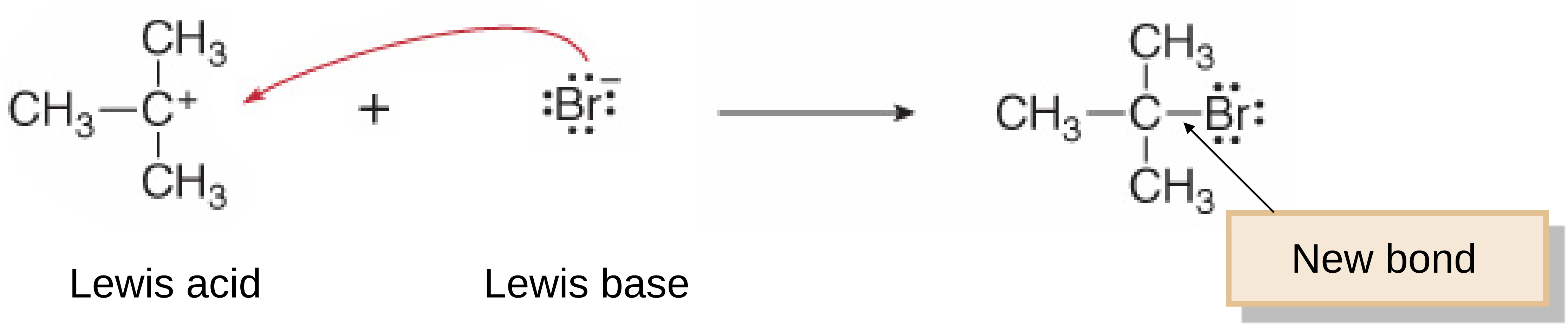


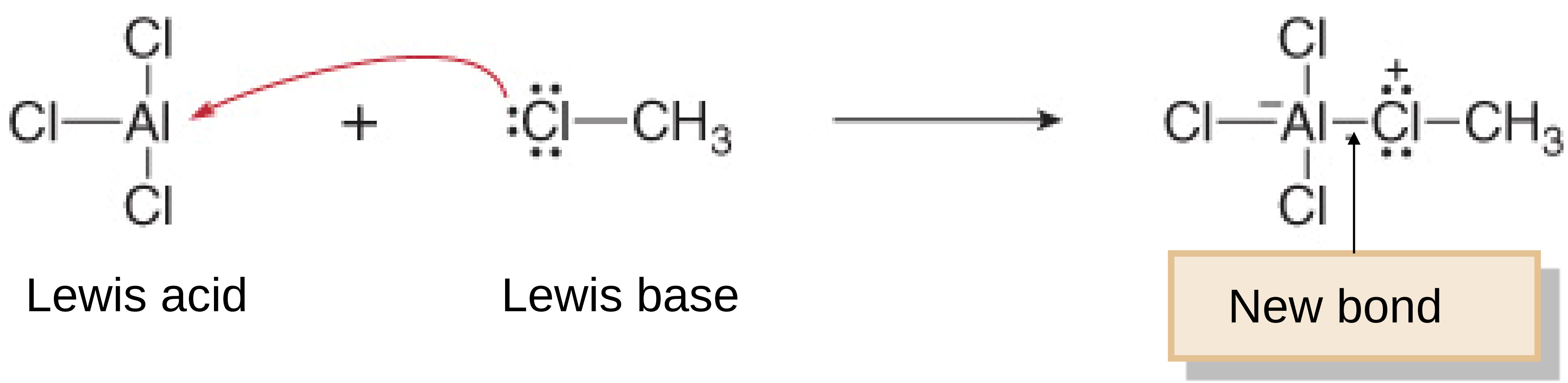
Lewis acid — electrophile

Lewis base — nucleophile

Electrophiles and Nucleophiles

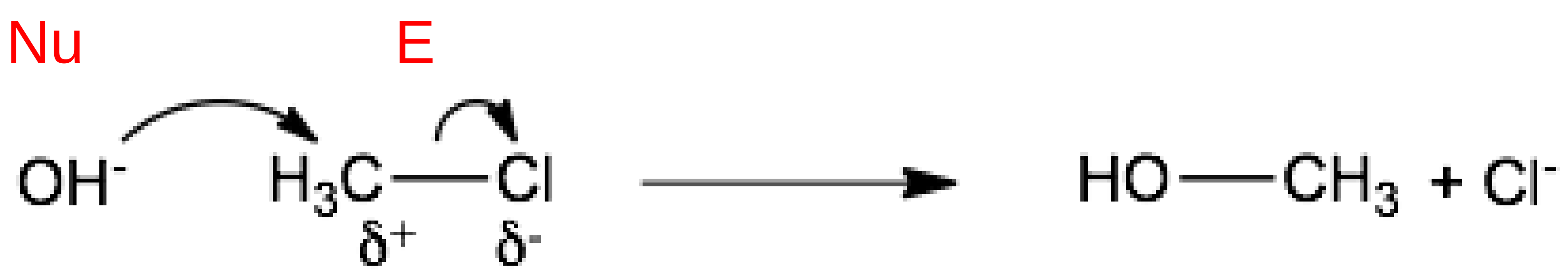
electrophile nucleophile

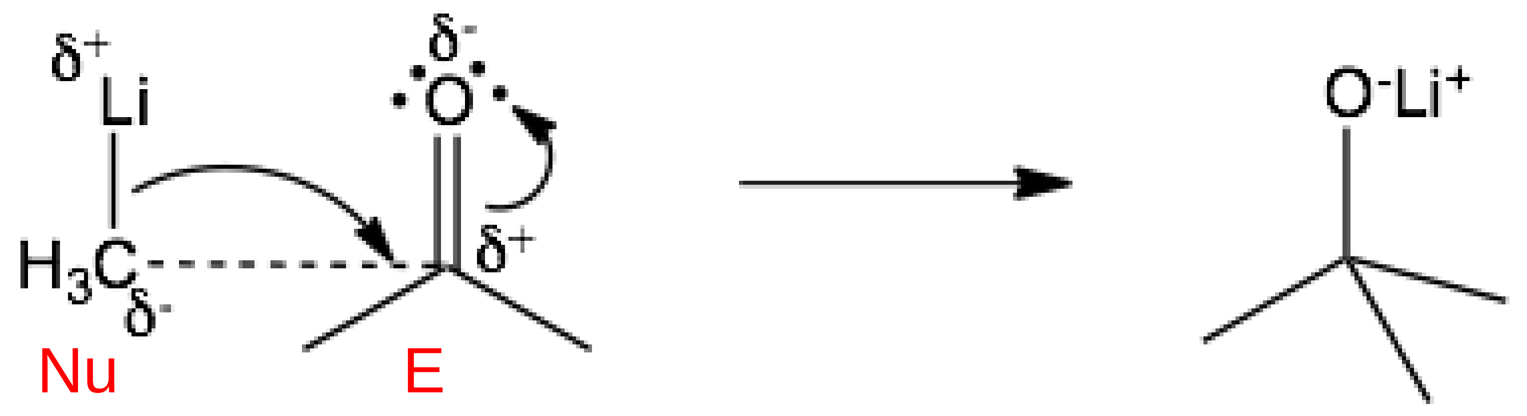




