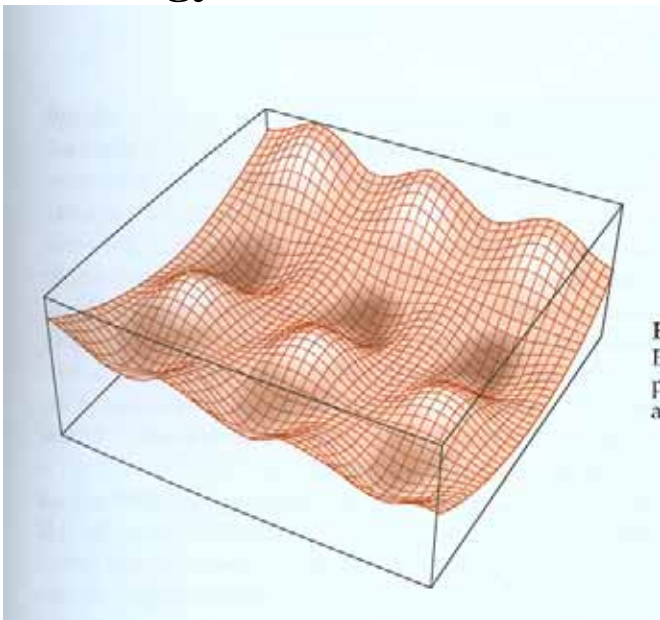


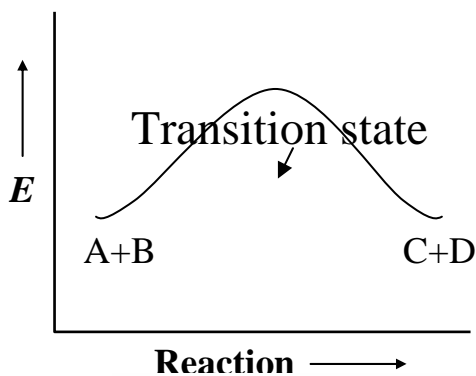
Chap. 5 Reactive intermediates

Energy surface

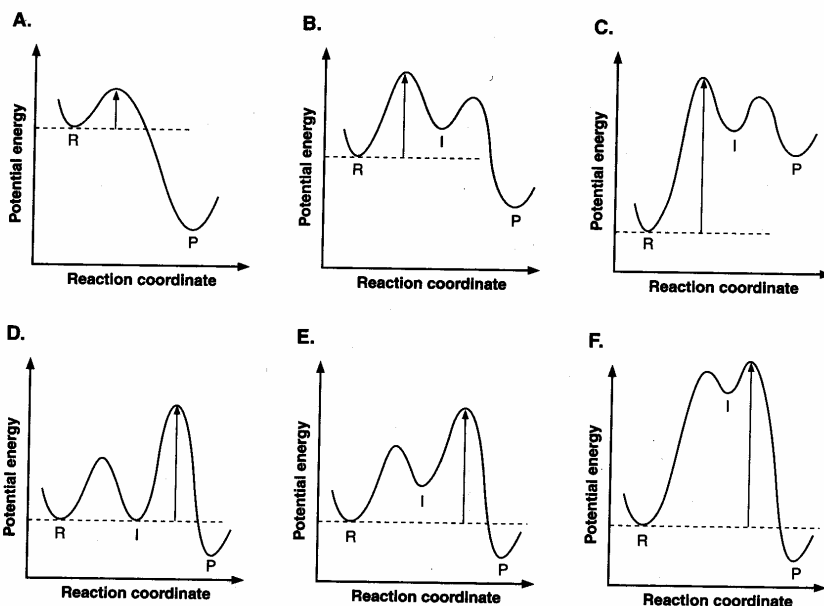


The plot of energy (potential and kinetic) as a function of $3N-6$ coordinates of the chemical system (reactants, intermediates, products)

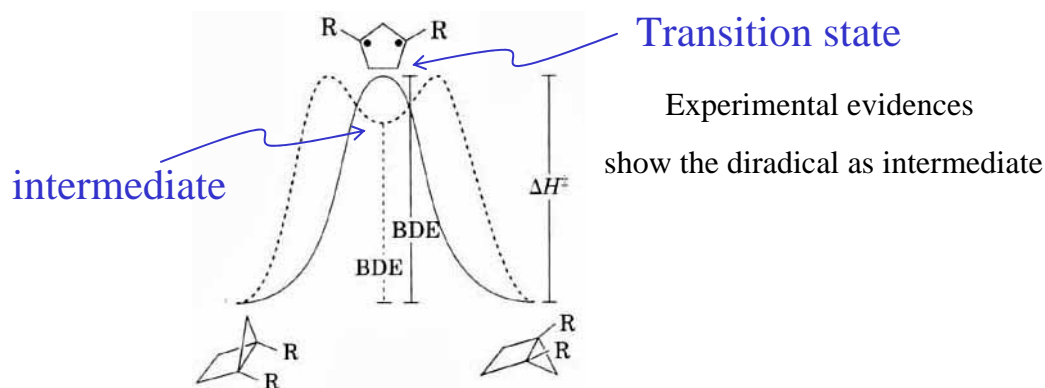
Reaction Coordinate diagram: The reaction coordinate is a one-dimensional slice of a $3N-6+1$ dimensional potential surface.



It goes through a maximum, but along a valley (potential minimum) with respect to motion perpendicular to the reaction coordinate



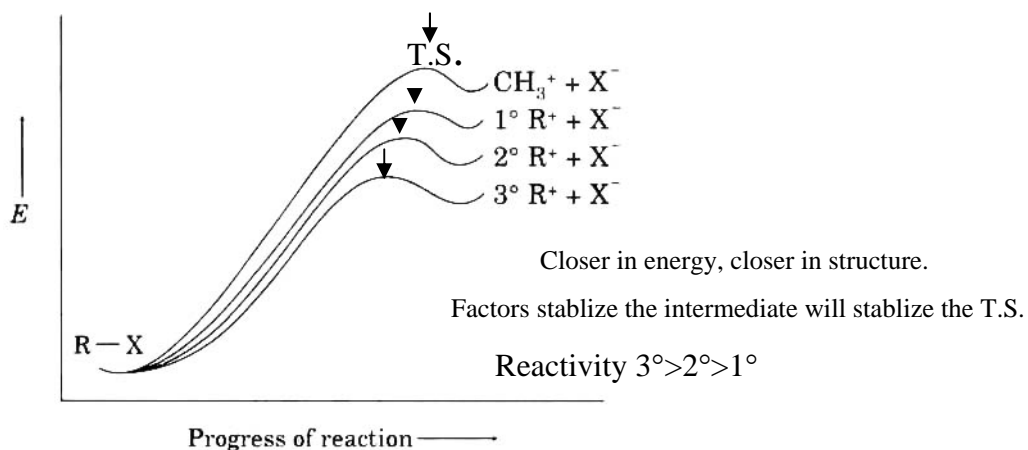
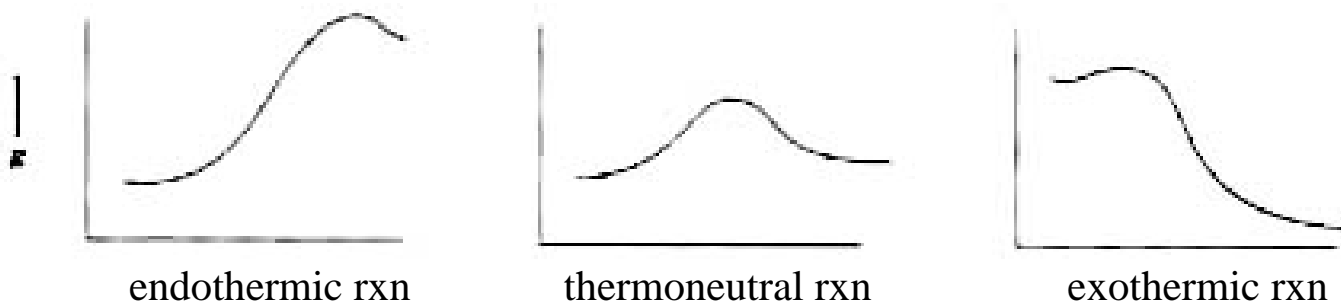
Intermediate & Transition State



Hammond Postulate

If two states, as for example, a transition state and an unstable intermediate, occur consecutively during a reaction process and have nearly the same energy content, their inter conversion will involve only a small reorganization of the molecular structure.