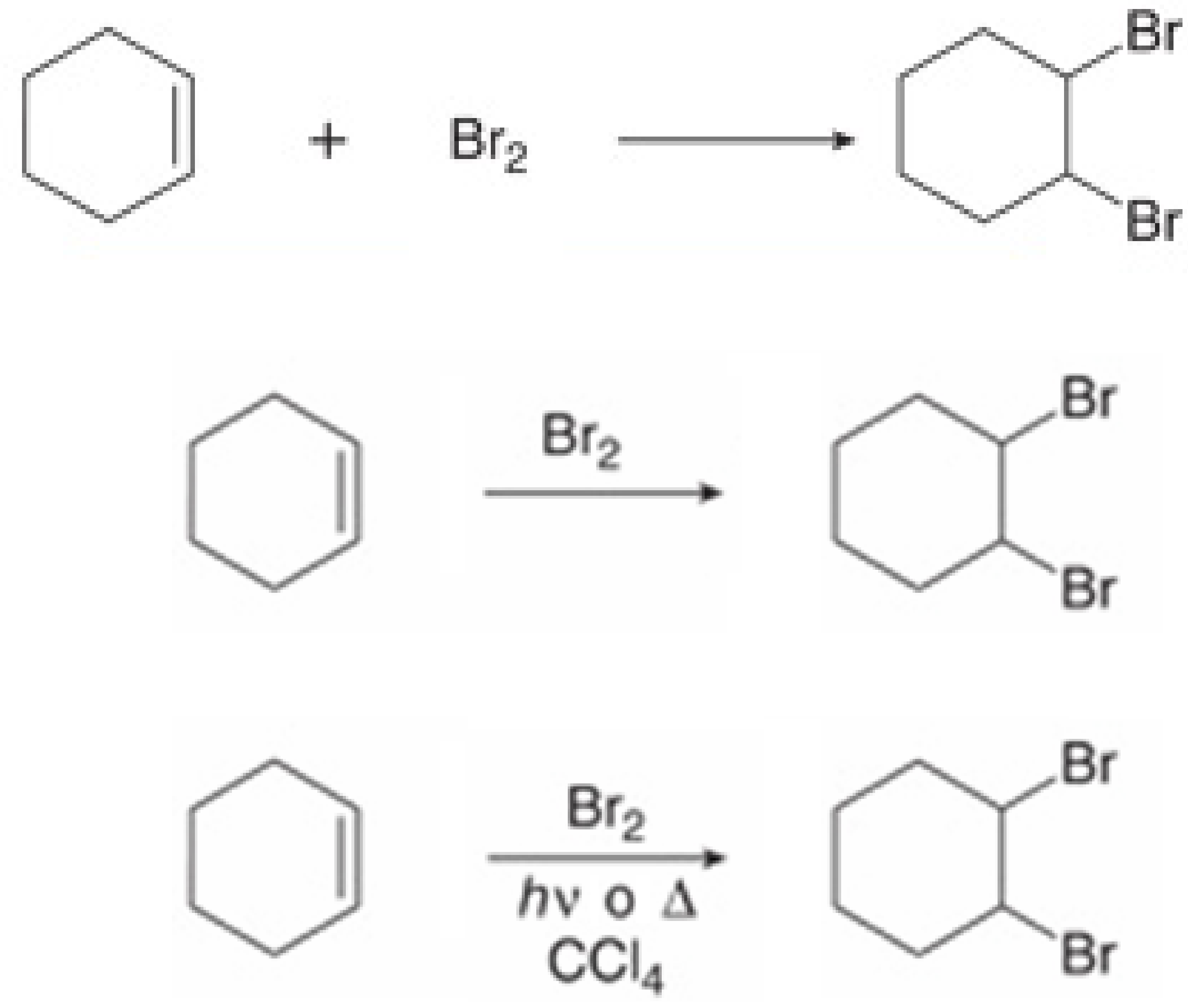
Electrophiles and Nucleophiles

- Nucleophiles and electrophiles may also contain polarized bonds





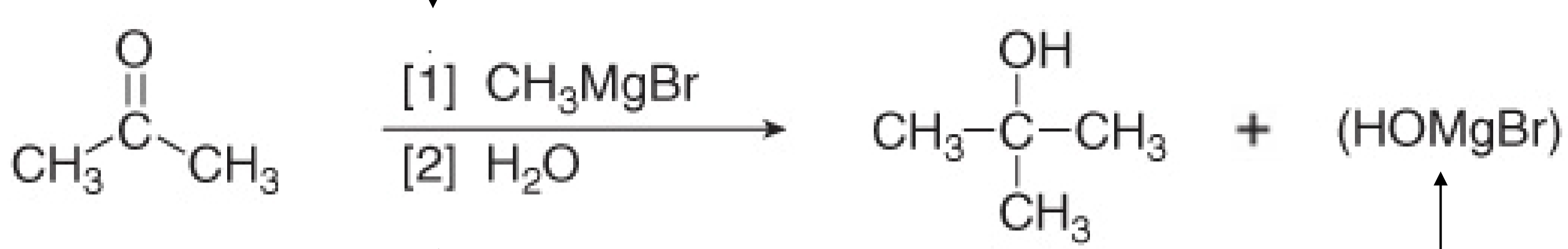
How to Write an Organic Reaction



How to Write an Organic Reaction

In a sequence, the individual steps are numbered.

1° step



2° step

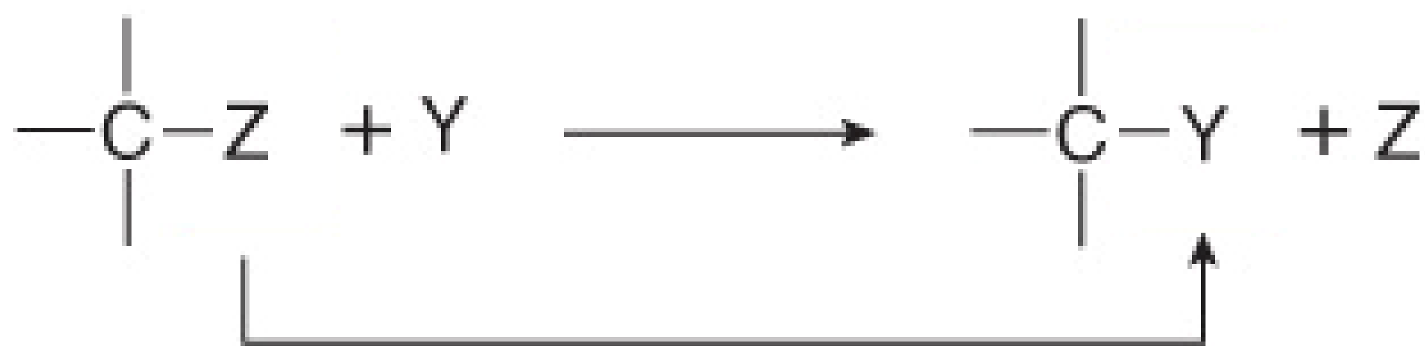
Inorganic byproducts
are generally omitted

Organic Reactions

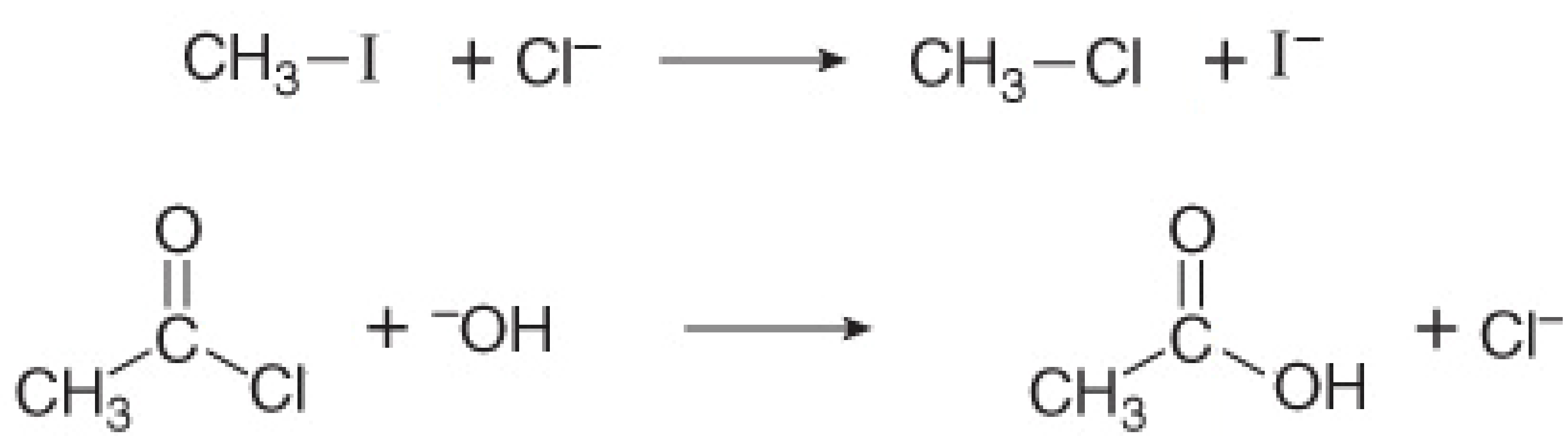
- Type of reaction (bond breaking/bond formation):
  - substitution
  - addition
  - elimination
  - rearrangement/transposition
- Mechanism = movement of electrons:
  - ionic (polar)
  - radicalic
  - pericyclic

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.