(\rightarrow close in energy, close in structure)



§ Carbocations

intermediates with formal charge of +1 on a carbon atom, or a collection of carbon atoms

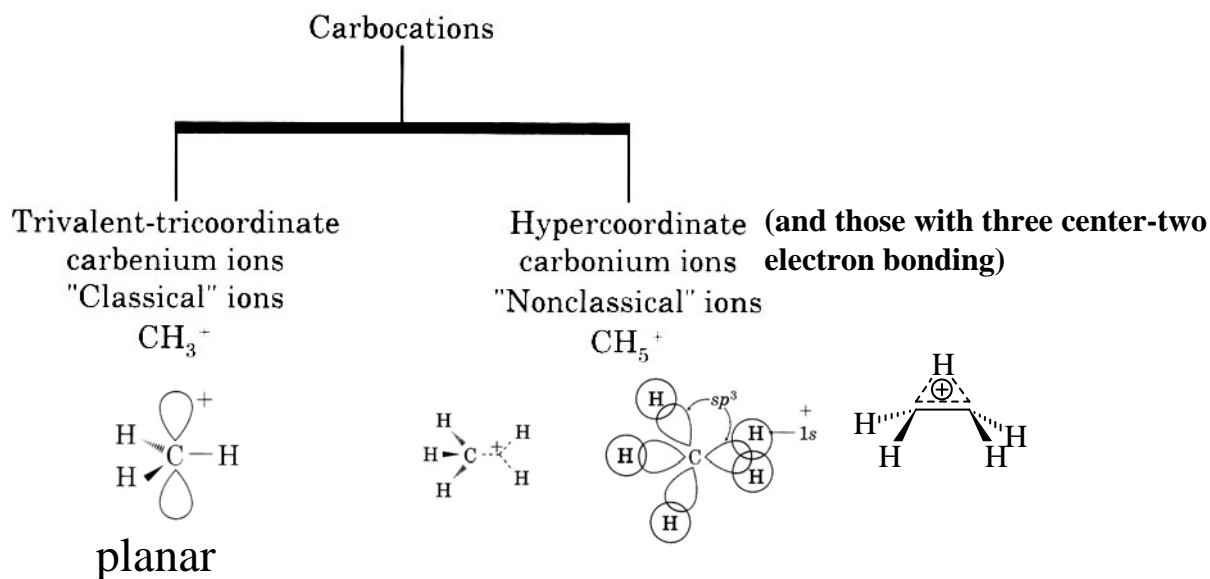


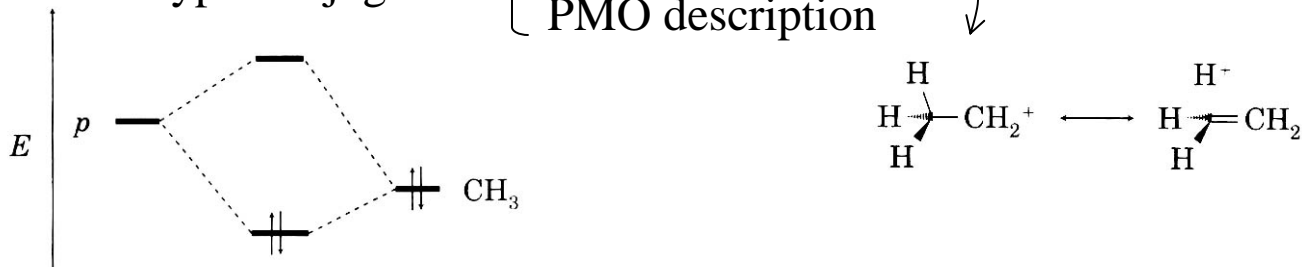
Table 5.2 Thermodynamic data for selected alkyl cations. (Reproduced from the compilation in reference 146.)

Cation	$\Delta H_f^\circ(\text{R}^+)$ (kcal/mol)	HIA (R ⁺) (kcal/mol)
Methyl	261	312
Ethyl	219	273
Isopropyl	192	247.4
<i>t</i> -Butyl	164	229.6
Allyl	226	256
Vinyl	266	287
Benzyl	213	234

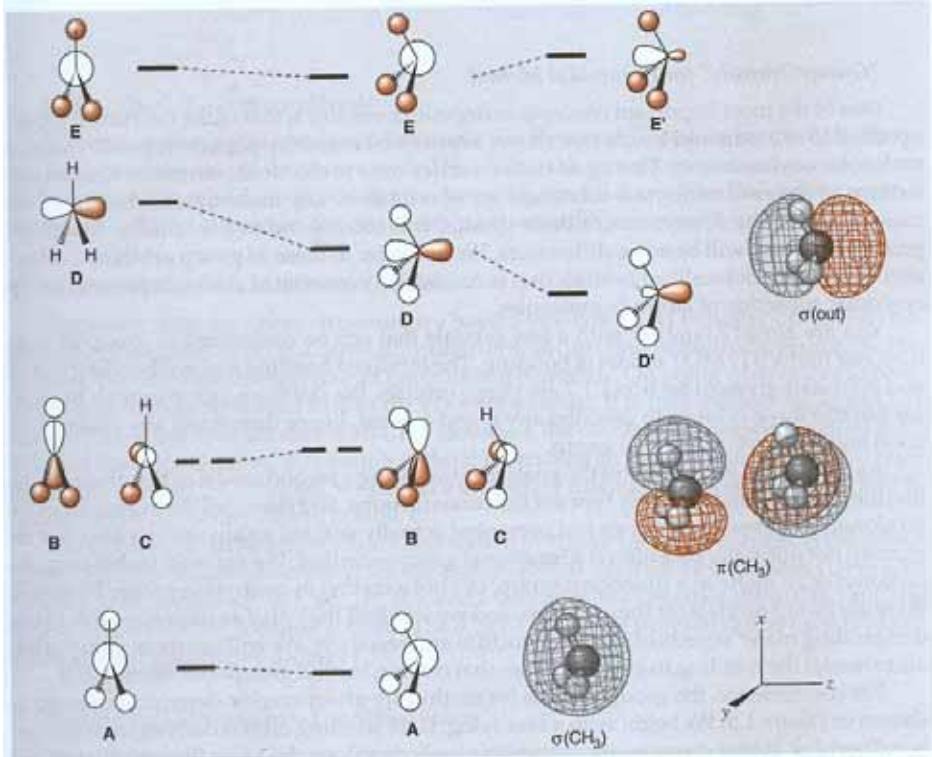
formation of carbenium $3^\circ > 2^\circ > 1^\circ$

1. alkyl gps are electron-donating. (Inductive effect)

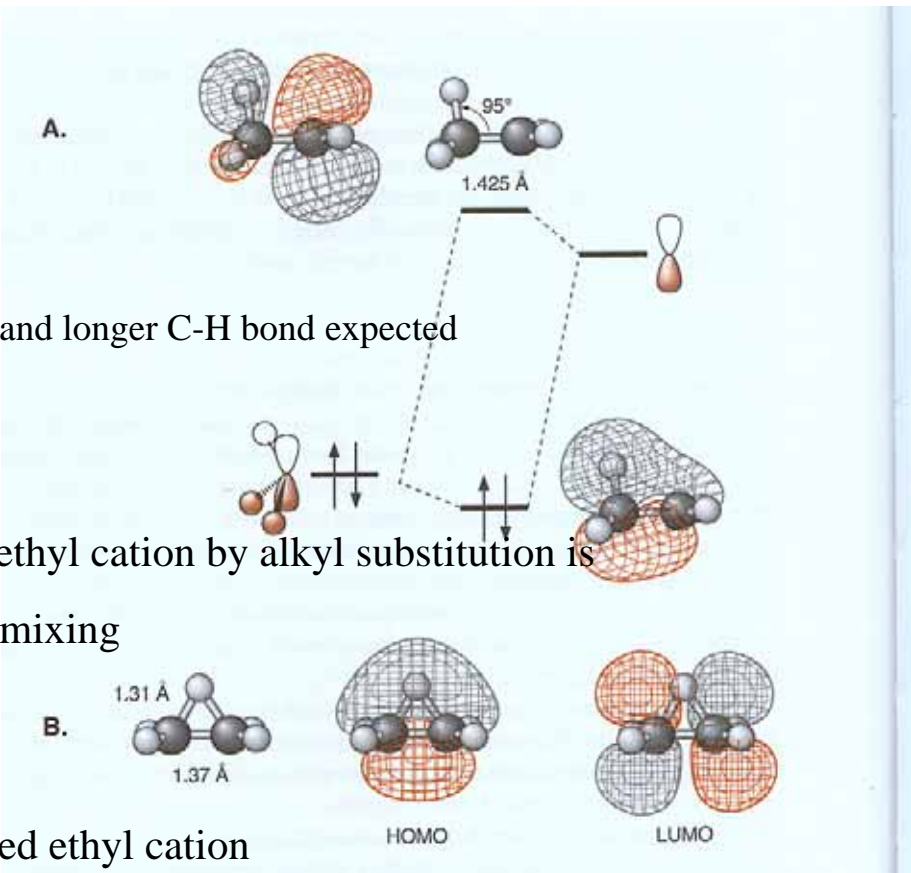
2. hyperconjugation { VB description
PMO description