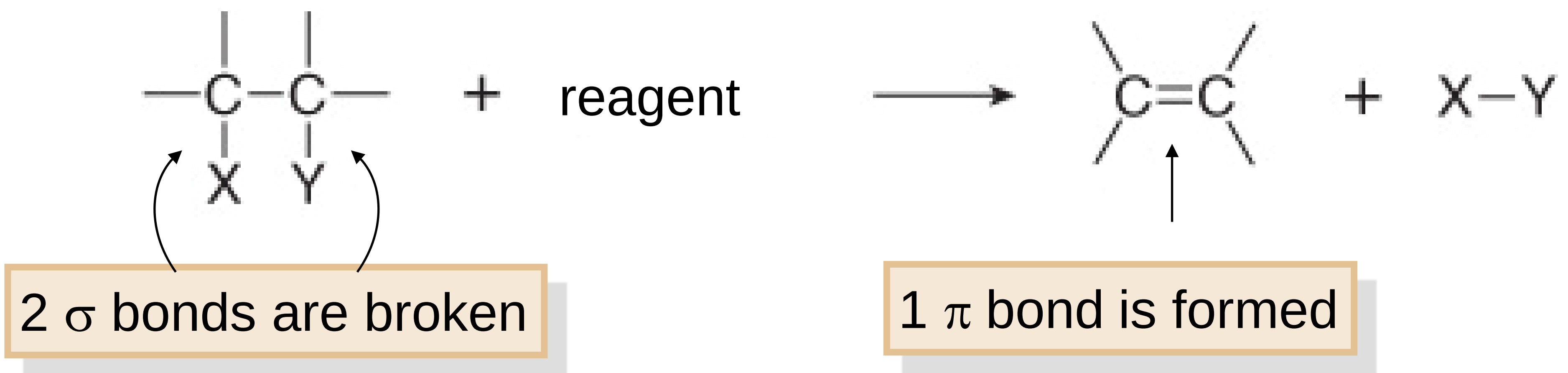


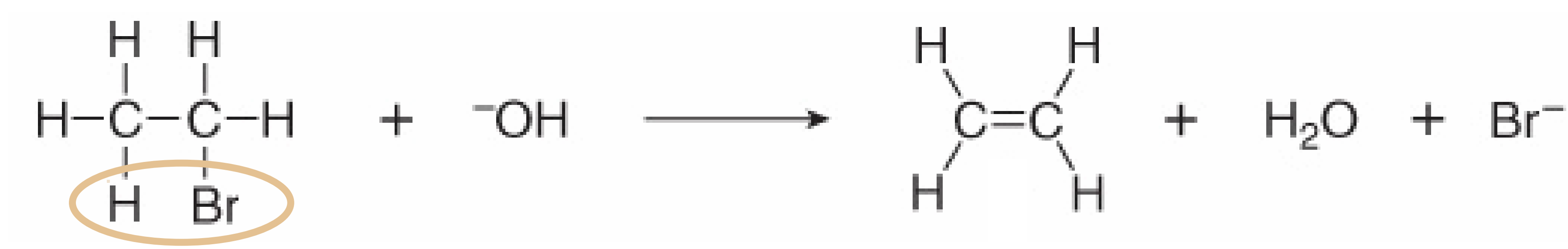
Y replaces Z

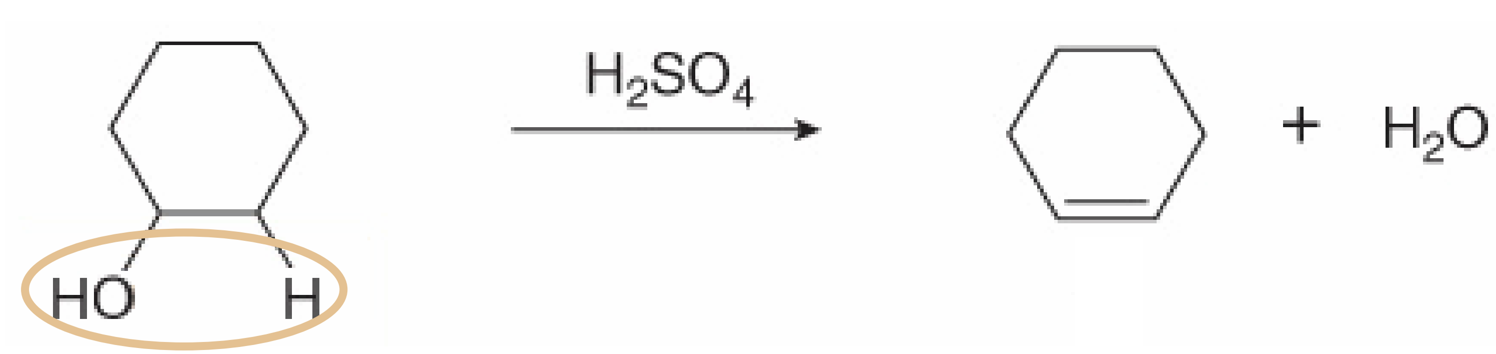


Eliminations

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

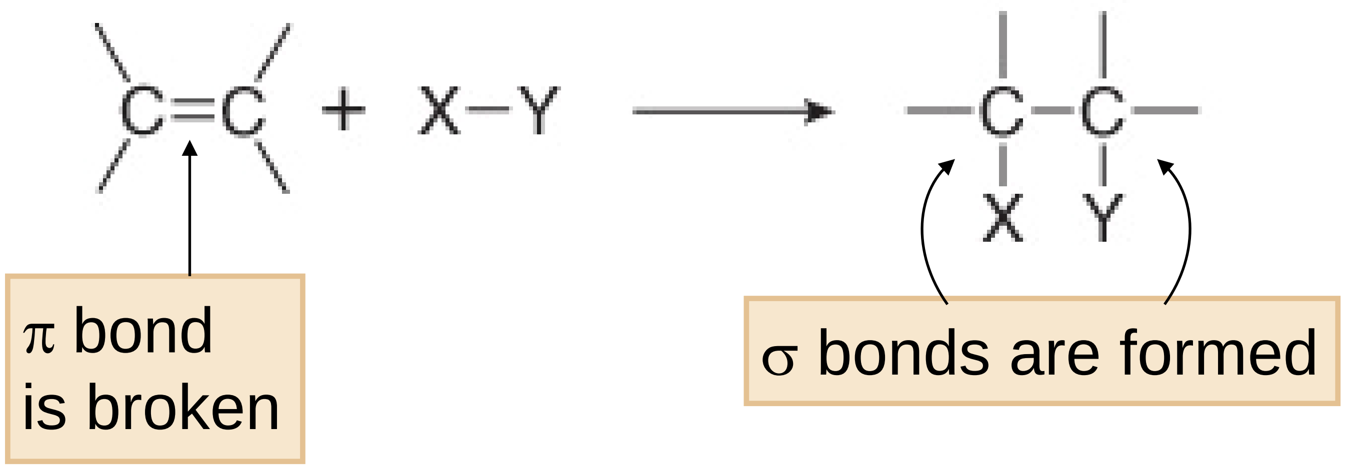


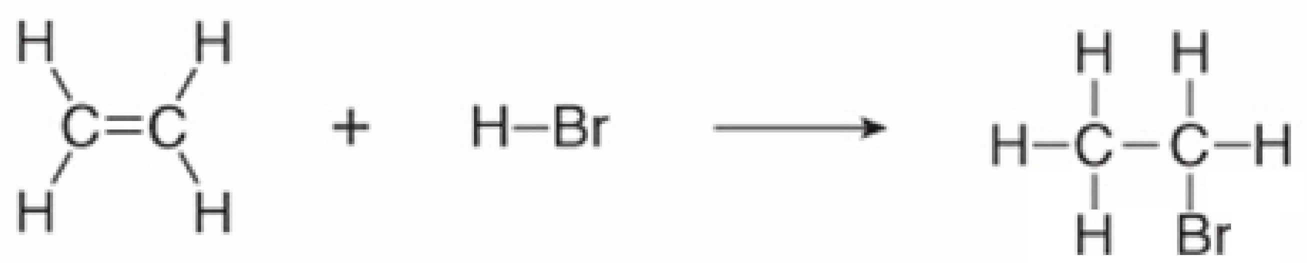


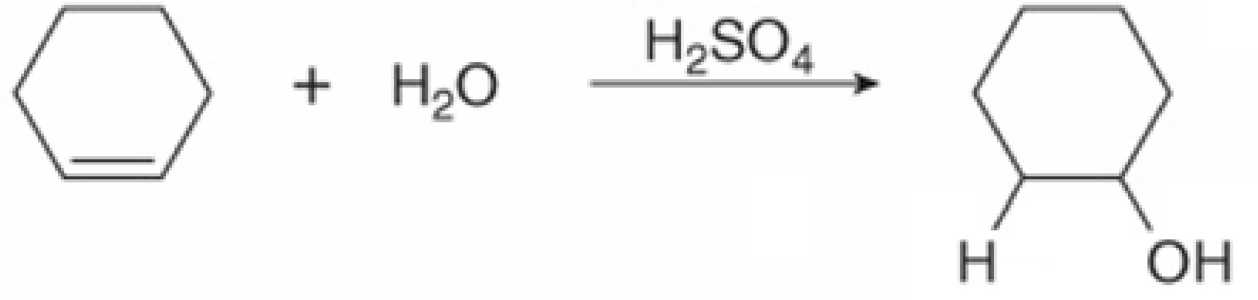


Additions

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





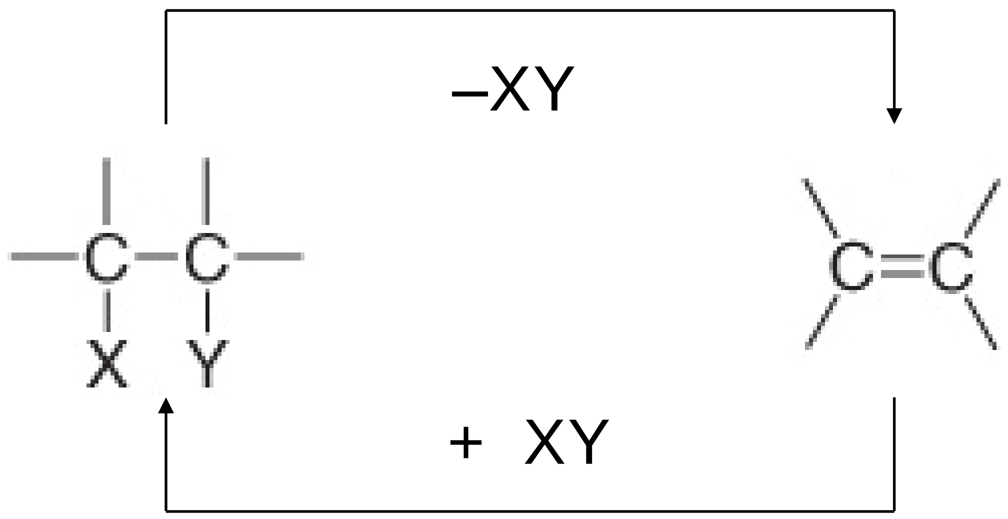


Additions and Eliminations

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

Elimination

a π bond is formed

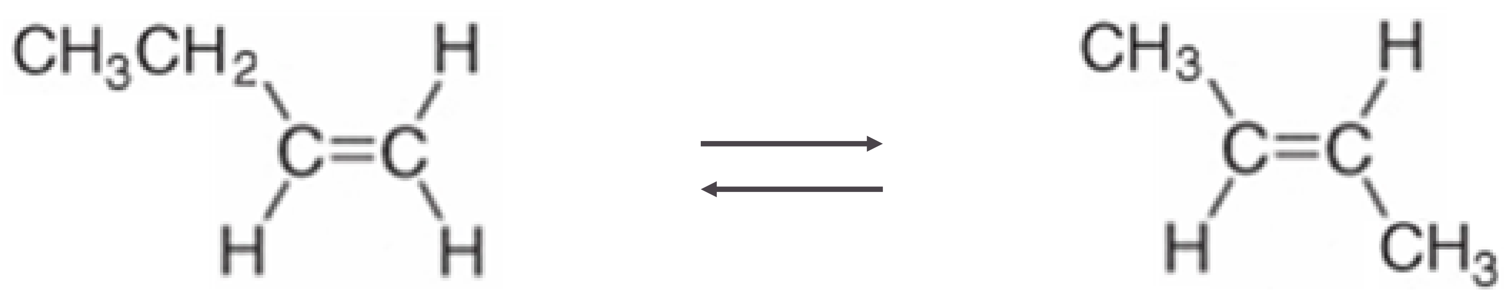


a π bond is broken

Addition

Rearrangements or Transpositions

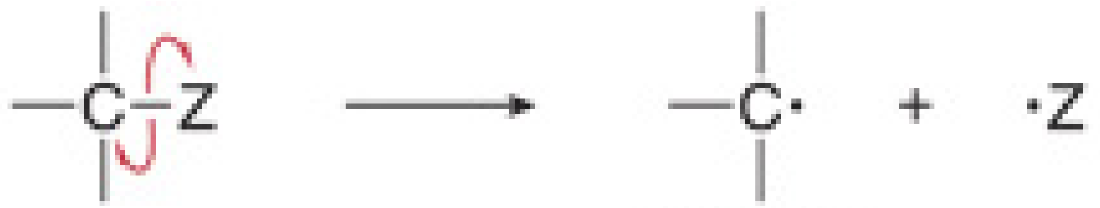