QMOT version



methyl cation with 6 valence electrons is planar



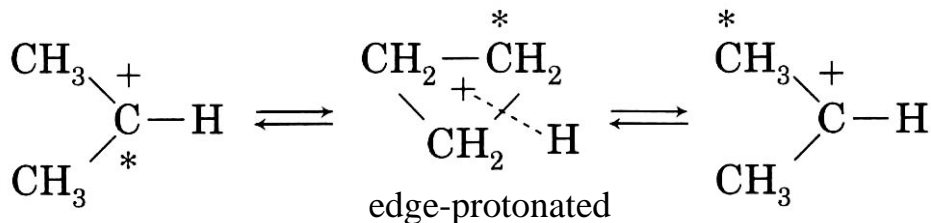
A shorter C-C bond and longer C-H bond expected

stabilization of methyl cation by alkyl substitution is a result of orbital mixing

Bridged ethyl cation

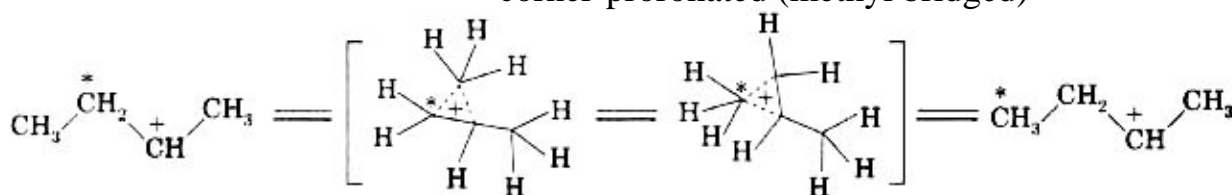
Rearrangements possible from 2° → 1°

The H can scramble in isopropyl cation,
Carbon-atom also scramble.



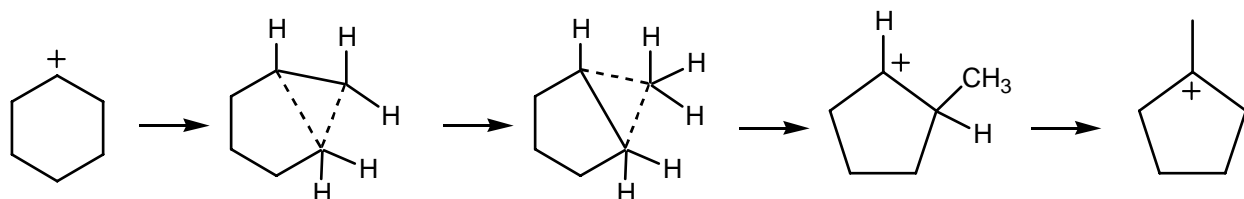
at -78°C , $t_{1/2} = 1\text{hr}$, ^{13}C scramble to all C

corner-pronated (methyl bridged)

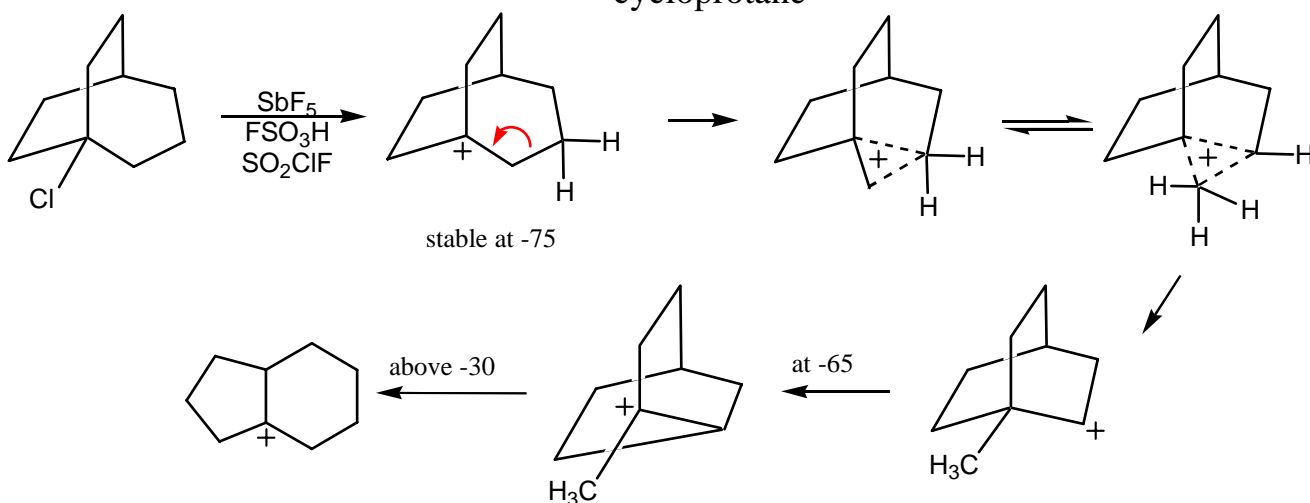


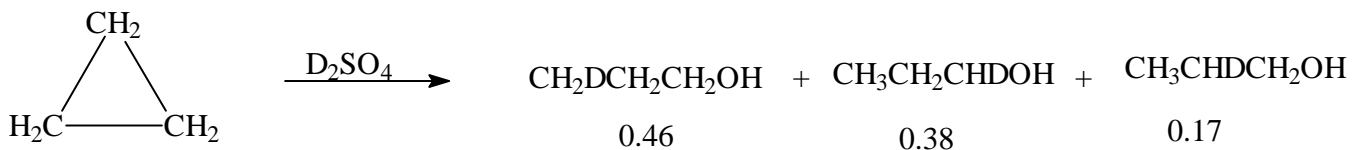
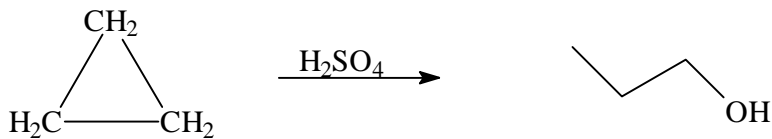
at -110°C , 2 sets of peak

at -40°C , one peak only

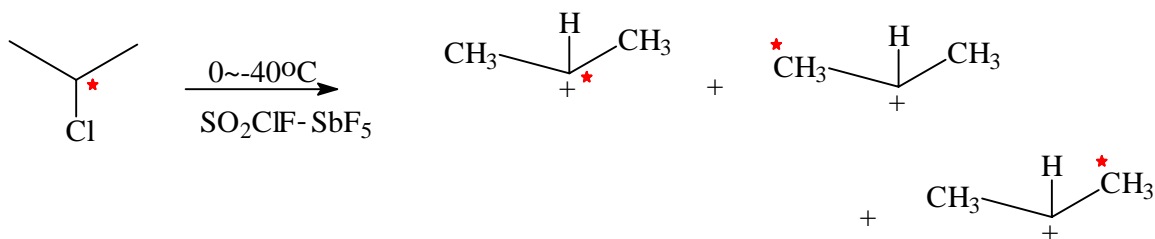
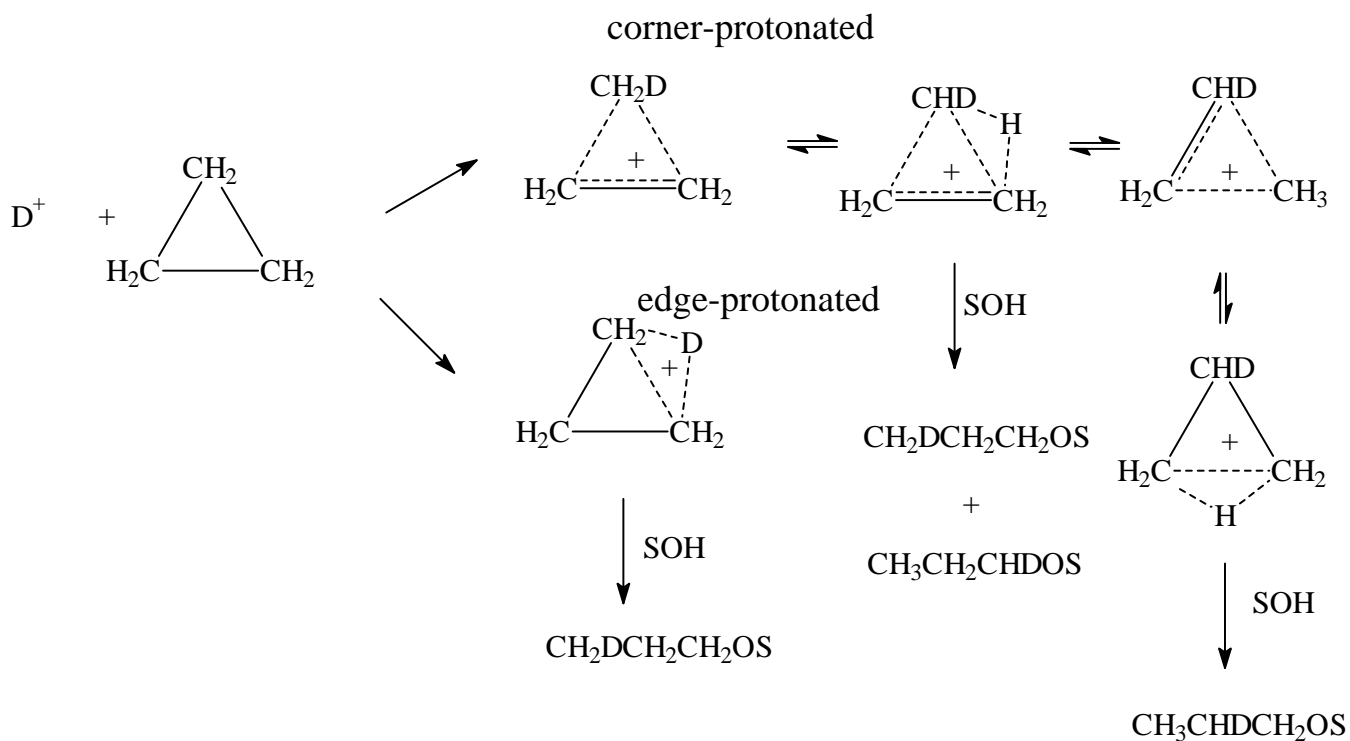