In a rearrangement or transposition the bonding pattern of a single reagent changes giving a constitutional isomer.



1-butene 2-butene

Bond Breaking and Forming

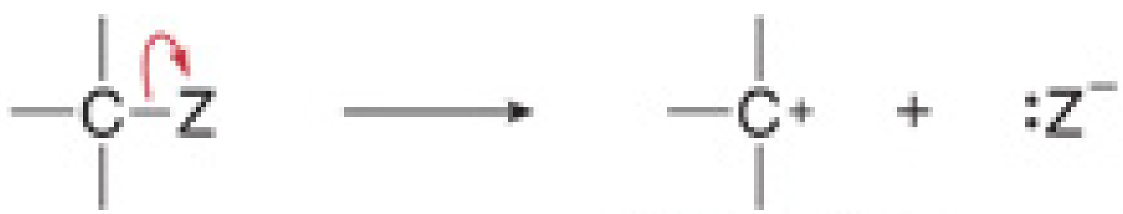
Omolysis



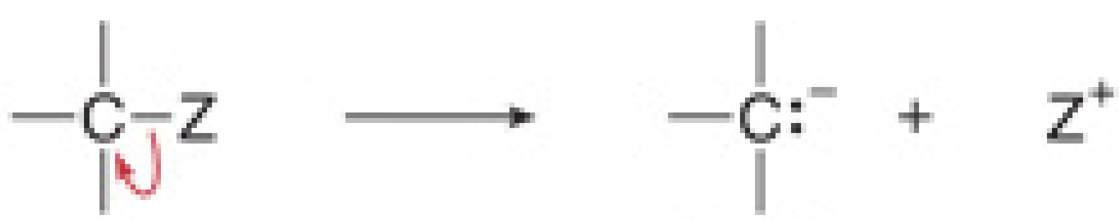
Radical

radicals are formed in
radical (omolitic) reactions

Heterolysis



Carbocation

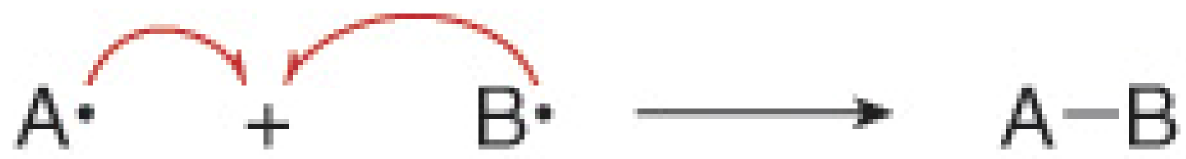


Carbanion

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

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

Bond Dissociation Energy

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

$$A{-}B \longrightarrow A\cdot \; + \; B\cdot$$

Breaking a bond requires energy

$\Delta H°$ = bond dissociation energy

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.

halogen size and bond length →

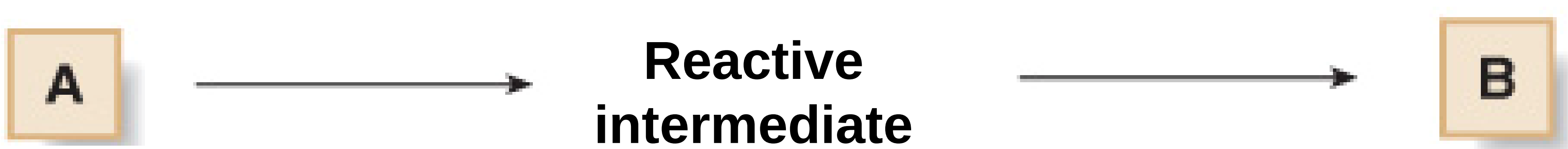
CH_3-F	CH_3-Cl	CH_3-Br	CH_3-I
$\Delta H°$ = 109 kcal/mole	84 kcal/mole	70 kcal/mole	56 kcal/mole

← **bond strength**

A Reaction Mechanism……

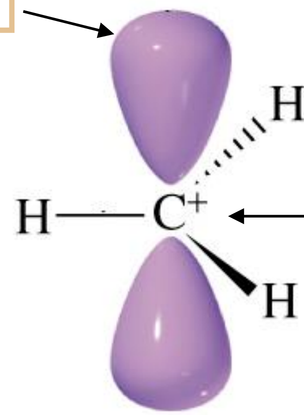
- Accounts for all reagents and products and their ratios.
- Describes in which order bonds are broken and formed and the rates of individual steps.
- In a *concerted reaction* reagents are directly converted into products in a single step.