corner-protonated
cyclopropane



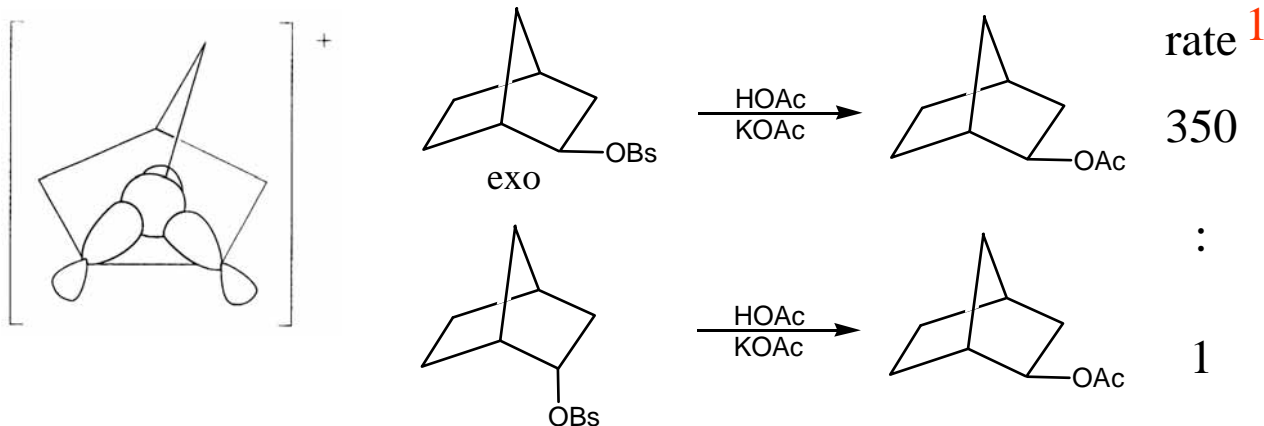


D scrambled to all carbons

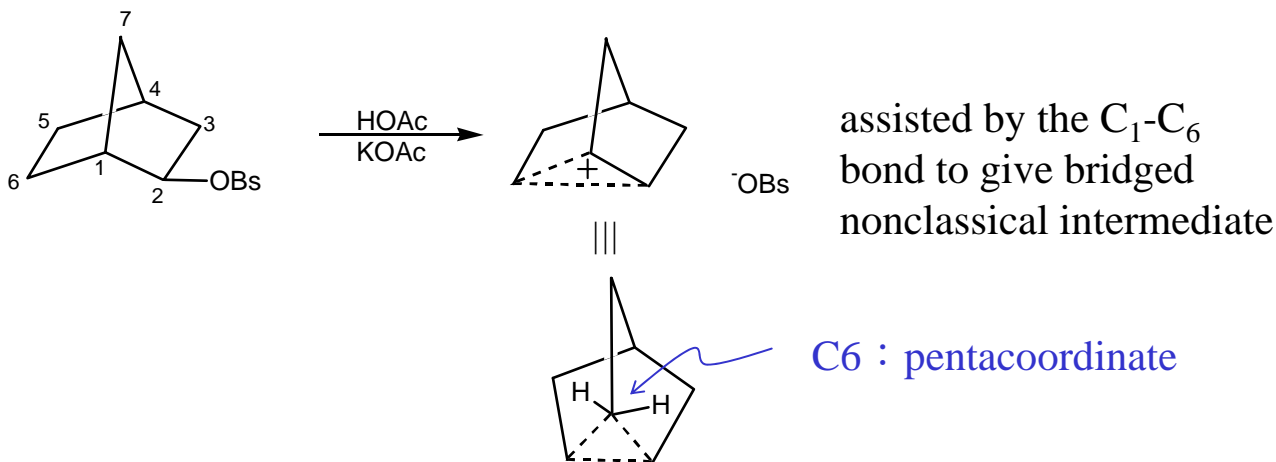


Nonclassical Ion

Bridged structure with delocalized σ bond
 \rightarrow a pair of e^- shared by three nuclei.



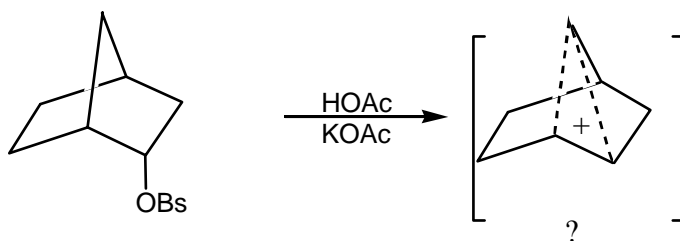
- 2 Optically active exo \rightarrow racemic exo
- 3 Optically active endo \rightarrow 93% racemic exo
- 4 For chiral exo S.M., recovered S.M. partially racemized.
- 5 For chiral endo S.M., recovered S.M. did not racemized.



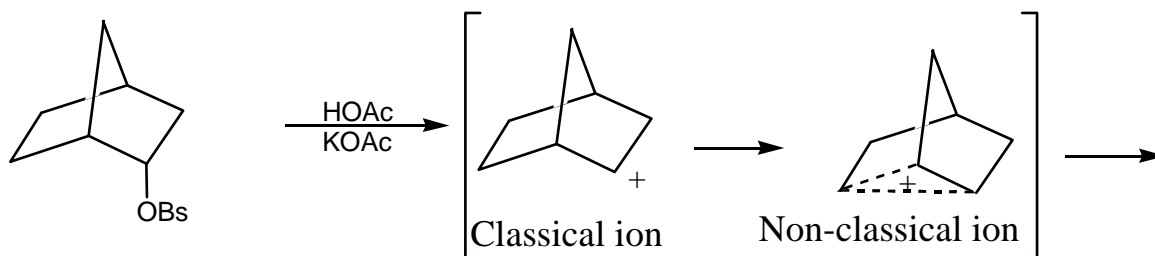
The rate enhancement was due to proper anti-alignment of the $C(1)-C(6)$ bond and the leaving gp at $C(2)$.

The stereochemical outcome is due to a symmetric intermed.

No backside assistance in endo compound



The endo S.M. undergoes a classical ion intermediate then nonclassical ion



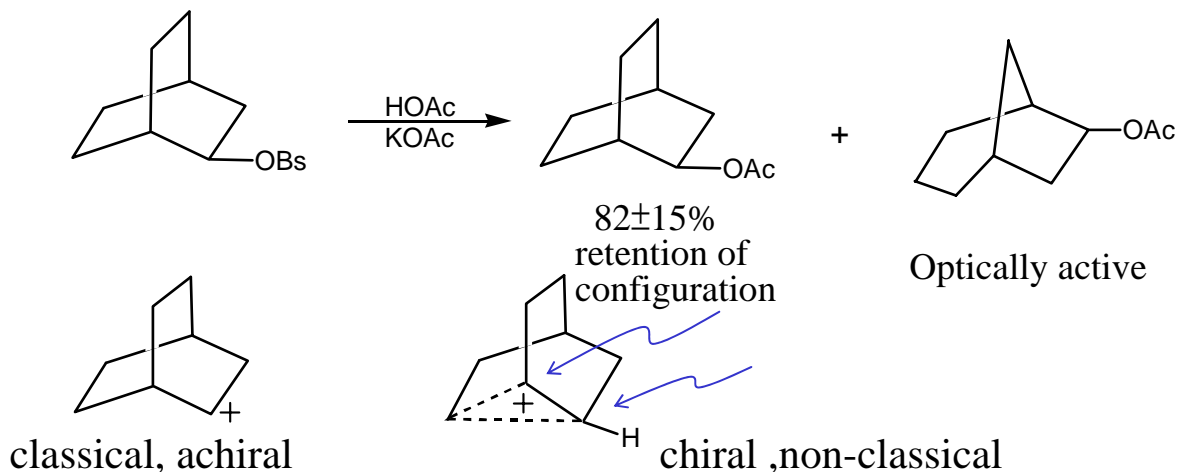
Two steps, the classical ion may be intercepted by solvent to retain configuration, depending on the nucleophilicity of the solvent.

Thus, in acetone, \rightarrow 87% racemization

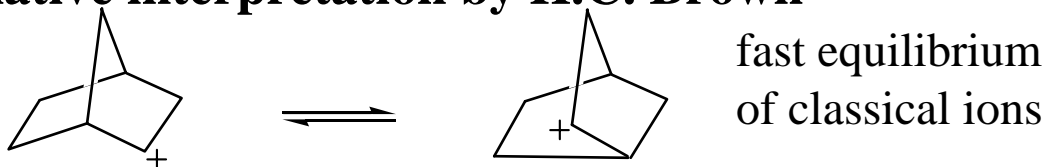
HOAc, \rightarrow 93% racemization

HCOOH \rightarrow 97% racemization

Observation in recovered S.M. is due to internal return of symmetrical Intermediate for exo S.M.

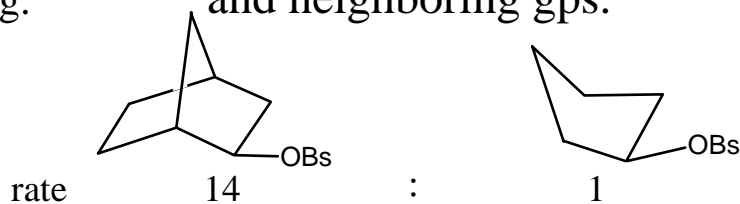


Alternative interpretation by H.C. Brown



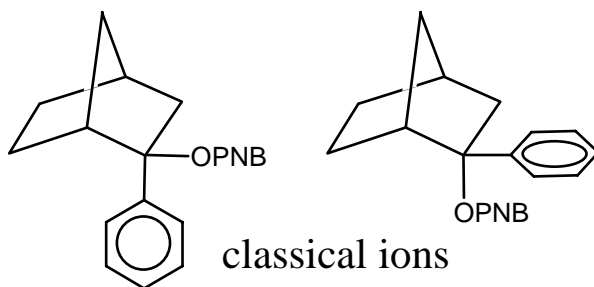
rate enhancement : release of torsional strain of leaving gp
and neighboring gps.

e.g.



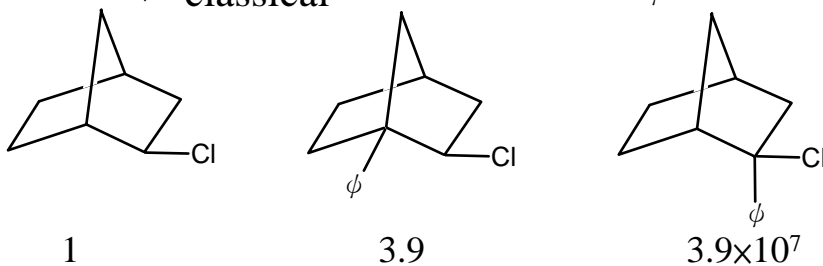
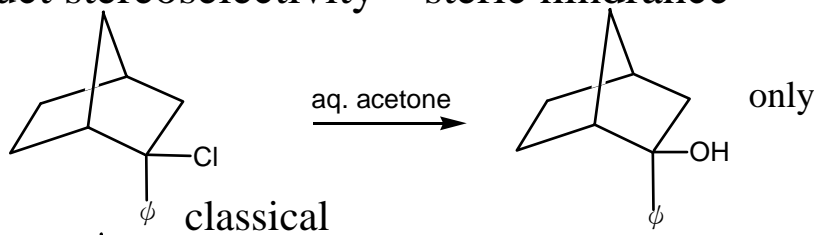
high exo/endo ratio : steric hindrance

e.g.



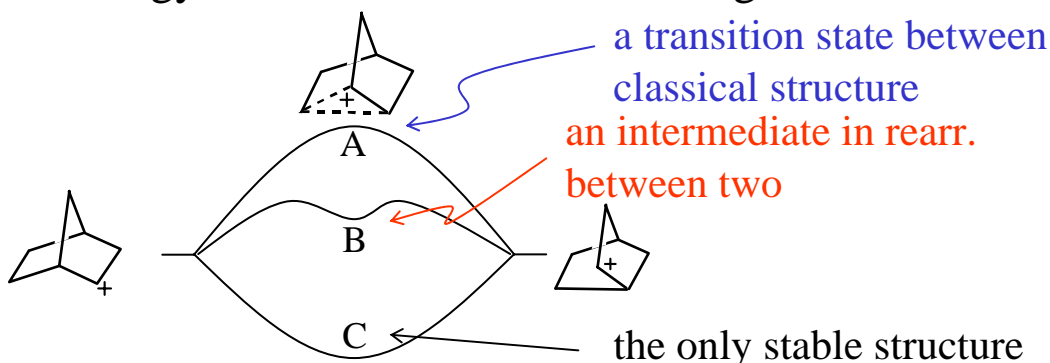
$$k_{\text{exo}}/k_{\text{endo}}=140$$

product stereoselectivity : steric hindrance



little involvement
of C_1-C_6 bond

potential energy for stable and unstable bridged ion



Direct Observation of Norbornyl cation by NMR: Olah

^{13}C NMR in $\text{SO}_2\text{-SbF}_5$ (super acid)

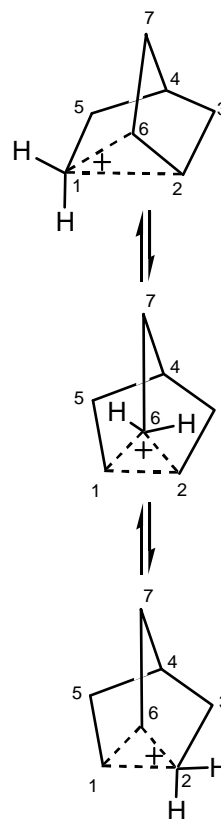
at -70°C , 101.8 ppm C-1,2,6
162 ppm C-3,5,7
156.1 ppm C-4

at -150°C and $\rightarrow 5^\circ\text{K}$
78.5 ppm C-1,2
171.4 ppm C-6
160.4 ppm C-4
145.8 ppm C-3,7
165.8 ppm C-5

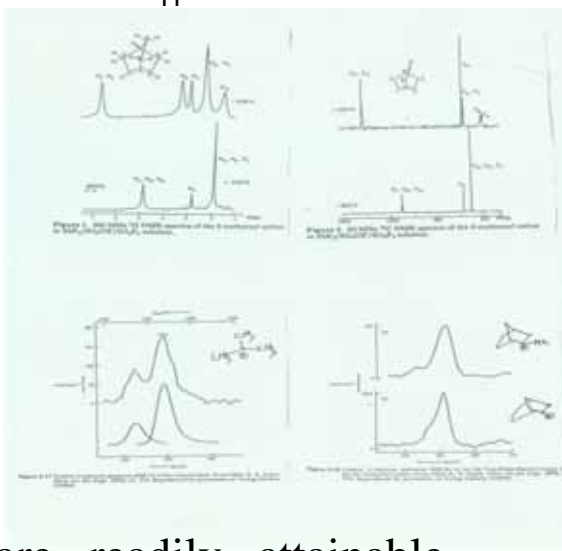
at -150°C , the hydride shift frozen

\rightarrow the NMR confirm the existence of norbornyl cation as non-classical.

or a equilibrating intermediate with barrier $< 0.2\text{kcal}$



^1H at -60°C ,
5.35 ppm (4H)
3.15 ppm (1H)
2.20 ppm (6H)



Summarize :

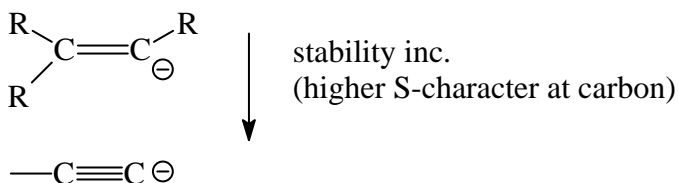
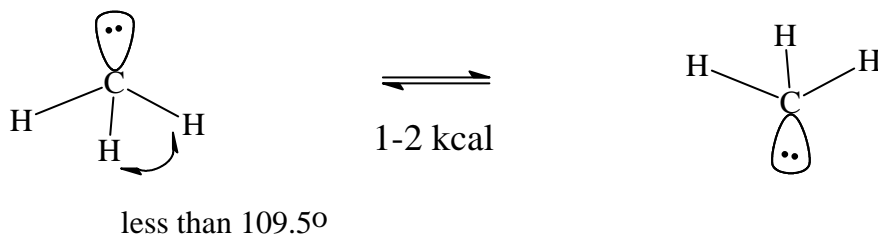
Nonclassical or bridged structure are readily attainable intermediate or transition state for many cations.

For norbornyl cation, the bridged structure is an intermediate. tertiary cation is nearly always classical cation.

primary cation can rearrange to more stable secondary or tertiary carbocation, with bridged structure as T.S..