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

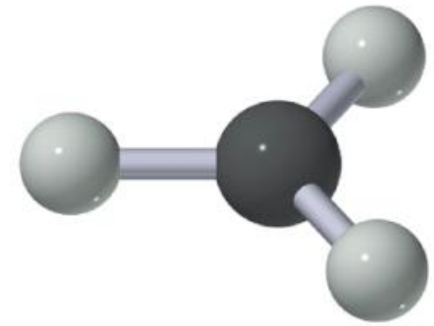


Carbocations, Carbanions, Radicals

empty *p* orbital

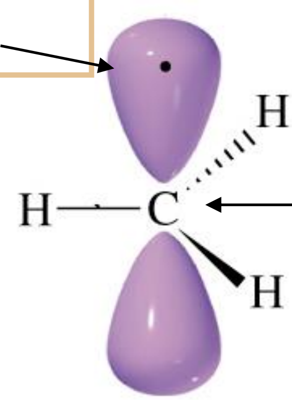


C sp^2 planar

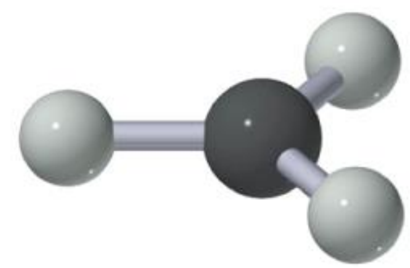


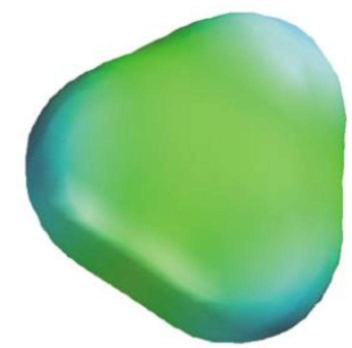
$^+CH_3$

Singly occupied *p* orbital



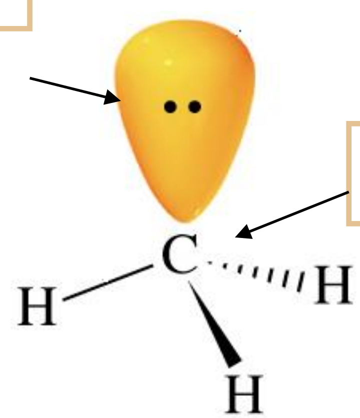
C sp^2 planar



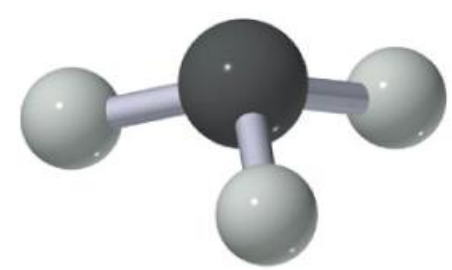


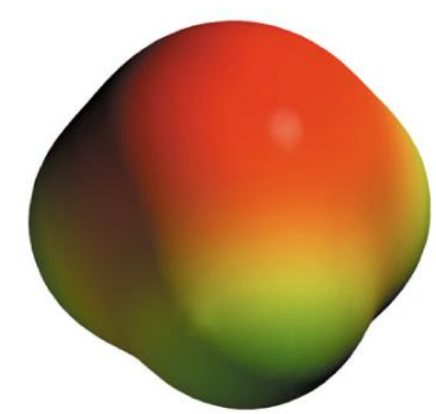
$\cdot CH_3$

lone pair sp^3



C sp^3 tetrahedral

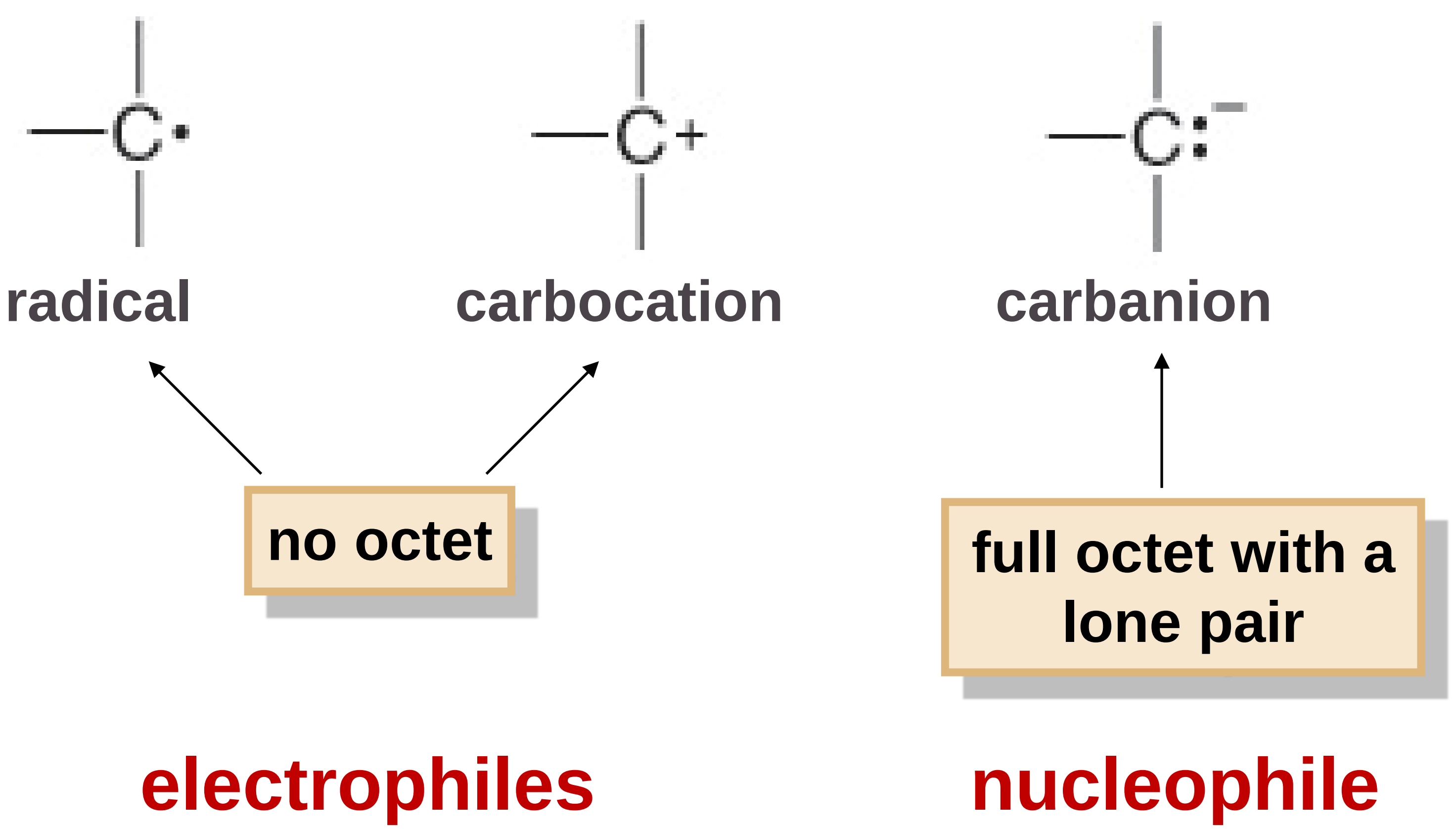




$\overset{-}{:}CH_3$

Carbocations, Carbanions, Radicals

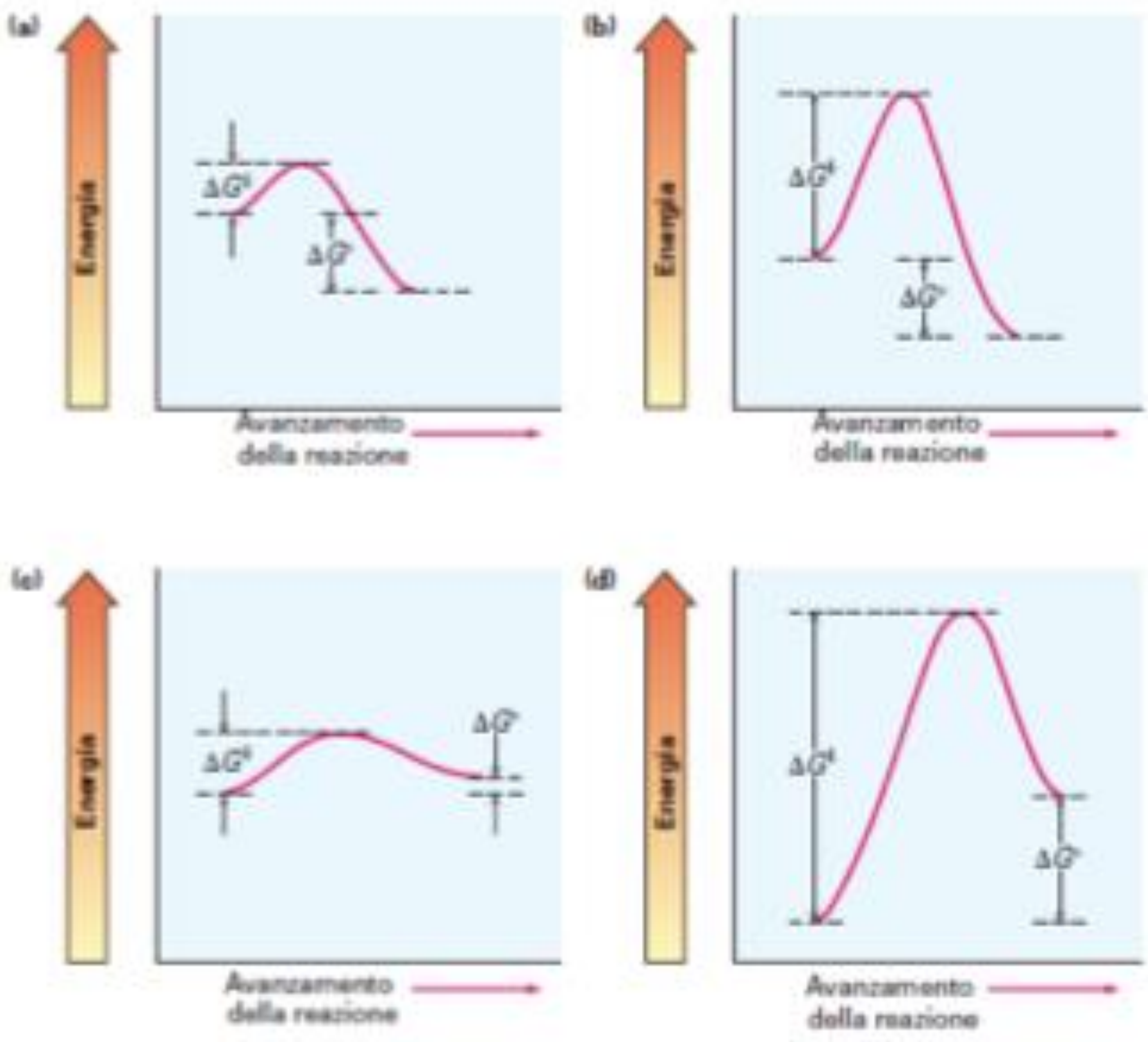
- Radicals and carbocations are electrophiles because the carbon atom does not have a full octet.
- Carbanions are nucleophiles because the carbon atom has a lone pair.