§ Carbanions:

intermediates with formal charge of -1 on carbon, 8 valence electrons

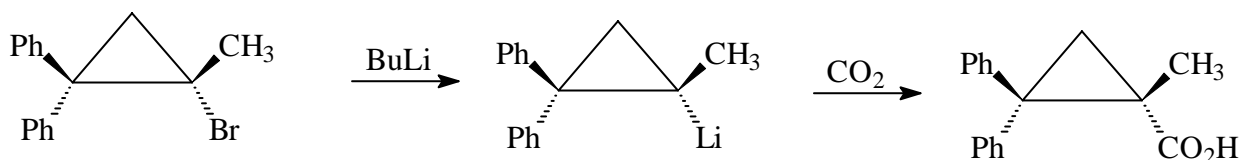


Metal-carbon bond can be polar-covalent, such as C-Li
Organometallic species can be associated species(oligomeric)

The barrier of inversion at carbanion carbon can be increased by incorporation of small ring, attaching electronegative substituent,

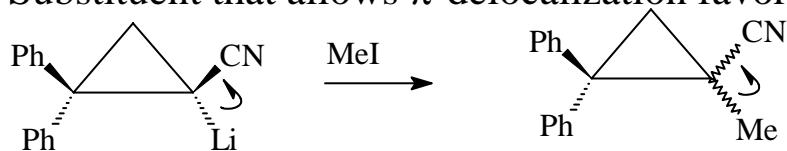
cyclopropyl anion is stable pyramidal

Inversion barrier for NH_3 $\sim 5\text{kcal}$, for NF_3 $\sim 50\text{kcal}$



100% retention of conformation

Substituent that allows π -delocalization favors planar structure



stabilized by resonance
less interaction with metal ion

racemic \rightarrow

a fast inverting tetrahedral carbanion center is indicated

Generation of carbanion

- reduction of carbon-halogen bond by metal
- deprotonation (acid/base rxn) by strong base
- reduction/addition of alkene
-

Stability of carbanion

Acidity $3^\circ < 2^\circ < 1^\circ$ in solution

(due to destabilization of e-donating alkyl groups?)

But in gas phase, measured acidity:

Ethene < propane(2°-H) < methane < isobutane(3°-H)

The solution acidity is complicated by solvation

The order of acidity of alcohol

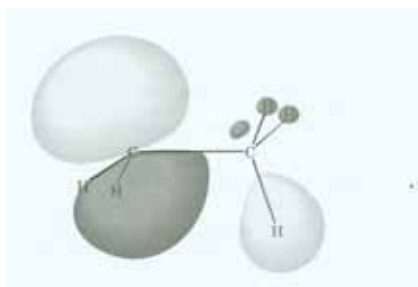
In gas phase

t-butyl > isopropyl > ethyl > methyl

In aqueous solution

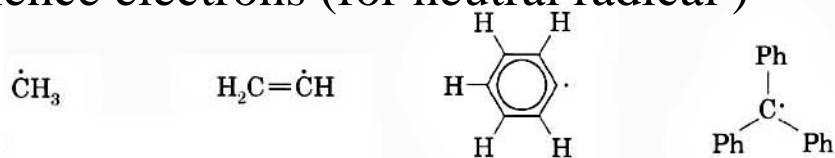
methyl > ethyl > isopropyl > t-butyl

The alkyl group can polarize the electron away from the center of negative charge and stabilize it.

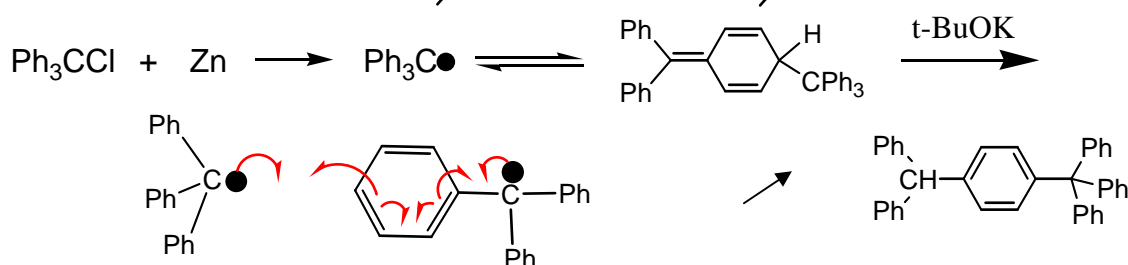
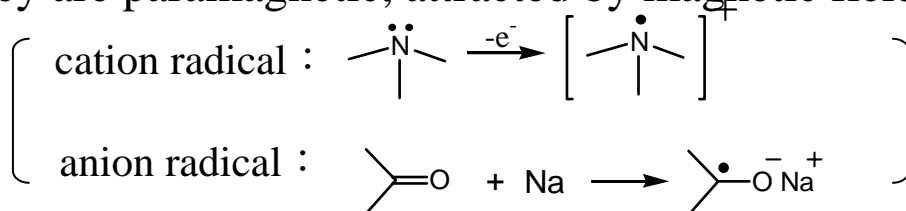


§ Free Radicals

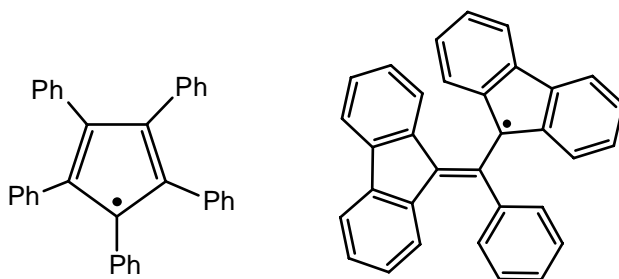
Structure with unpaired electron and zero formal charge
7 valence electrons (for neutral radical)



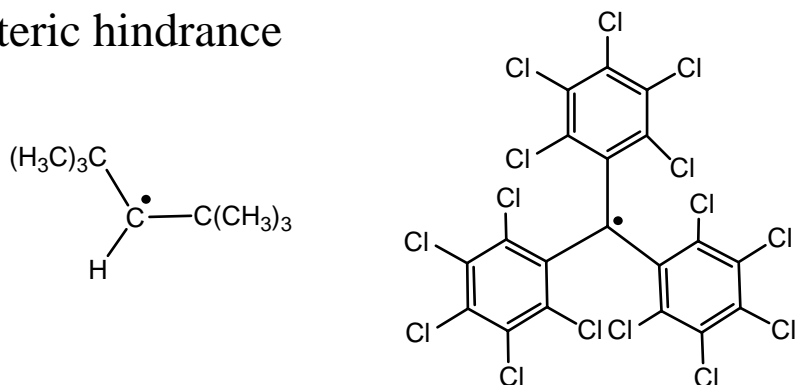
They are paramagnetic, attracted by magnetic field.



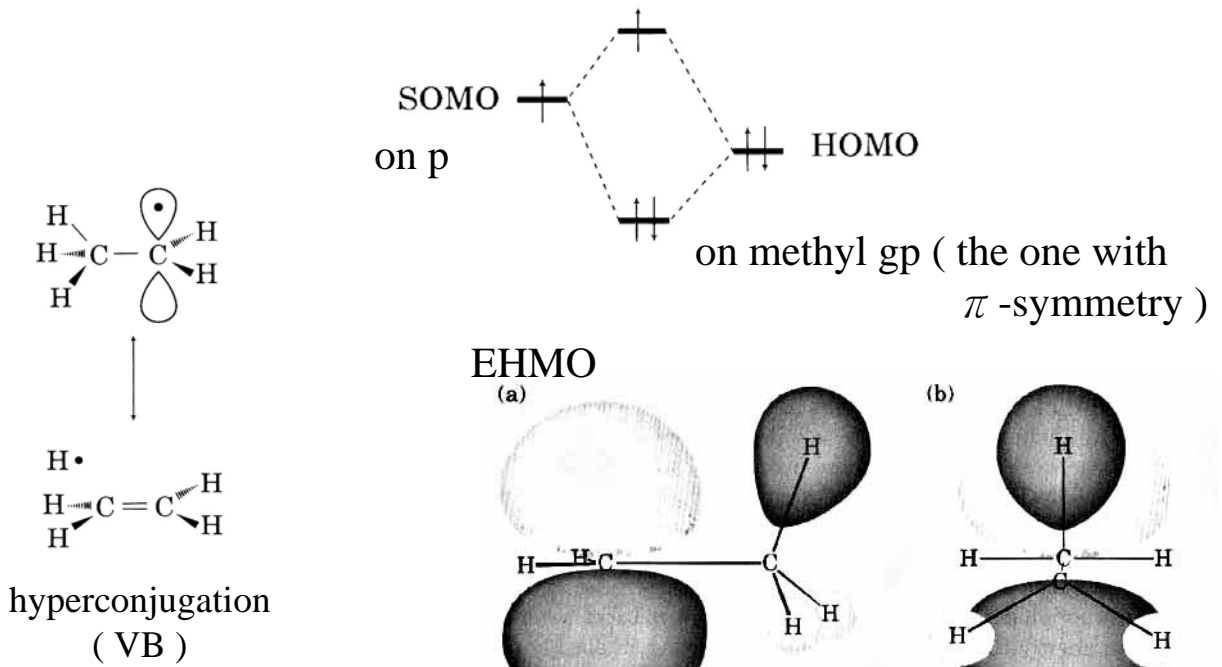
Radicals are in general reactive intermediate, but can be stabilized via delocalization of the radical : such as



or by steric hindrance

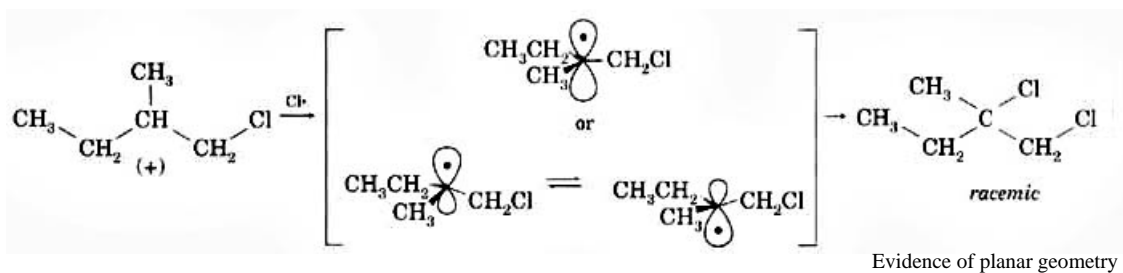
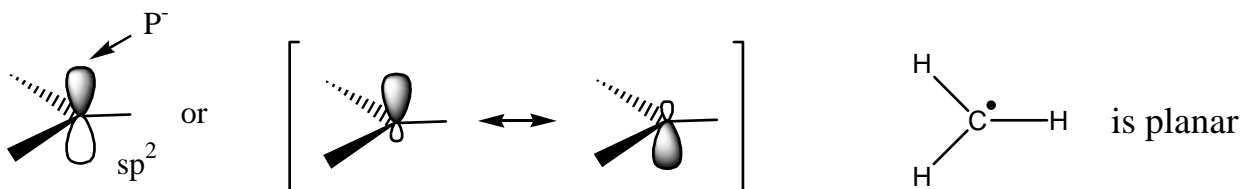


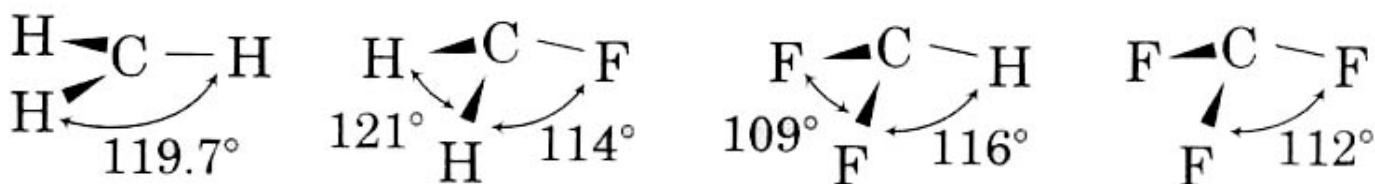
PMO & EHMO description of ethyl radical



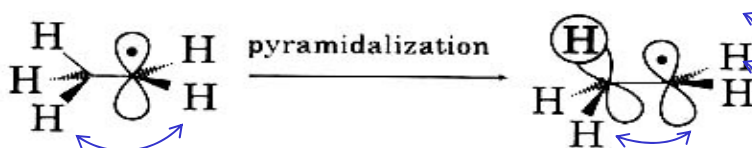
Structure and bonding

alkyl radical

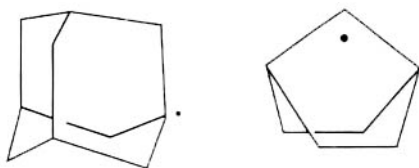




→
Methyl radical is planar, with very small barrier for pyramidalization. All other radicals are non-planar. Electronegative substituent shifts the shape to pyramidal.



bridgehead radical are less strained, as compare to planar carbonium ion



stability of radical

Table 5.1 ΔH_f° values for selected radicals and bond dissociation energies for selected alkanes.

Radical (R \cdot)	ΔH_f° (kcal/mol)	BDE (R-H) (kcal/mol)
H	52.1 ^a	104.2 ^a
Methyl	34.9 \pm 0.2 ^b	104.9 ^c
Ethyl	28.3 \pm 0.4 ^b	100.6 ^c
<i>n</i> -Propyl	24.0 \pm 0.5 ^c	100.9 ^c
<i>i</i> -Propyl	22.3 \pm 0.6 ^c	99.3 ^c
	21.3 \pm 0.7 ^b	
<i>sec</i> -Butyl	16.7 \pm 0.5 ^c	99.0 ^c
<i>t</i> -Butyl	11.7 \pm 0.4 ^d	95.9 \pm 0.4 ^d
	12.4 \pm 0.5 ^c	

methyl < 1° < 2° < 3°

due to hyperconjugation

^aData from reference 65. ^bData from reference 67. ^cData from reference 68. ^dData from reference 69. ^eCalculated from ΔH_f° values of the radicals and the alkane.

§ carbenes

6 valence electrons on a CR_2

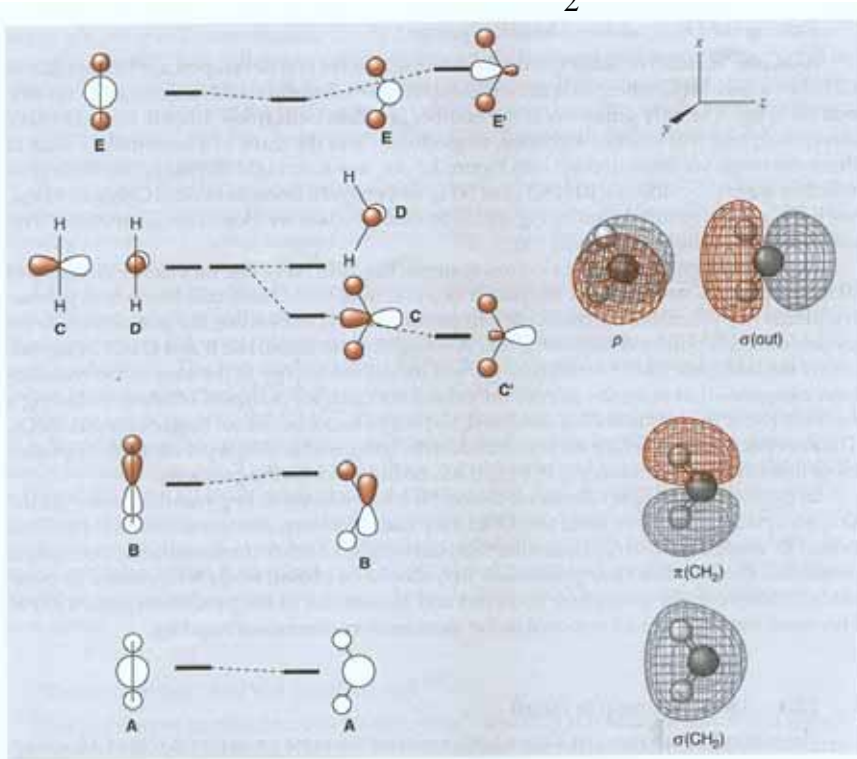


Figure 1.9 The Walsh diagram for CH_2 . The linear form is shown on the left, and it is converted to the bent form. Also shown is a secondary mixing between the C and E orbitals to make C' and E'. The computed MOs and the standard group orbital designations are also given.

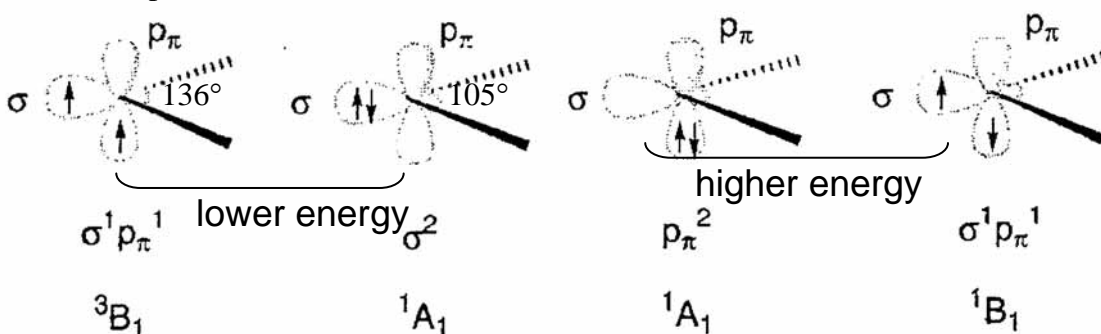
Ground state multiplicity affects reactivity (e.g. singlet has ambiphilic character; triplet reacts as diradical)

Large σ -p- π separation \Rightarrow singlet ground state

Smaller σ -p- π separation \Rightarrow triplet ground state.

The substituents affect the ground state multiplicity

Ground state for simple carbene

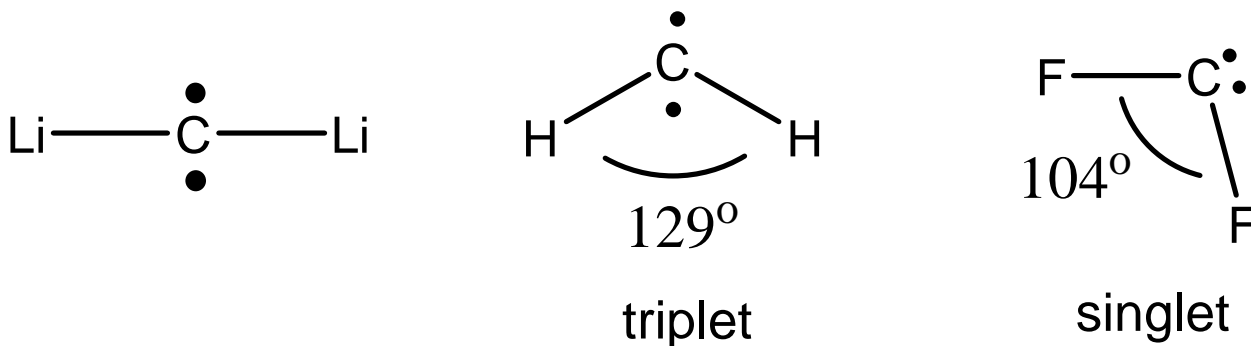


The substituents affect the ground state multiplicity

Inductive effect: (inductively stabilize σ by increasing its S-character)

σ -withdrawing group favors singlet

σ -donating group favors triplet

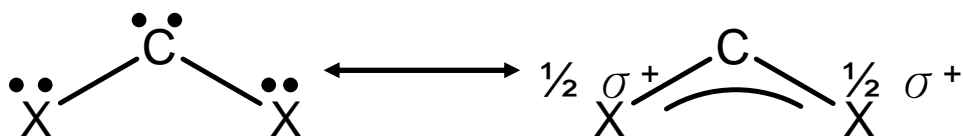


Resonance Effect:

X: +R (-F, -Cl, -Br, -I, -NR₂, -PR₂, -OR, -SR)

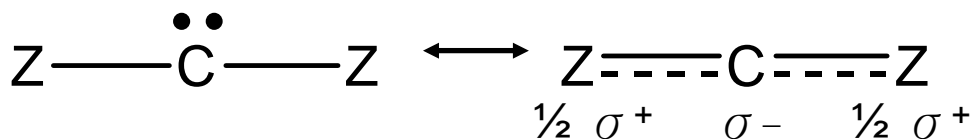
Z: -R (-COR, -CN, CF₃, -BR₂, -SiR₃, -PR₃⁺)

(X,X) -carbene => bent singlet

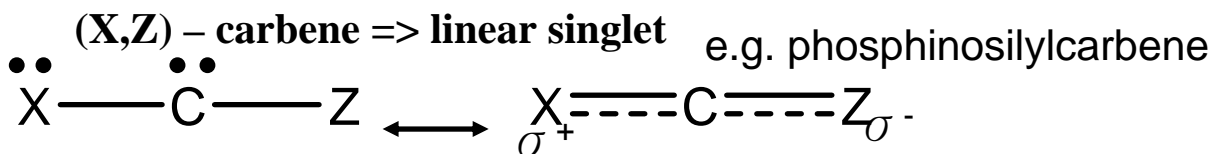


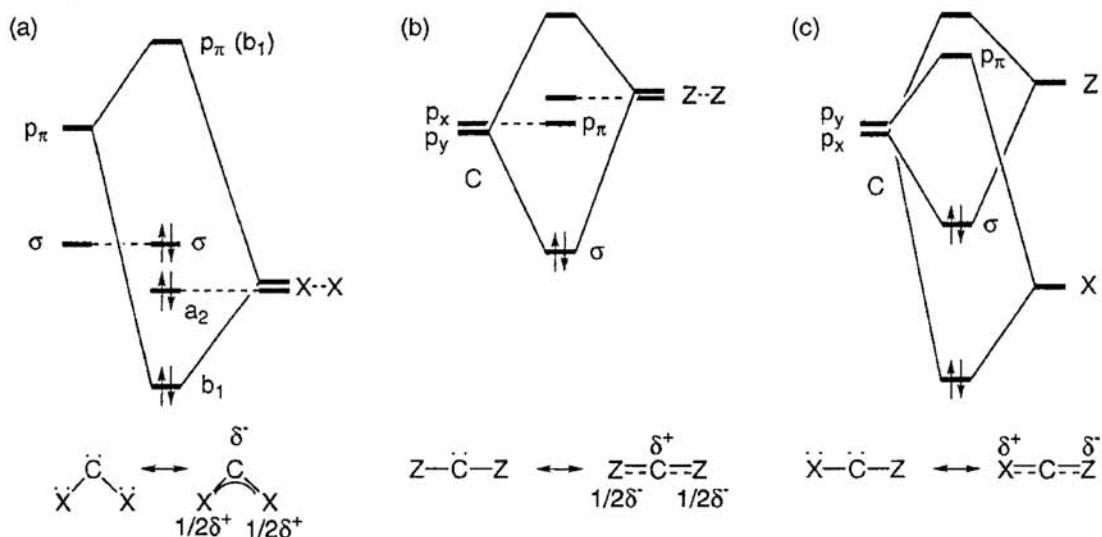
e.g. dimethoxycarbene, dihalocarbene

(Z,Z) - carbene => linear singlet carbene



e.g. diborylcarbene, dicarbomethoxycarbene





X: π -electron-donating substituents; Z: π -electron-withdrawing substituents

Steric effect:

increasing steric bulkness \rightarrow increase the bond angle \Rightarrow favor triplet

Dimethylcarbene, di(t-butyl)carbene diadamantylcarbene

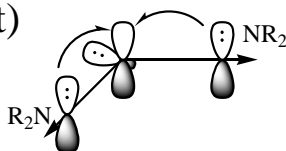
Bent singlet, 111°

triplet, $^\circ$

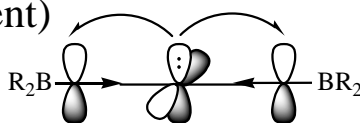
triplet, 152°

To stabilize a carbene:

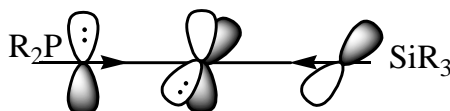
two π -donor, σ -attractor substituents (push push resonance, pull pull inductive substituent)



Two π -attractor, σ -donor substituents (pull pull resonance, push push inductive substituent)



A π -donor, π -acceptor (push pull resonance substituent)

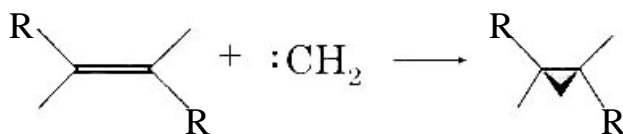


Reaction of Carbene

triplet carbene behaves as diradical

singlet carbene behaves as both carbocation and carbanion.

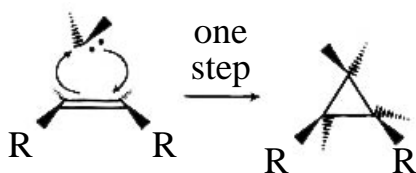
Addition



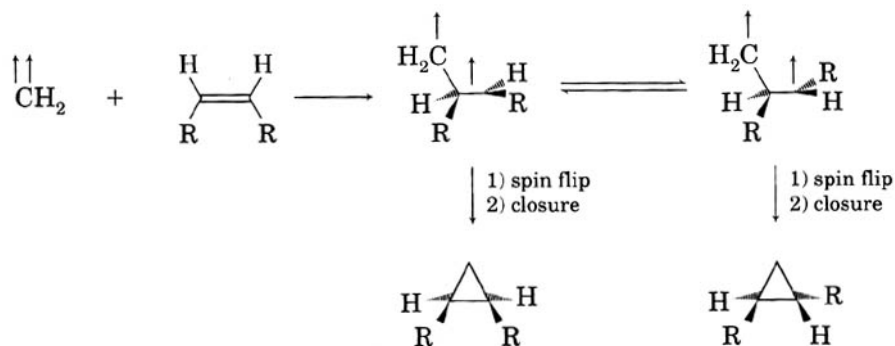
Singlet carbene inserts stereospecifically

triplet carbene inserts non-stereospecifically

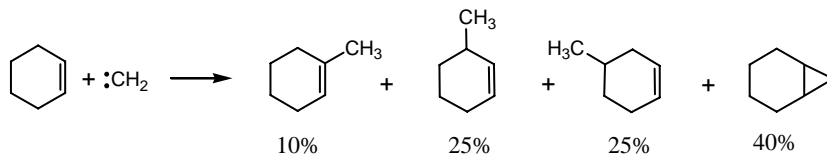
Singlet



Triplet



Insertion



Rearrangement