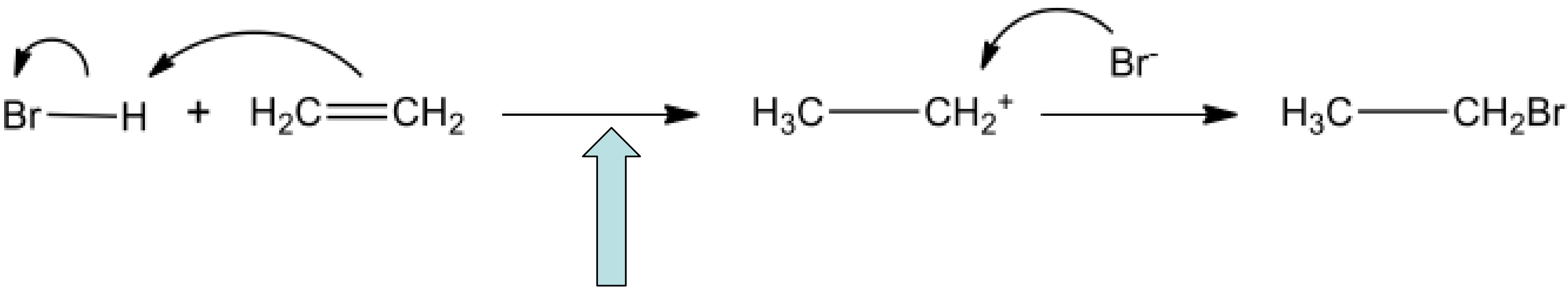
Transition State Theory - Energy Diagrams

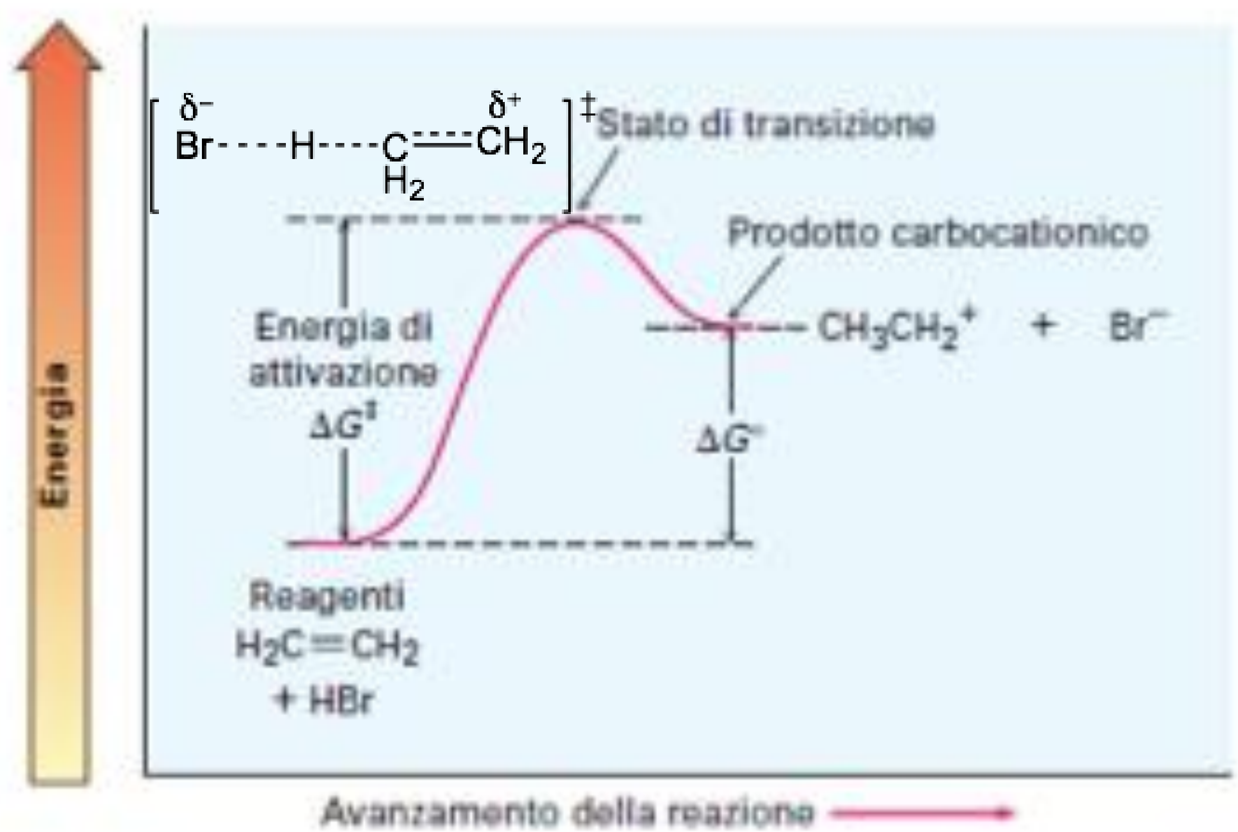
- The activation energy $\Delta G^{\ddagger}$ is the energy required for a reaction to take place.
- $\Delta G^{\ddagger} = \Delta H^{\ddagger} - T\Delta S^{\#}$
- $\Delta G^{\ddagger}$ is correlated with the reaction's rate constant.
- Eyring equation: $$k = \frac{k_B T}{h} e^{-\frac{\Delta G^{\#}}{RT}}$$
- 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



Energy Diagrams





Energy Diagrams

Complete energy diagram for the two-step reaction: