

Stereoelectronic Effects

Recent Advances and New Insights

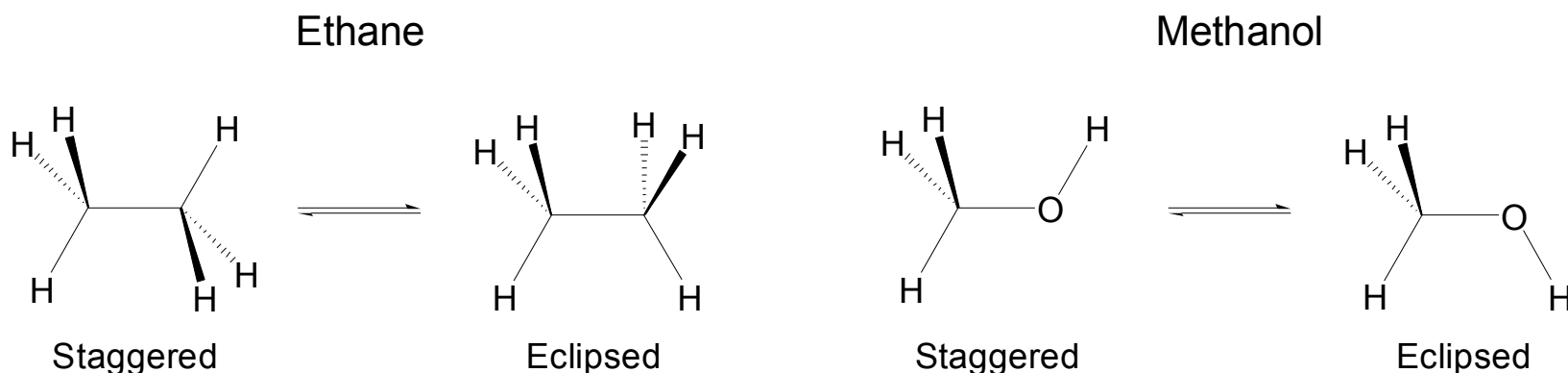
An Evans Group Afternoon Seminar
Keith Fandrick
October 10, 2003

- I. Introduction to Hyperconjugation and NBO Analysis
- II. The Role of Hyperconjugation in Cyclohexane
- III. σ -Acceptor Abilities and Trends
- IV. Recent Examples

Keywords: hyperconjugation, stereoelectronic, cyclohexane, conformational energies, σ -acceptor, equilibrium, Ceiplak, Anh, ring-opening, silyl, Fock, NBO, methylcyclohexane, dioxane, W-effect, Perlin,

Ethane and Methanol, Staggered vs Eclipsed Conformations

Arguments for Hyperconjugation



Deleted Hyperconjugative Interaction

Preferred Conformer

No Deletion

Staggered

No Hyperconjugation

Eclipsed

No Vicinal Hyperconjugation

Eclipsed

No Geminal Hyperconjugation

Staggered

Deleted Hyperconjugative Interaction

Preferred Conformer

No Deletion

Staggered

No Hyperconjugation

Eclipsed

No Vicinal Hyperconjugation

Eclipsed

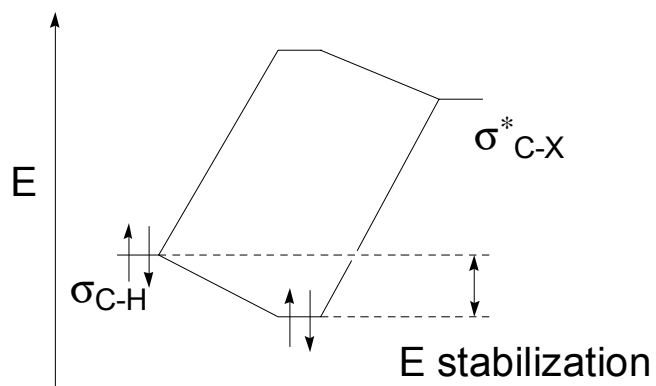
No Geminal Hyperconjugation

Staggered

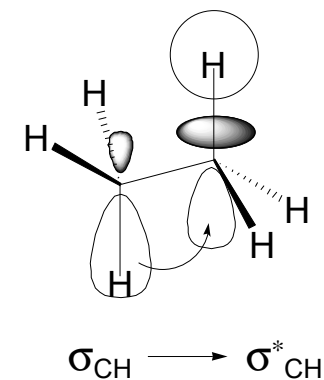
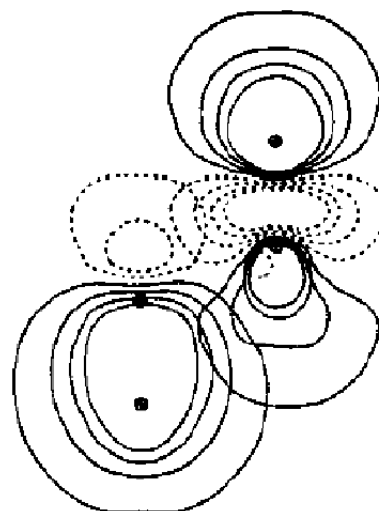
The Stereoelectronic Interactions of Ethane

Hyperconjugation not Sterics leads to the Staggered Conformation

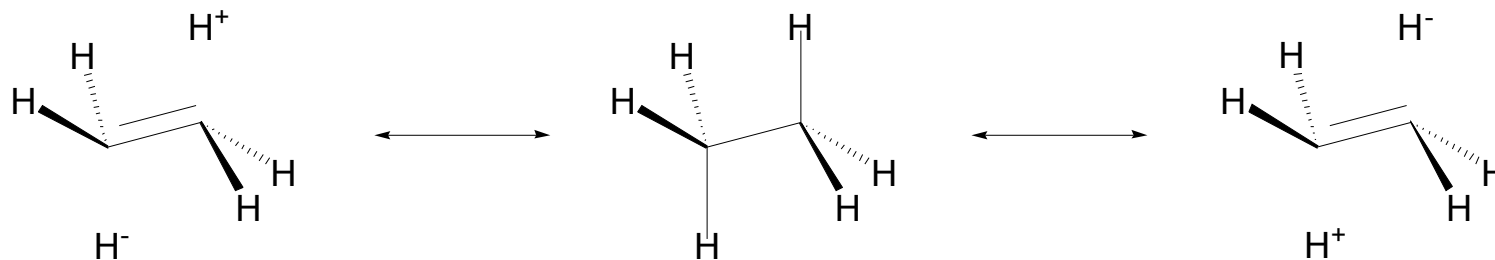
Energy Lowering Due to Hyperconjugation



Orbital drawings



Resonance Theory Representation



Evans D. A.; *Chem. 206 notes*, **2001**
Alabugin, I. V.; *J. Am. Chem. Soc.*, **2001**, 3175
Goodman, L.; *Nature*, **2001**, 401, 565

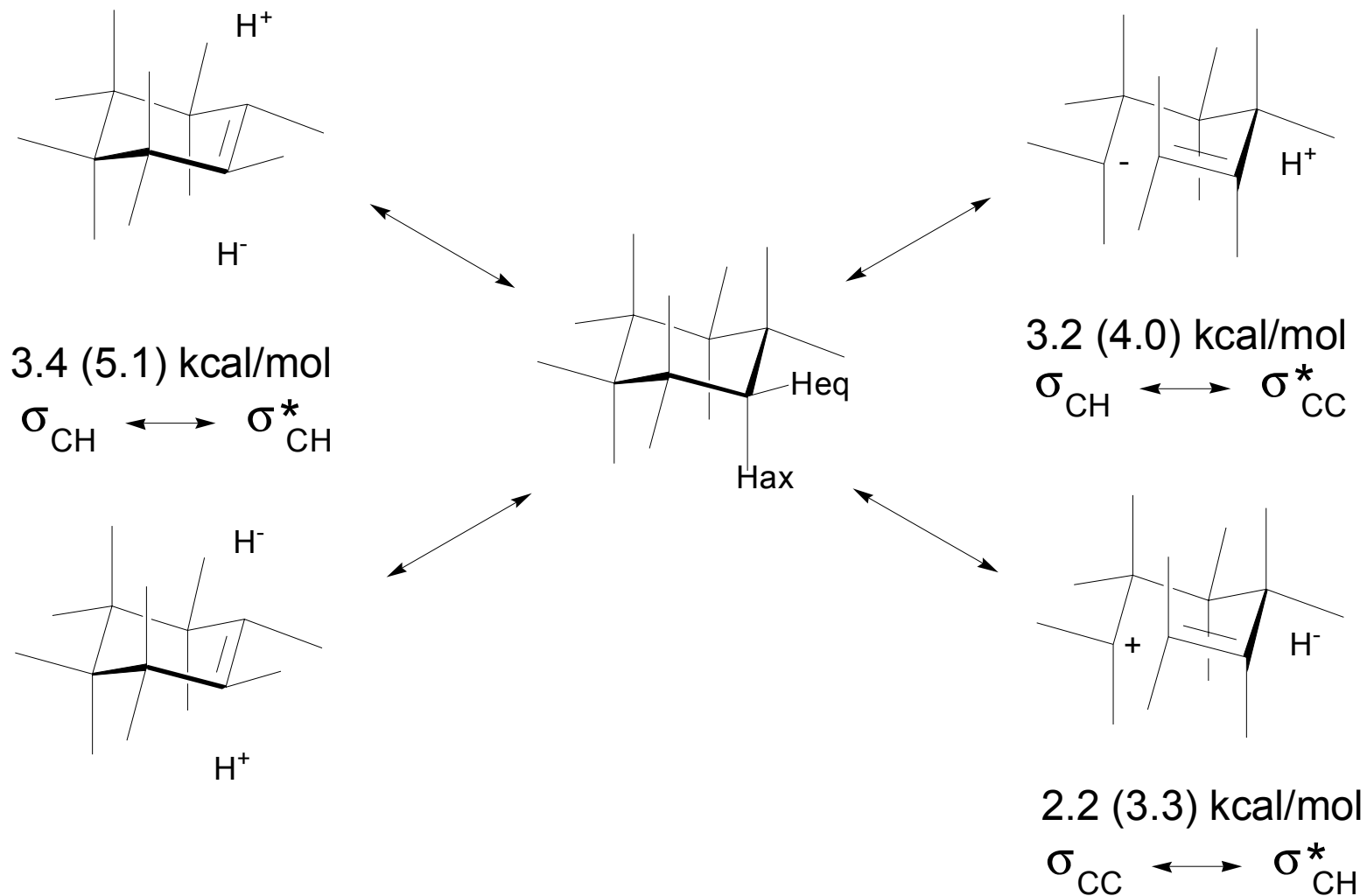
NBO Analysis

- Structures optimized at the HF/6-31G**, MP2/6-31G**, and B3LYP/6-31+G* levels using GAUSSIAN 94/98 packages
- NBO 4.0 program was interfaced with the GAUSSIAN 94/98 packages
- NBO program transforms the canonical delocalized Hartree-Fock (HF) MO's into localized hybrid orbitals (natural bonding orbitals, NBO)
- Filled NBO's describe the hypothetical "strictly" localized Lewis structures
- Deviation of the molecule from the optimized structure from the NBO description can be used to measure the energetics of delocalizations/hyperconjugation
- Energetics of the delocalizations were estimated from the second order perturbation approach and calculated by deletion of the corresponding off-diagonal elements of the Fock matrix in the NBO basis

Alabugin, I. V. *J. Org. Chem.* **2000**, 65, 3910
Weinhold F. *Encyclopedia of Computational Chemistry*;
Schleyer P. **1998**, p 1792

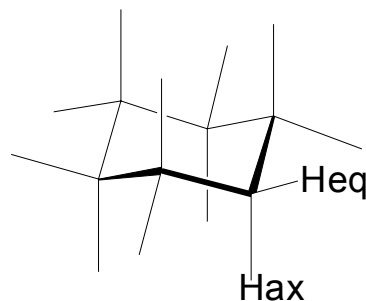
NBO Analysis of Cyclohexane

The Four Main Hyperconjugation Interactions



Energies correspond to RHF/6-31G** (B3LYP/6-31+G**)

NBO Analysis of Cyclohexane



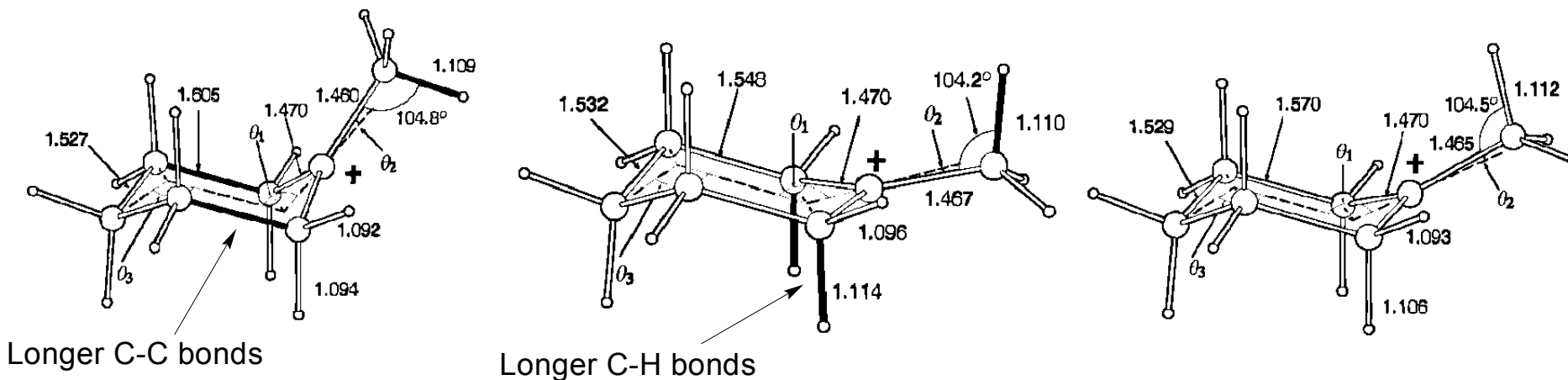
Bond	Bond Length, Å		$^1J_{CH}$, Hz	ΣE_{del} , Kcal/mol	
	RHF/6-31G**	B3LYP/6-13+G**		RHF	B3LYP
C-H _{ax}	1.0871	1.1001	122	13.5	20.4
C-H _{eq}	1.0895	1.0971	126	10.7	14.6

-Calculated longer bond lengths correspond to lower C-H coupling constants, in accord with a *Normal* Perlin effect ($J_{CHax} < J_{CHeq}$)

-Analysis indicates: **C-H bonds are better donors than C-C bonds**

1-Methyl-1-cyclohexyl Cation

Two Distinct Chair Conformations, Hyperconjugative effects

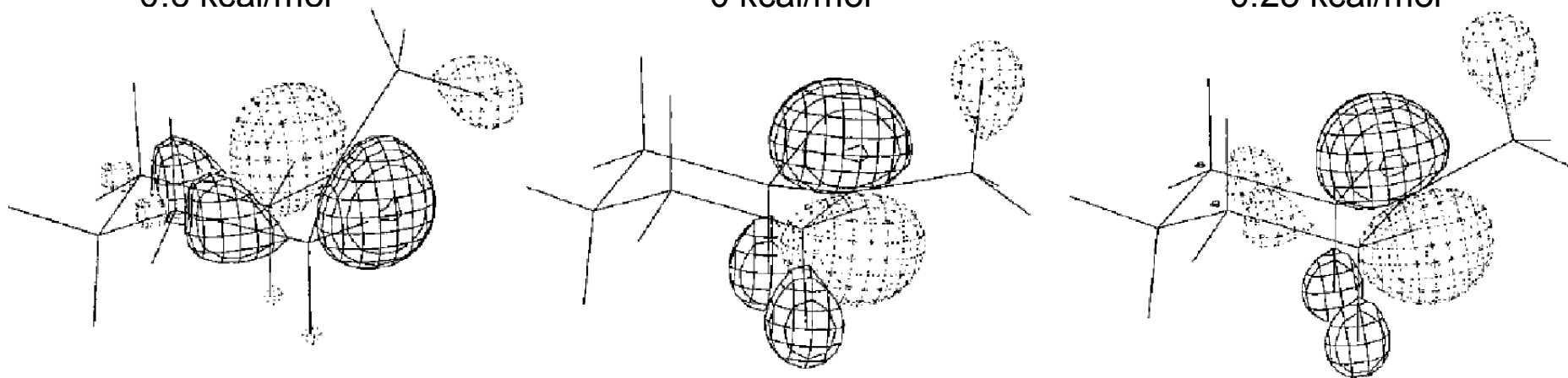


Relative Energy

0.6 kcal/mol

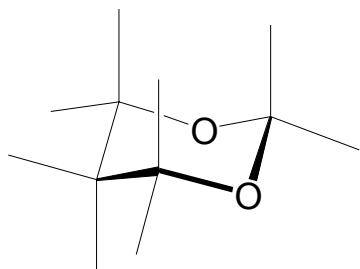
0 kcal/mol

0.25 kcal/mol



-At least two different structures are observed for the methyl-cyclohexyl cation by NMR

1,3-Dioxane, W-Effect?



-Almost equal J_{CHax} and J_{CHeq} at C5

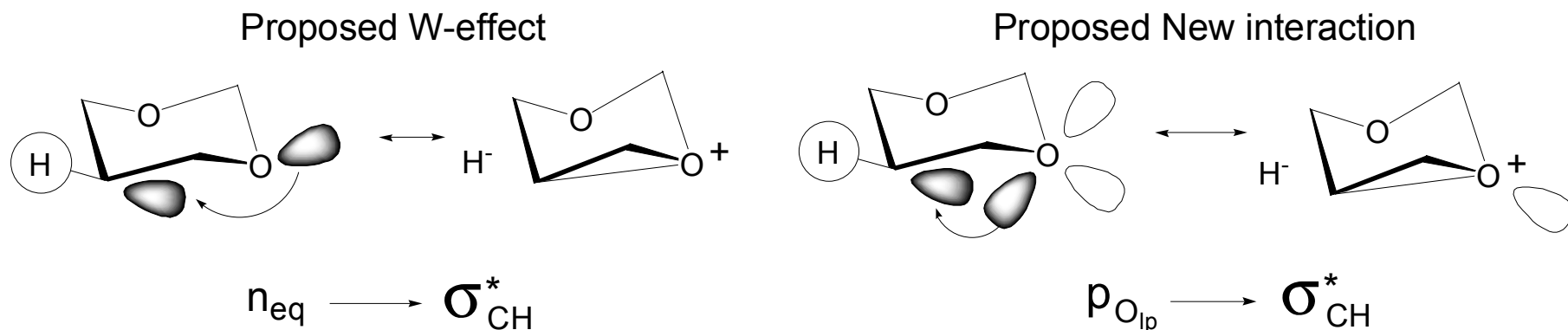
-Reverse Perlin effect with alkyl and aryl substituted 1,3-dioxanes

$-n_{\text{eq}} \rightarrow \sigma_{\text{CH}}^* < 1 \text{ kcal/mol}$ (W-effect)

Summary of Delocalizing Interactions for C-H bonds
In 1,3-Dioxane

donor orbital	acceptor orbital	energy, kcal/mol	
		RHF/6-31G**	B3LYP/6-31+G**
→ $\sigma_{\text{C}(5)-\text{H}(5)_{\text{ax}}}$	$\sigma_{\text{C}(6)-\text{H}(6)_{\text{ax}}}^*$	3.28	4.66
	$\sigma_{\text{C}(5)-\text{H}(5)_{\text{ax}}}^*$	3.29	4.76
→ $\sigma_{\text{C}(5)-\text{H}(5)_{\text{eq}}}$	$\sigma_{\text{C}(6)-\text{O}(1)}^*$	4.23	4.50
	$\sigma_{\text{C}(5)-\text{H}(5)_{\text{eq}}}^*$	1.63	2.86
	LP(2)O(1)	0.68	2.7
	$\sigma_{\text{C}(2)-\text{H}(2)_{\text{ax}}}^*$	2.33	5.40
	$\sigma_{\text{C}(2)-\text{H}(2)_{\text{ax}}}^*$	5.86	11.59
→ $\sigma_{\text{C}(2)-\text{H}(2)_{\text{eq}}}$	$\sigma_{\text{C}(6)-\text{O}(1)}^*$	4.05	4.23
	$\sigma_{\text{C}(2)-\text{H}(2)_{\text{eq}}}^*$	1.92	3.50
	LP(1)O(1)	2.18	2.95
	$\sigma_{\text{C}(6)-\text{H}(6)_{\text{eq}}}^*$	2.11	2.88
	LP(1)O(1)	2.04	4.88
	$\sigma_{\text{C}(6)-\text{H}(6)_{\text{ax}}}^*$	6.27	12.41
	$\sigma_{\text{C}(6)-\text{H}(6)_{\text{ax}}}^*$	3.28	4.66
	$\sigma_{\text{C}(5)-\text{H}(5)_{\text{ax}}}^*$	3.29	4.76
	$\sigma_{\text{O}(1)-\text{C}(2)}^*$	1.81	3.32
	$\sigma_{\text{O}(1)-\text{C}(2)}^*$	3.39	3.11
	$\sigma_{\text{C}(6)-\text{H}(6)_{\text{eq}}}^*$	2.41	3.43
	$\sigma_{\text{C}(5)-\text{C}(4)}^*$	3.03	3.28

NBO analysis of 1,3-Dioxane, extra interaction



-W-effect found to be small, <1 kcal/mol.

-P orbital for a lone pair is a better donor than the corresponding sp^3 lone pair.

-New interaction is favored due to better orbital overlap.

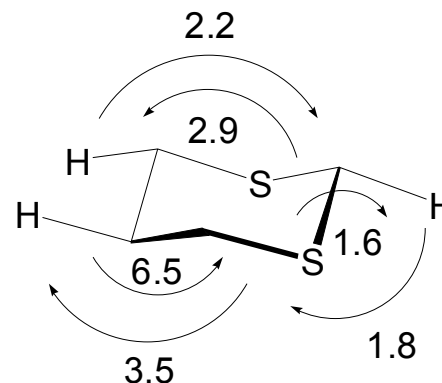
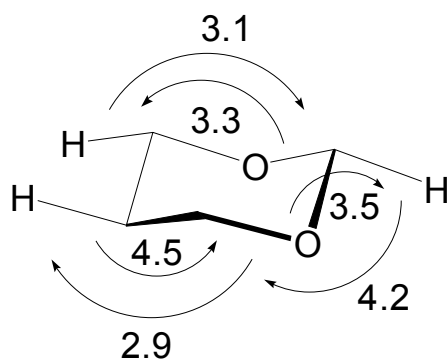
-Interaction is smaller than $\sigma_{CH_{eq}} \longleftrightarrow \sigma_{CO}^*$, but it serves to tip the balance of delocalizing interactions in the favor of "equatorial" delocalization.

Alabugin, I. V.; *J. Org. Chem.* **2000**, *65*, 3910

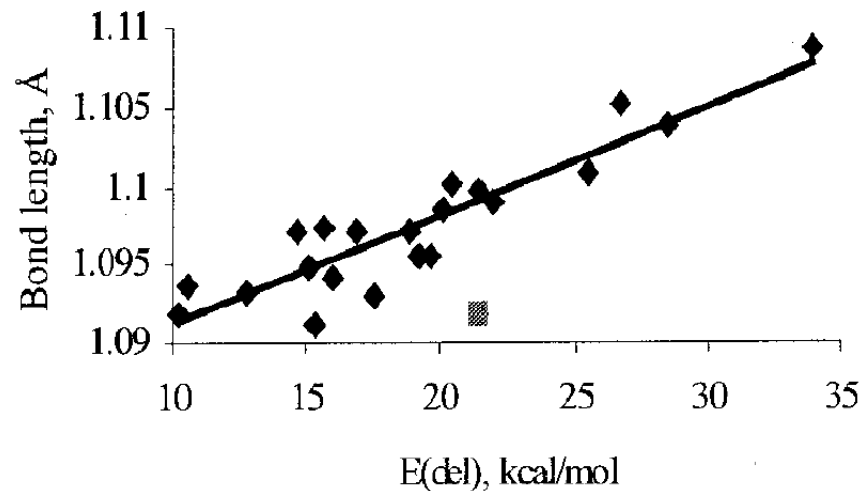
Cuevas, G.; *J. Am. Chem. Soc.*, **2002**, *124*, 13088

Conclusions from NBO analysis

Summary of equatorial interactions for dioxane and dithiane



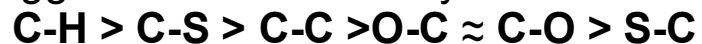
$E(\text{del})$ vs. bond length, B3LYP



Square denotes the C(2)-H_{eq} in 1,3-dioxane

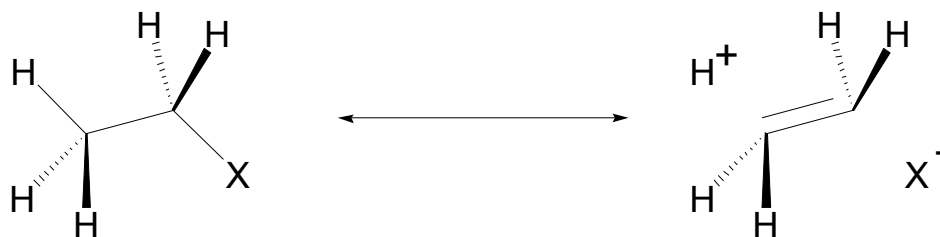
-NBO analysis, $E(\text{del})$, correlates well with C-H bond lengths in cyclohexane, 1,3-dithiane, and 1,3-dioxane

-NBO analysis of 1,3-dioxane and 1,3-dithiane suggests the donor ability of σ -bonds are:

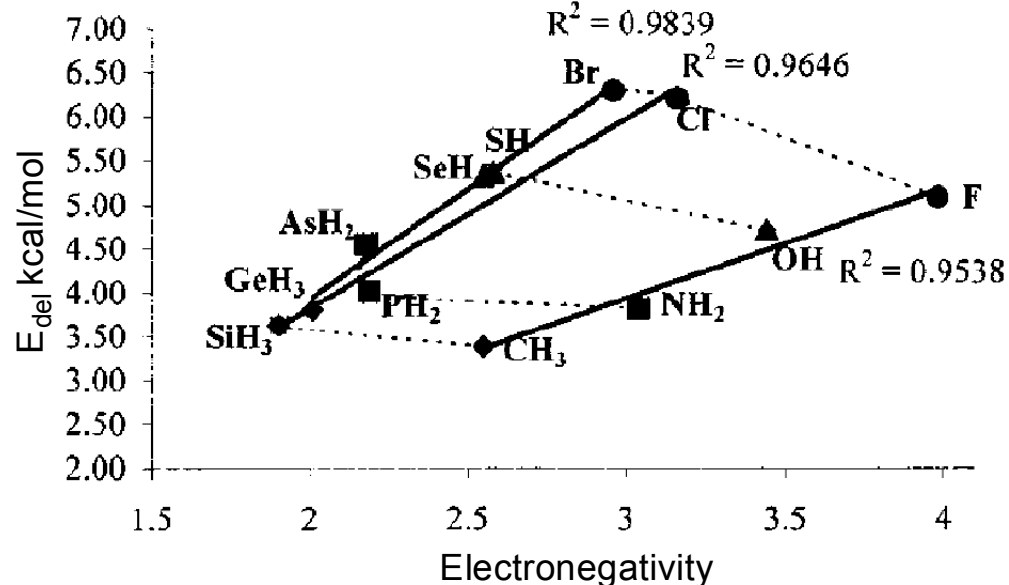


σ -Acceptor Abilities: Trends

For Monosubstituted Ethanes, $\text{CH}_3\text{CH}_2\text{X}$



Correlation of E_{del} for $\sigma_{\text{C-H}} \rightarrow \sigma_{\text{C-X}}^*$ interactions and Electronegativity



- E_{del} calculated by deletion of the off-diagonal Fock matrix elements between interacting orbitals, NBO analysis

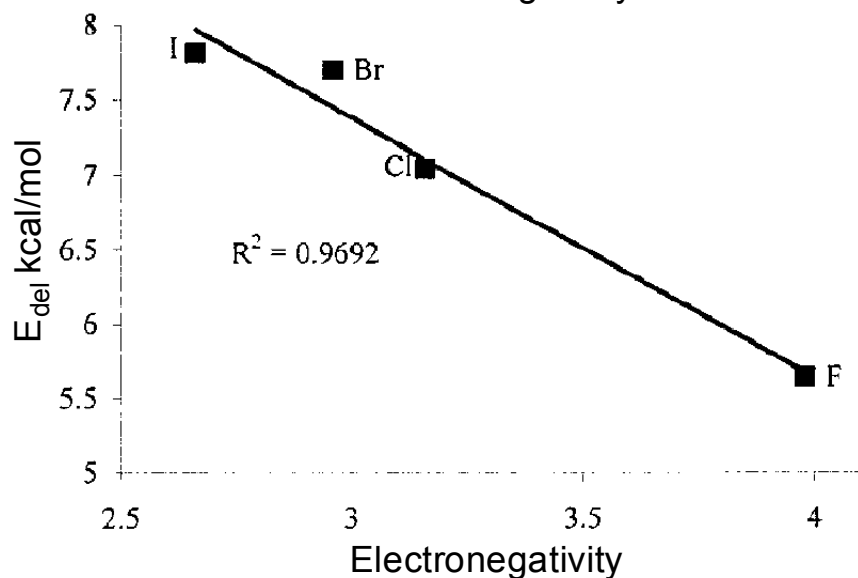
- σ -Acceptor abilities correlate with electronegativity across a period

-Down a row, σ -acceptor abilities increase

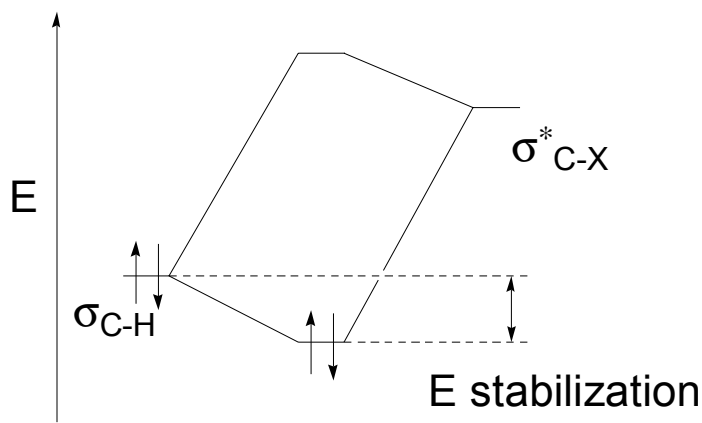
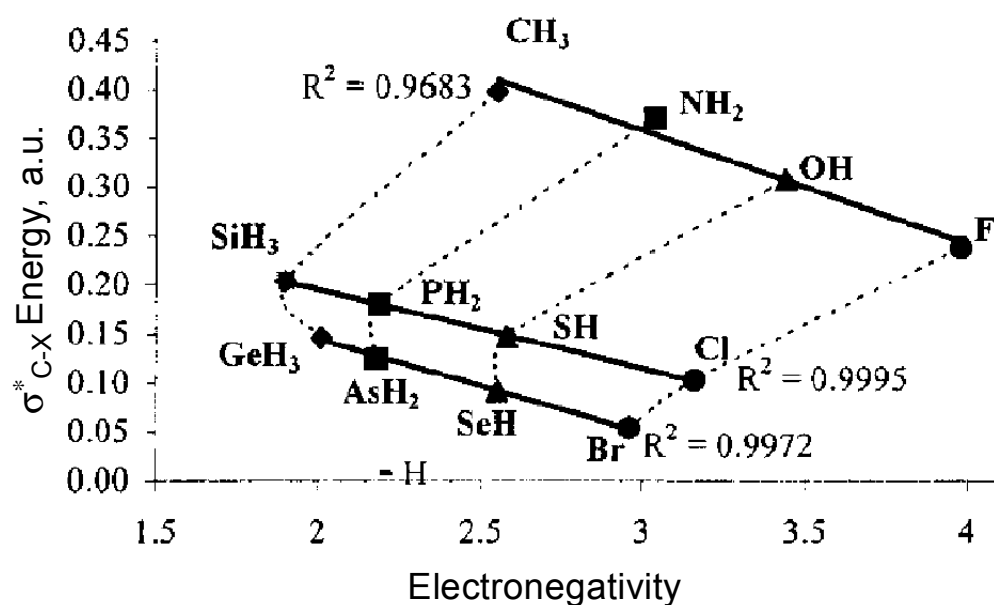
σ -Acceptor Abilities: Trends

The Origin of the σ -Acceptor Trends in Ethane

Correlation of E_{del} for $\sigma_{\text{C-H}} \rightarrow \sigma_{\text{C-X}}^*$ Interactions and Electronegativity

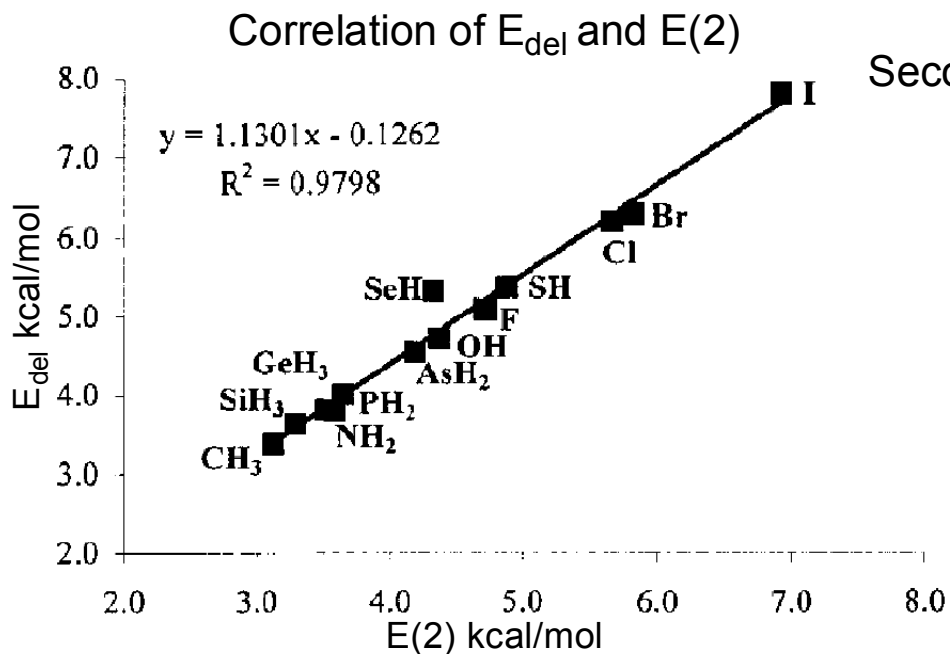


Correlation energy of $\sigma_{\text{C-X}}^*$ and Electronegativity



$-E_{\text{del}}$ depends on the energy separation of the HOMO and LUMO

σ -Acceptor Abilities: Trends



Second-order perturbation analysis of the Fock Matrix in the NBO basis set

$$E(2) = -\eta_{\sigma} \frac{(\sigma/F/\sigma^*)^2}{\epsilon_{\sigma^*} - \epsilon_{\sigma}} = -\eta_{\sigma} \frac{F_{ij}^2}{\Delta E}$$

ΔE is the energy difference between the σ and σ^* orbitals

η_{σ} is the population of the donor σ orbital

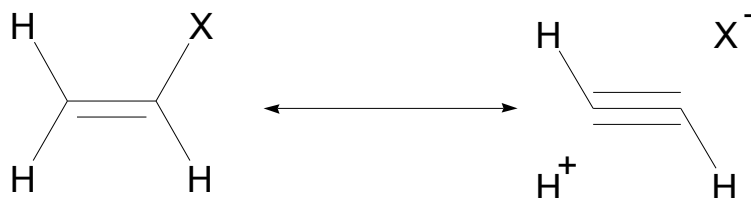
F_{ij} is correlated with the orbital overlap matrix element S_{ij} and the acceptor orbital polarization

- $E(2)$ overestimates stabilizing interactions, but shows excellent correlation with E_{del}

-Energetics of delocalizations depends on: ΔE , orbital overlap, and polarization of the acceptor orbital

σ -Acceptor Abilities: Trends

Delocalizing interactions with substituted ethenes:



-Halogen acceptor abilities are $F < Cl > Br$

-In ethanes, the ΔE term is more important, In ethenes, the significance of F_{ij} increases

-Rationale for the increase dependence of F_{ij} is the shorter C=C bond relative to C-C

- F_{ij} depends on the overlap of the donor and acceptor orbitals, thus it has an exponential dependence on the distance between the two orbitals

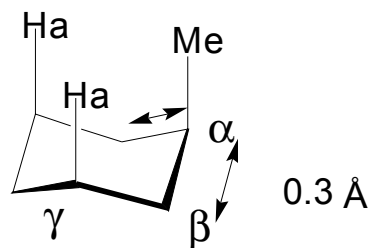
-Anh's warning: one must compare similar systems when using FMO

Alabugin I. V.; *J. Am. Chem. Soc.*, **2002**, *124*, 3175

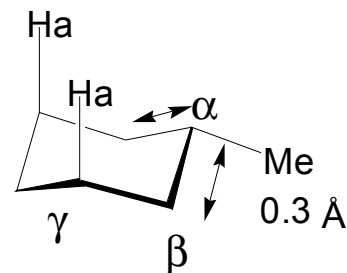
Anh, N. T.; *New J. Chem.*, **1997**, *21*, 861

Testing the Steric Model, Methylcyclohexane

Elongation of the $C_{\alpha}-C_{\beta}$ bond by 0.3 Å



$\Delta E = 32.00$ kcal/mol



$\Delta E = 32.46$ kcal/mol

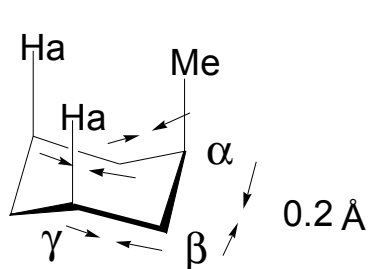
Parameters and Energetics (kcal/mol), Bond Lengths (Å) and Angles (deg.)

Conformation	State	ΔE	$C_{\alpha}-C_{\beta}$	$C_{\beta}-C_{\gamma}$	$C_{\beta}-C_{\alpha}-C_{Me}$	$H_a-C_{\gamma}-C_{\beta}$	H_a-H	$C_{Me}-C_{\gamma}$
Axial	Ground	0	1.545	1.538	112.4	109.9	2.381	3.211
Axial	Distorted	32.00	1.845	1.521	112.2	109.8	2.507	3.402
Equatorial	Ground	0	1.540	1.537	111.7	109.1		
Equatorial	Distorted	32.46	1.840	1.522	109.8	109.5		

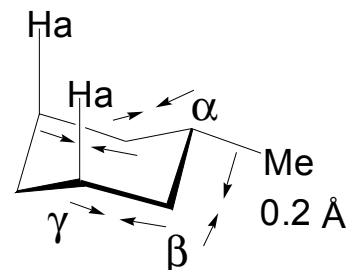
-Consistent with Steric Model

Testing the Steric Model, Methylcyclohexane

Compression of the $C_{\alpha}-C_{\beta}$ and $C_{\beta}-C_{\gamma}$ bonds by 0.2 Å



$$\Delta E = 70.05 \text{ kcal/mol}$$



$$\Delta E = 70.59 \text{ kcal/mol}$$

Parameters and Energetics (kcal/mol), Bond Lengths (Å) and Angles (deg.)

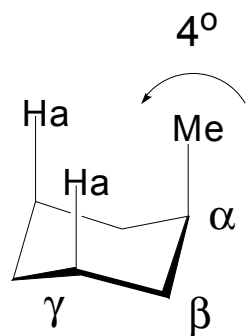
Conformation	State	ΔE	$C_{\alpha}-C_{\beta}$	$C_{\beta}-C_{\gamma}$	$C_{\beta}-C_{\alpha}-C_{Me}$	$H_a-C_{\gamma}-C_{\beta}$	H_a-H	$C_{Me}-C_{\gamma}$
Axial	Ground	0	1.545	1.538	112.4	109.9	2.381	3.211
Axial	Distorted	70.05	1.345	1.338	112.0	112.3	2.294	3.005
Equatorial	Ground	0	1.540	1.537	111.7	109.1		
Equatorial	Distorted	70.59	1.340	1.336	111.8	111.4		

-Not Consistent with Steric Model

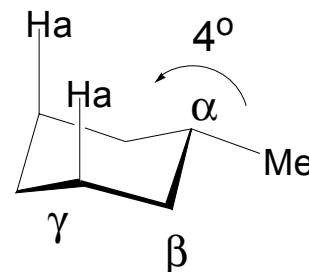
-Note: same argument used to explain higher conformational energies of 2-methyl-1,3-dioxanes

Testing the Steric Model, Methylcyclohexane

Bending the $C_{\alpha}-C_{\beta}-C_{Me}$ bond angle inward by 4°



$\Delta E = 1.18$ kcal/mol



$\Delta E = 1.21$ kcal/mol

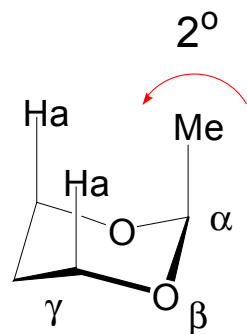
Parameters and Energetics (kcal/mol), Bond Lengths (Å) and Angles (deg.)

Conformation	State	ΔE	$C_{\alpha}-C_{\beta}$	$C_{\beta}-C_{\gamma}$	$C_{\beta}-C_{\alpha}-C_{Me}$	$H_a-C_{\gamma}-C_{\beta}$	H_a-H	$C_{Me}-C_{\gamma}$
Axial	Ground	0	1.545	1.538	112.4	109.9	2.381	3.211
Axial	Distorted	1.18	1.547	1.538	108.4	110.3	2.266	3.135
Equatorial	Ground	0	1.540	1.537	111.7	109.1		
Equatorial	Distorted	1.21	1.540	1.338	107.7	109.2		

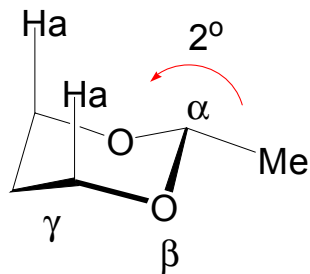
-Not Consistent with Steric Model

-Note: bending the angle outward is consistent with steric model

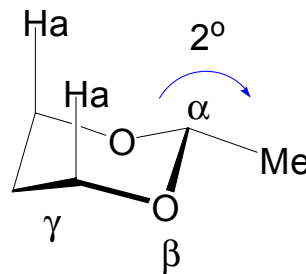
Testing the Steric Model: 2-Methyl-1,3-dioxane



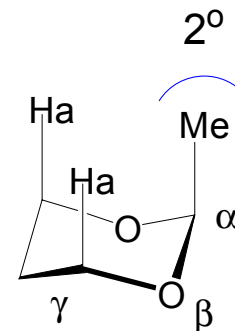
$$\Delta E = 0.37 \text{ kcal/mol}$$



$$\Delta E = 0.33 \text{ kcal/mol}$$



$$\Delta E = 0.35 \text{ kcal/mol}$$



$$\Delta E = 0.37 \text{ kcal/mol}$$

Parameters and Energetics (kcal/mol), Bond Lengths (Å) and Angles (deg.)

Conformation	State	ΔE	$C\alpha-O\beta$	$O\beta-C\gamma$	$O\beta-C\alpha-C_{Me}$	$H_a-C\gamma-O\beta$	H_a-H	$C_{Me}-C\gamma$
Axial	Ground	0	1.395	1.405	112.5	110.7	2.350	3.075
Axial	Distorted	0.37	1.420	1.427	110.6	111.0	2.277	3.052
Axial	Distorted	0.37	1.420	1.428	114.6	111.0	2.361	3.100
Equatorial	Ground	0	1.391	1.404	108.6	109.7		
Equatorial	Distorted	0.33	1.415	1.427	106.3	109.8		
Equatorial	Distorted	0.35	1.415	1.425	110.3	109.8		

- Expect greater steric interactions due to shorter C-O bonds
- Compression of $C\alpha-C\beta$ bond by 0.2 \AA leads to a smaller energy gap than expected
- Bending $O\beta-C\alpha-C_{Me}$ bond inward and outward does not show energetics consistent with steric model

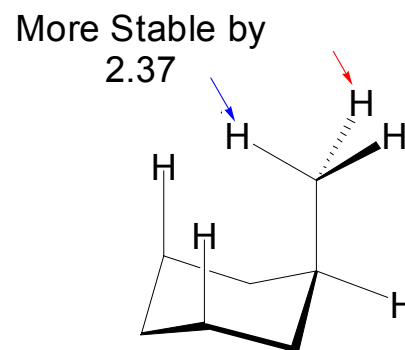
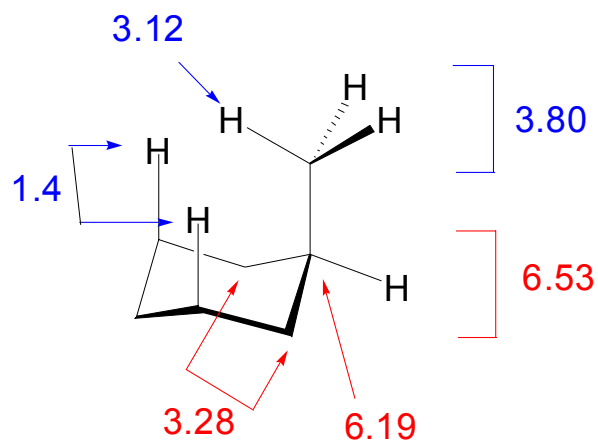
Methylcyclohexane, AIM Atomic Energies

The Role of Ring Strain

Structural optimizations were performed with Gaussian 94

AIMPAC was used to calculate AIM atomic energies

AIMPAC/AIM allows one to calculate the energetics of a part or a group of given structure



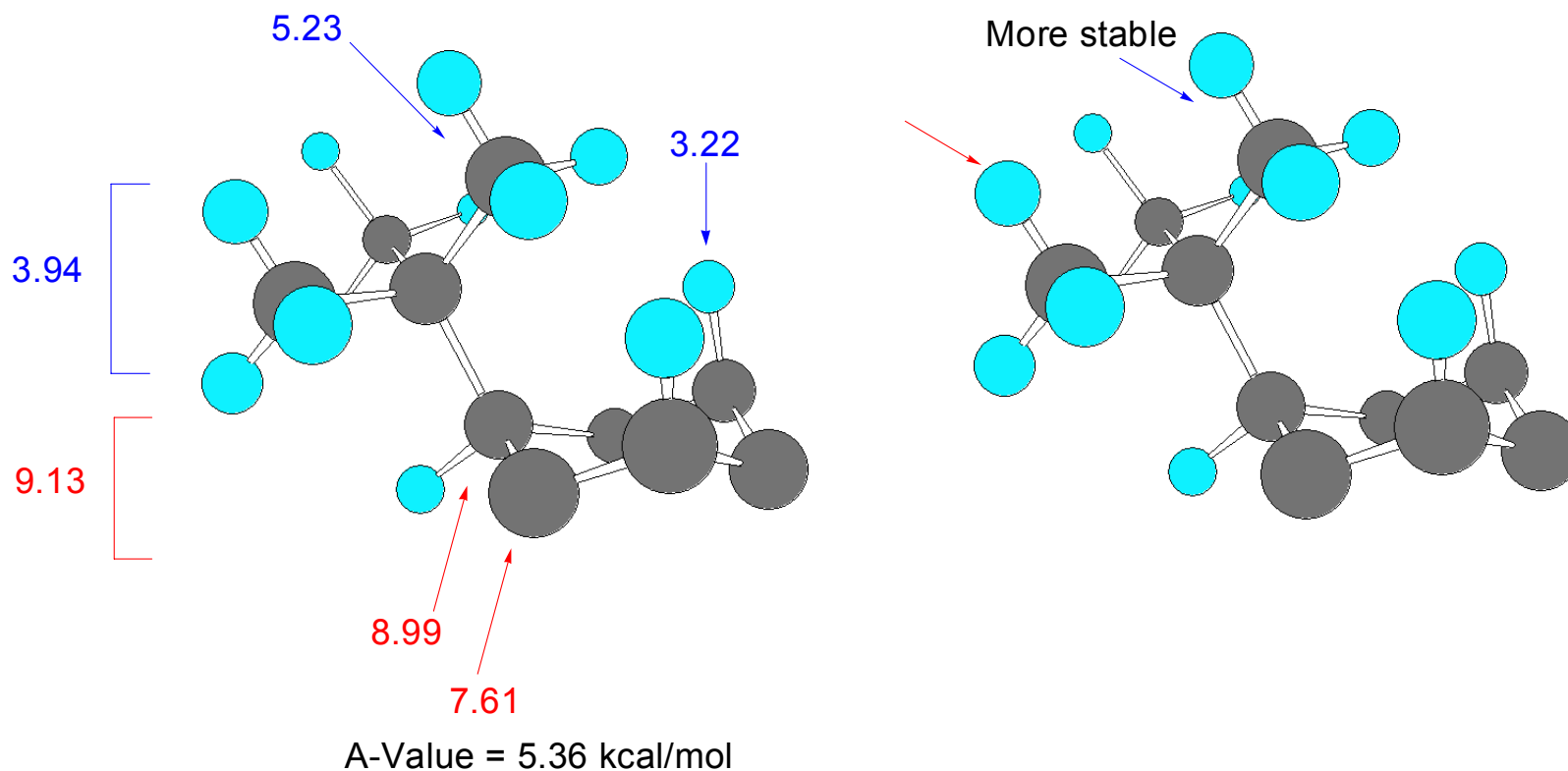
A-value = 1.8 to 2.2 kcal/mol

Energies (kcal/mol) are the comparison of the equatorial versus axial energy differences of the indicated group or atom

Energies in **Blue** correspond to **stabilization** (lower energy) relative to the equatorial conformer, energies in **Red** indicate **destabilization** (higher energy) relative to the equatorial conformer

t-Butylcyclohexane, AIM Atomic Energies

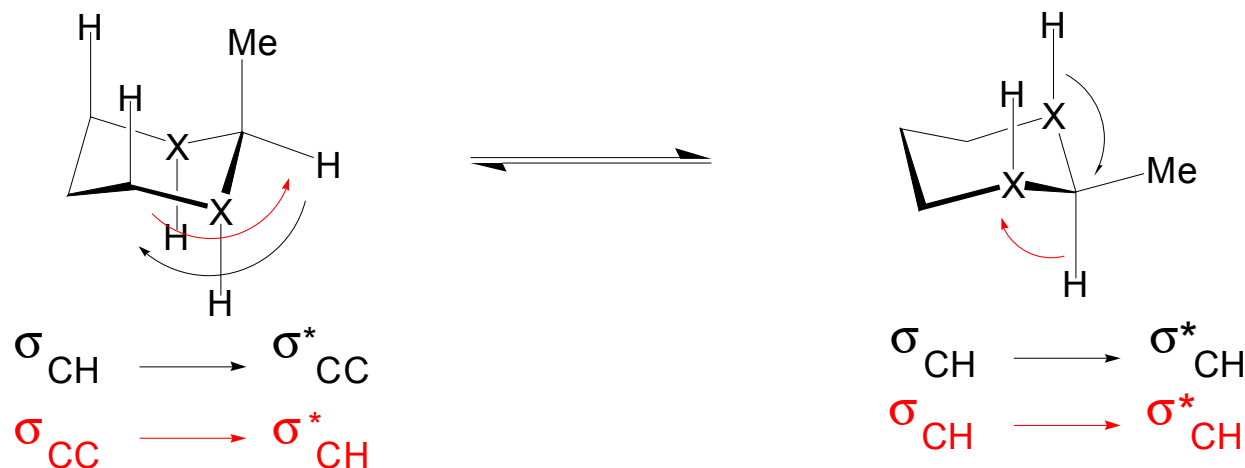
The Role of Ring Strain



Energies (kcal/mol) are the comparison of the equatorial versus axial energy differences of the indicated group or atom

Energies in **Blue** correspond to **stabilization** (lower energy) relative to the equatorial conformer, energies in **Red** indicate **destabilization** (higher energy) relative to the equatorial conformer

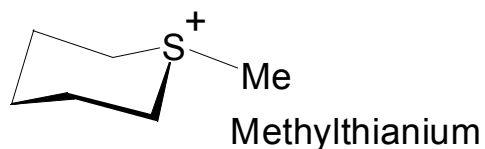
Alternate Explanation For Equatorial Preference



-Following Alabugin's results, $\Sigma E(\text{del})_{\text{Hax}} > \Sigma E(\text{del})_{\text{Heq}}$, Authors propose that the equatorial preference is a reflection, or partly due, to the axial preference for the methine hydrogen due to greater hyperconjugative interactions

-The proposition offers an alternative explanation for the trend of conformational energies of halocyclohexanes, E_{CX} ; $\text{Br} < \text{Cl} < \text{F}$. The trend is due, or partly due to the order of acceptor abilities of the anti-bonding C-X orbitals.

-The explanation also provides a rationale for the low conformational energy of methylthianium. It does not have an acceptor orbital to stabilize the equatorial conformation.



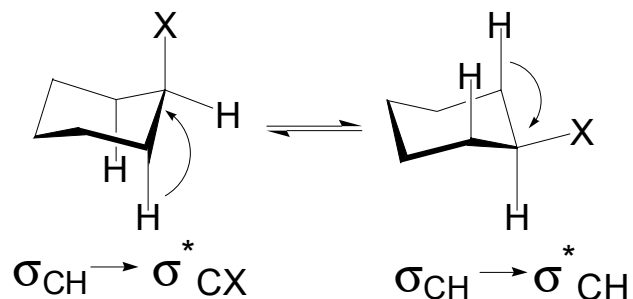
Riberiro, D. S.; *J. Org. Chem.*, **2003**, *68*, 6780

Alabugin, I. V.; *J. Org. Chem.* **2000**, *65*, 3910

Alternate Explanation For Equatorial Preference

Testing Ribeiro's Hypothesis

Is there a relationship between the acceptor abilities of substituents on substituted cyclohexane and conformational energies?

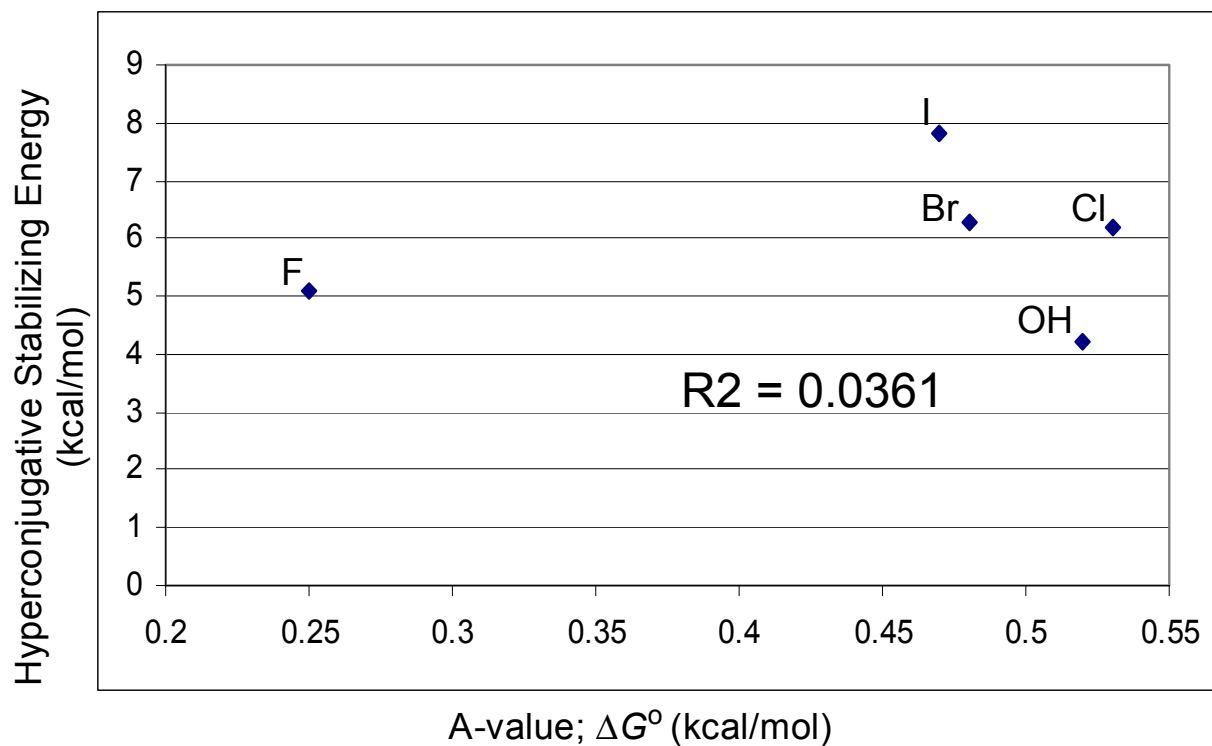


If there is, than one should see a correlation between A values and the acceptor abilities of C-X bonds

Result:

No correlation, but not so fast...

Plot of A-values vs Hyperconjugative Stabilizing Energy



Note, acceptor orbital energies are taken from Alabugin ethane calculations

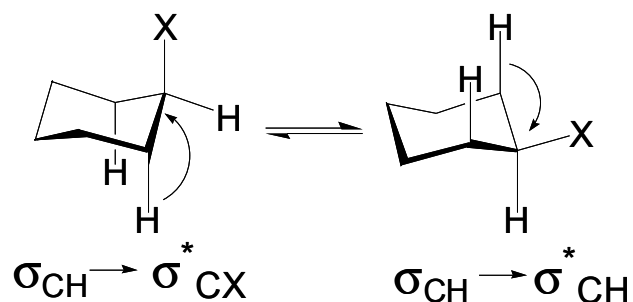
A-values: D. A. Evans, *Chem. 206* notes, **2001**, lecture 6.

Acceptor Energies: Alabugin, I. V.; *J. Am. Chem. Soc.*, **2002**, 3175

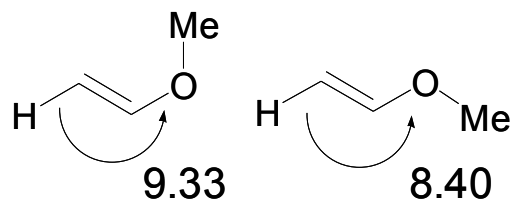
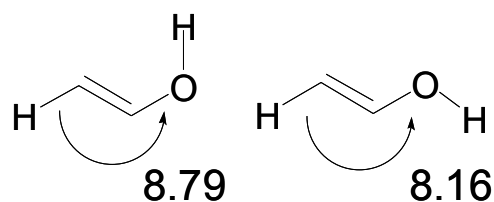
Alternate Explanation For Equatorial Preference

Testing Ribeiro's Hypothesis

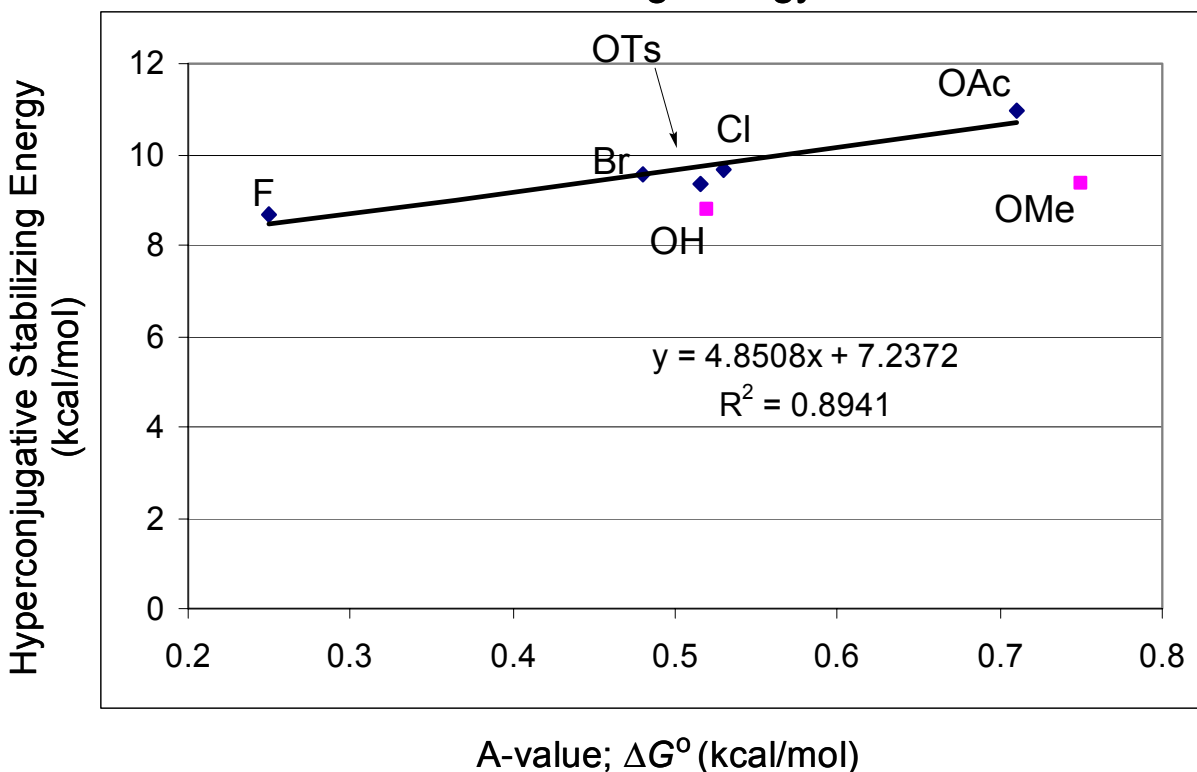
Same analysis, but using the acceptor orbital values from the ethene calculations



Note: OH and OMe change their acceptor orbital abilities depending on their conformations.



Plot of A-values vs Hyperconjugative Stabilizing Energy

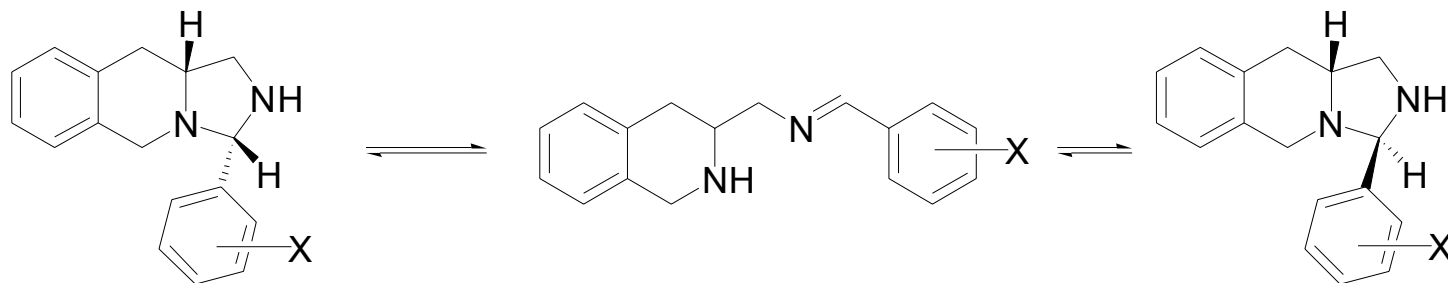


A-values: D. A. Evans, *Chem. 206* notes, **2001**, lecture 6.
March. S.; *Advanced Organic Chemistry*, **2001**

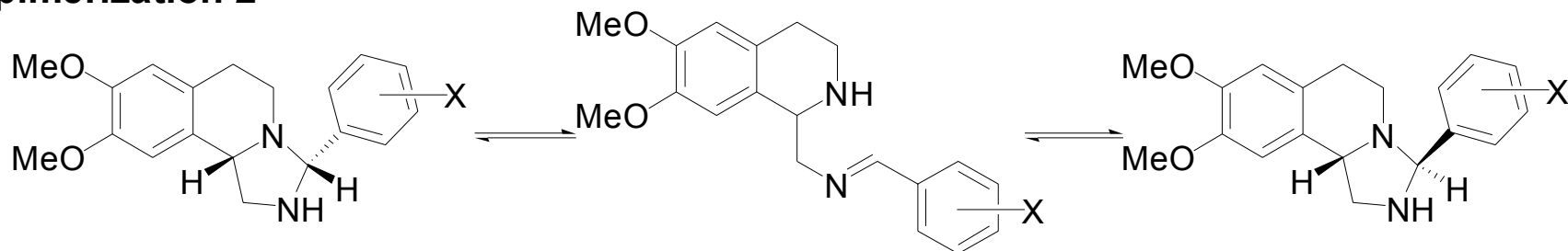
Acceptor Energies: Alabugin, I. V.; *J. Am. Chem. Soc.*, **2002**, 3175

Epimerization Equilibrium of 2-Aryl-1,3-*N,N*-Heterocycles

Epimerization 1



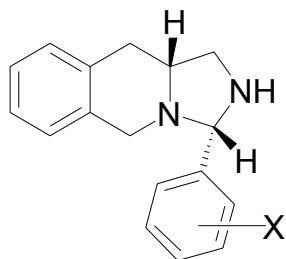
Epimerization 2



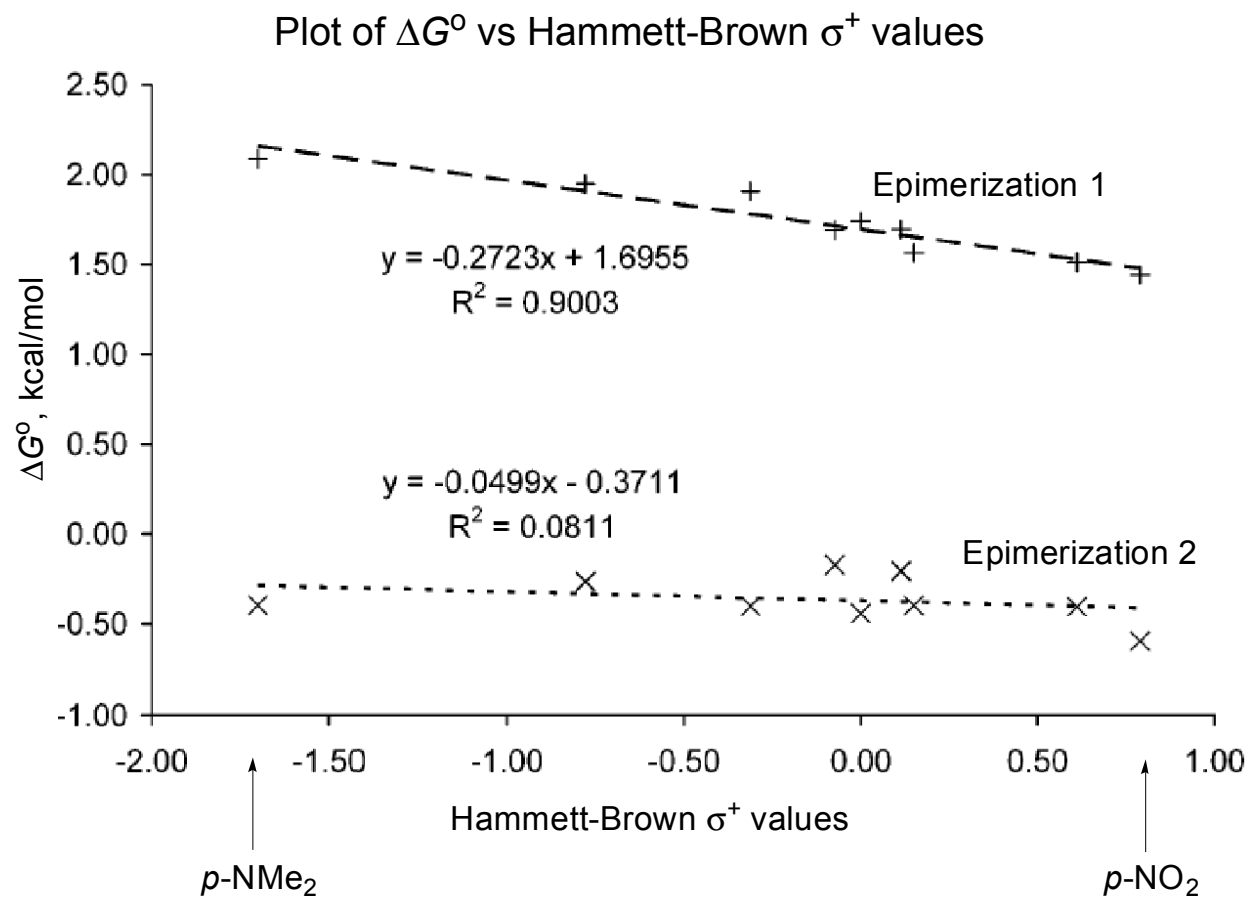
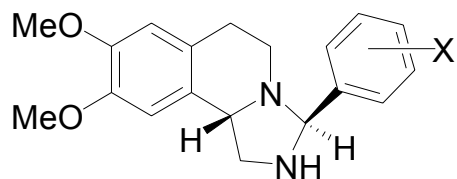
X = *p*-NO₂, *p*-CF₃, *p*-Br, *p*-Cl, H, *p*-F, *p*-Me, *p*-OMe, *p*-NMe₂

Epimerization Equilibrium of 2-Aryl-1,3-*N,N*-Heterocycles

Epimerization 1



Epimerization 2



Epimerization Equilibrium of 2-Aryl-1,3-*N,N*-Heterocycles

Second-order perturbation analysis of the Fock matrix, NBO basis

Stabilization energy from a single donor-acceptor interaction

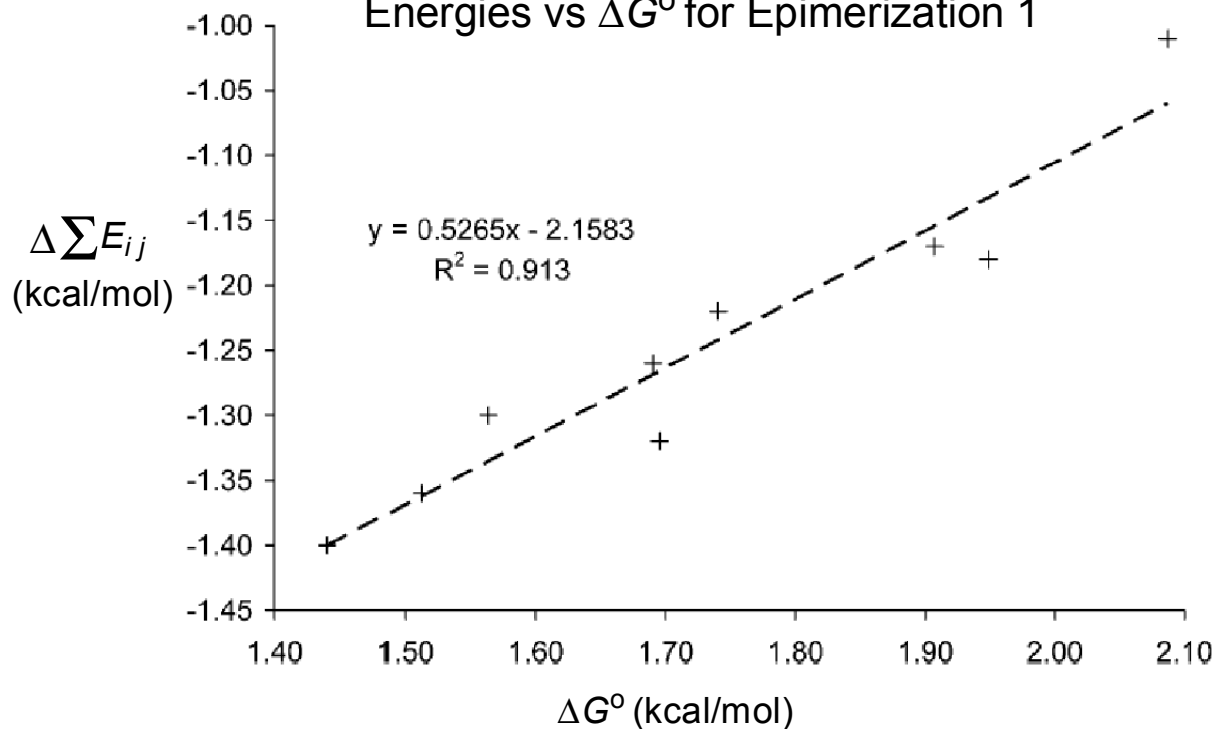
$$E(2)_{ij} = -\eta_{\sigma} \frac{(\sigma/F/\sigma^*)^2}{\epsilon_{\sigma^*} - \epsilon_{\sigma}} = -\eta_{\sigma} \frac{F_{ij}^2}{\Delta E}$$

Difference in Hyperconjugative Stabilization Energies in the Epimerization Equilibrium

$$\Delta \sum E_{ij} = \Delta \sum E_{ij}^R - \Delta \sum E_{ij}^L$$

R and L denotes right and left sides of the epimerization equilibrium

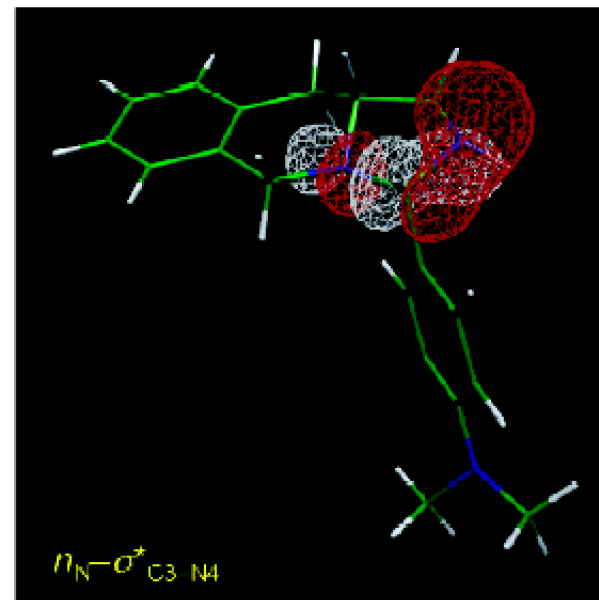
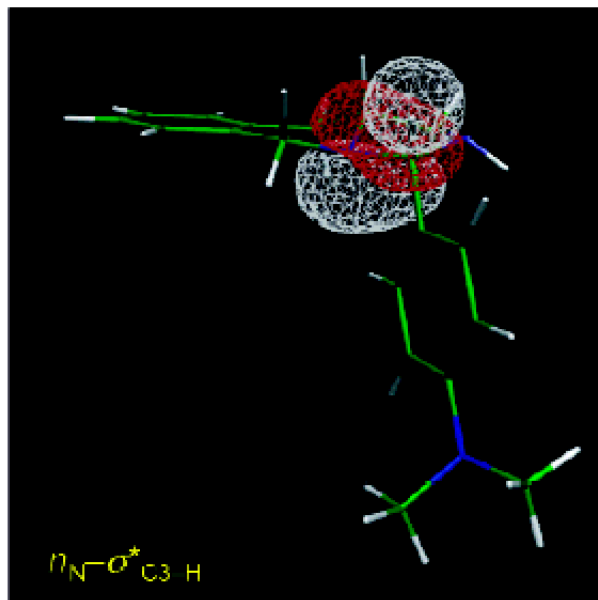
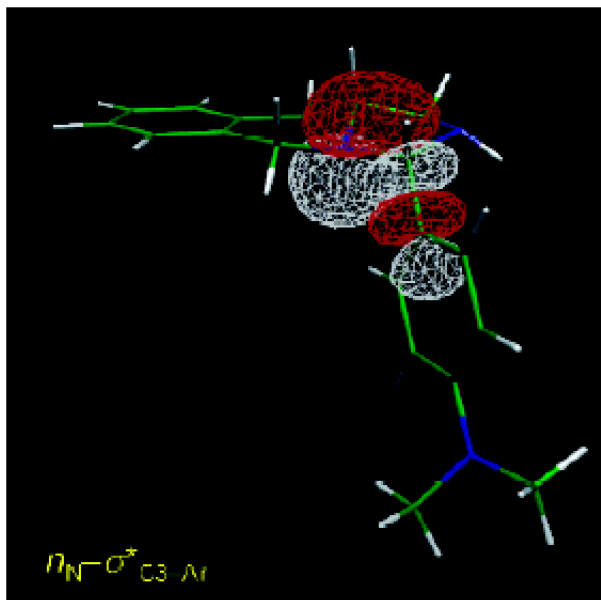
Plot of Theoretical Stereoelectronic Stabilization Energies vs ΔG° for Epimerization 1



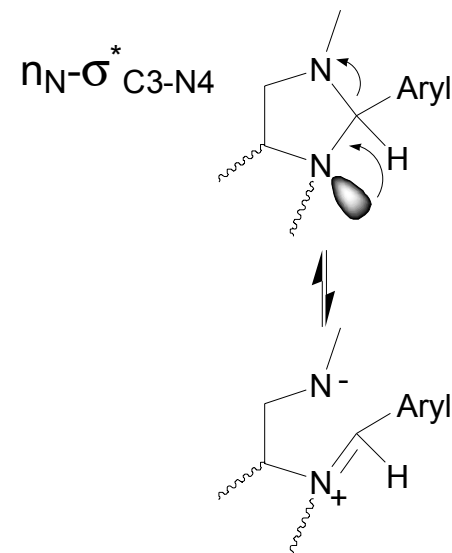
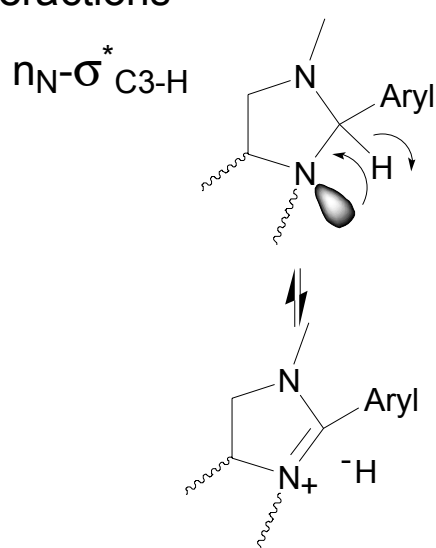
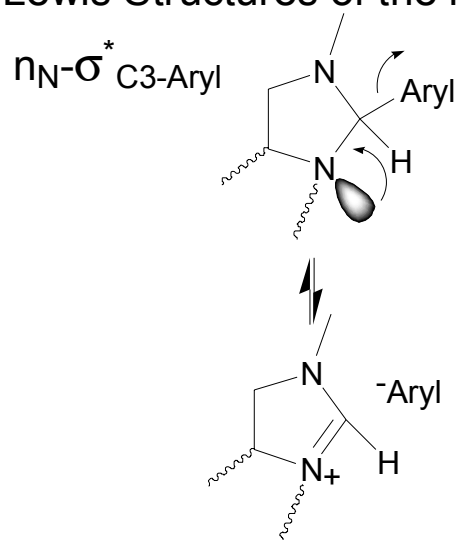
-A similar plot for Epimerization 2 displays an R^2 value of 0.1202

Epimerization Equilibrium of 2-Aryl-1,3-*N,N*-Heterocycles

The relevant hyperconjugative stabilizing interactions for Epimerization 1

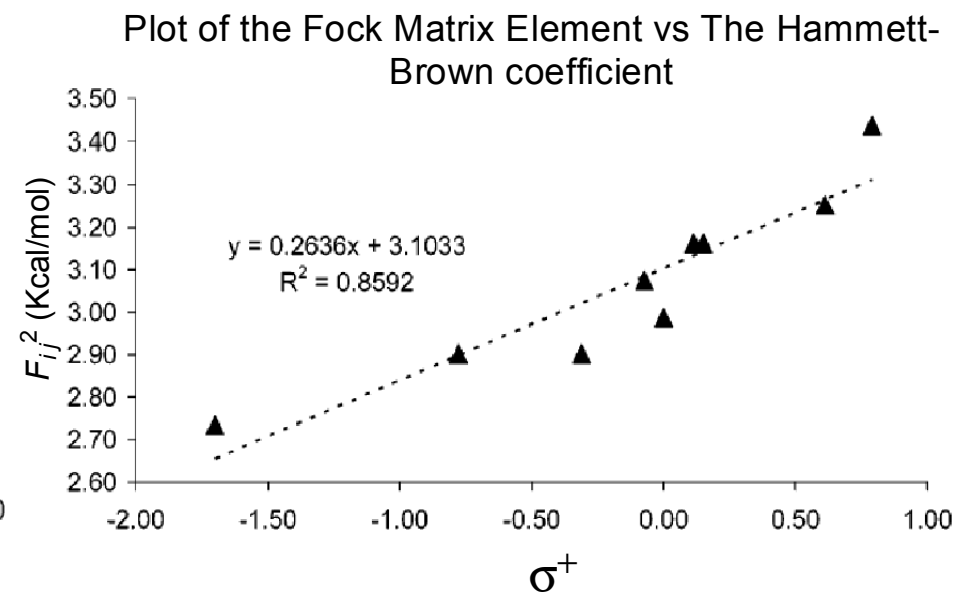
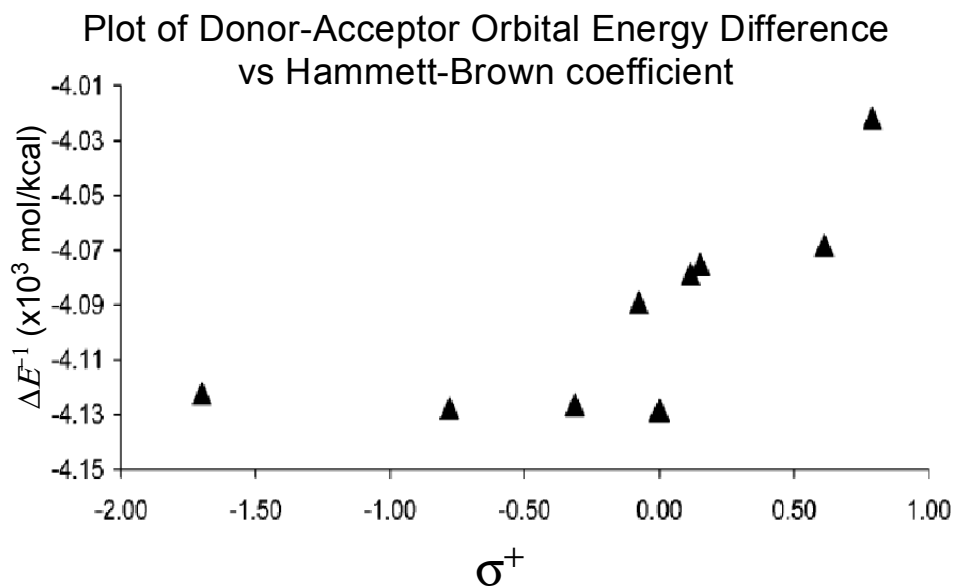


Lewis Structures of the relevant interactions



Epimerization Equilibrium of 2-Aryl-1,3-*N,N*-Heterocycles

Role of donor-acceptor energy difference and Fock matrix element



$$E(2)_{ij} = -\eta_{\sigma} \frac{F_{ij}^2}{\Delta E}$$

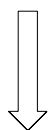
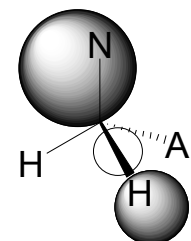
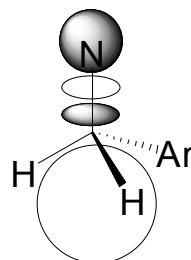
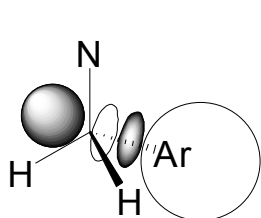
-Delocalizing interaction energies are more dependent upon the Fock matrix element, due to the higher changes in the Fock matrix energetics relative to the donor acceptor energy difference terms.

Epimerization Equilibrium of 2-Aryl-1,3-*N,N*-Heterocycles

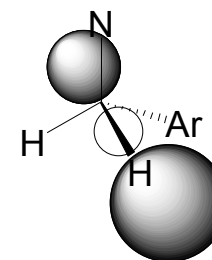
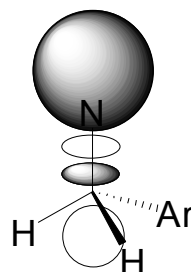
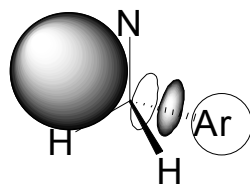
Role of bond polarization in hyperconjugative stabilization

Graphical Representation of the Polarization Coefficients on C3

p-NMe₂



p-NO₂



$\sigma^*_{\text{C-Ar}}$

$\sigma^*_{\text{C-N}}$

$\sigma^*_{\text{C-H}}$

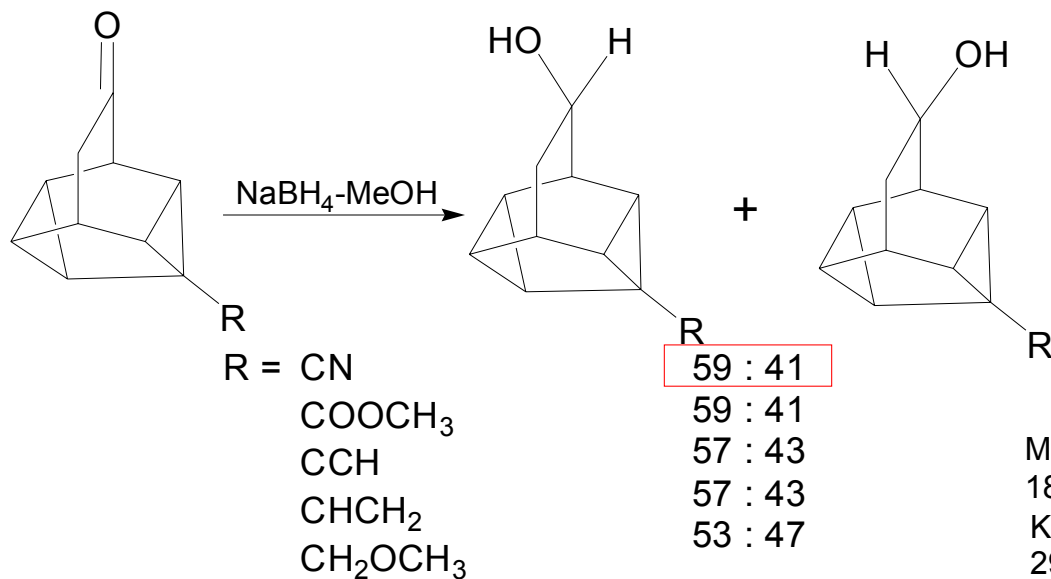
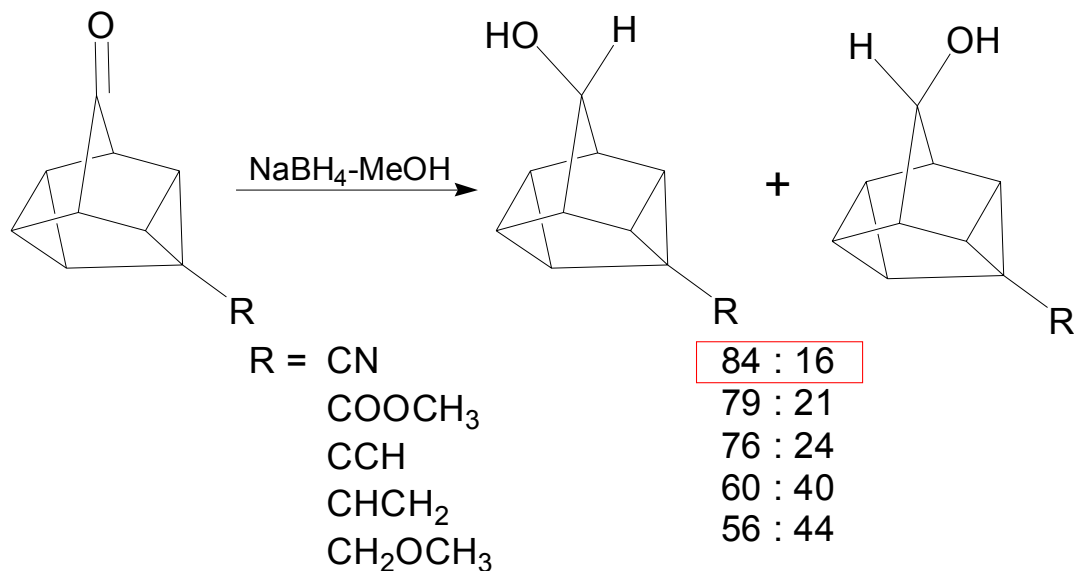
- F_{ij} is correlated with the overlap matrix element S_{ij} and acceptor orbital polarization

-Conformational changes of the heterocycles are around 1°

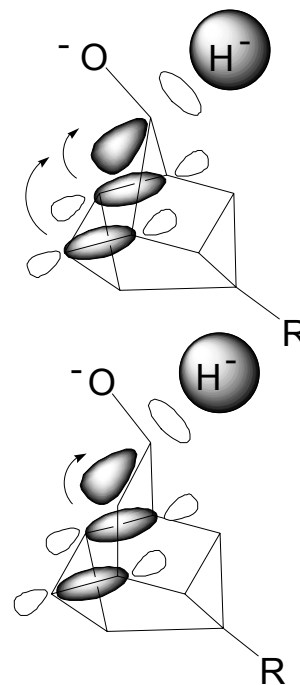
-Bond polarization change of $\sigma^*_{\text{C3-Aryl}}$ and the *decrease of the other two interactions* accounts for the stabilization energies and the observed epimerization equilibrium

The Cieplak Model: Recent Advances

Recent Literature Example: Reduction of Snoutanones and Adamantanones



Cieplak's Model



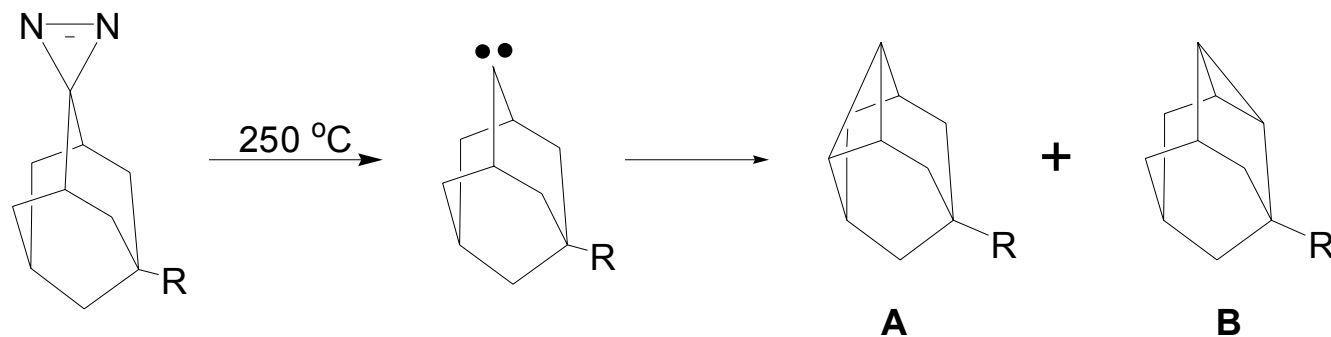
FMO prohibits such an interaction. The interactions should weaken and elongate the forming bond in the transition state

Mehta, G.; *J. Chem. Soc., Perkin Trans. 1*, **1998**, 1895

Kaneno, D.; Tomoda, S.; *Org. Lett.*, **2003**, 2947-2949

The Cieplak Model: Alternate Explanation

Carbenes: Experimental Results

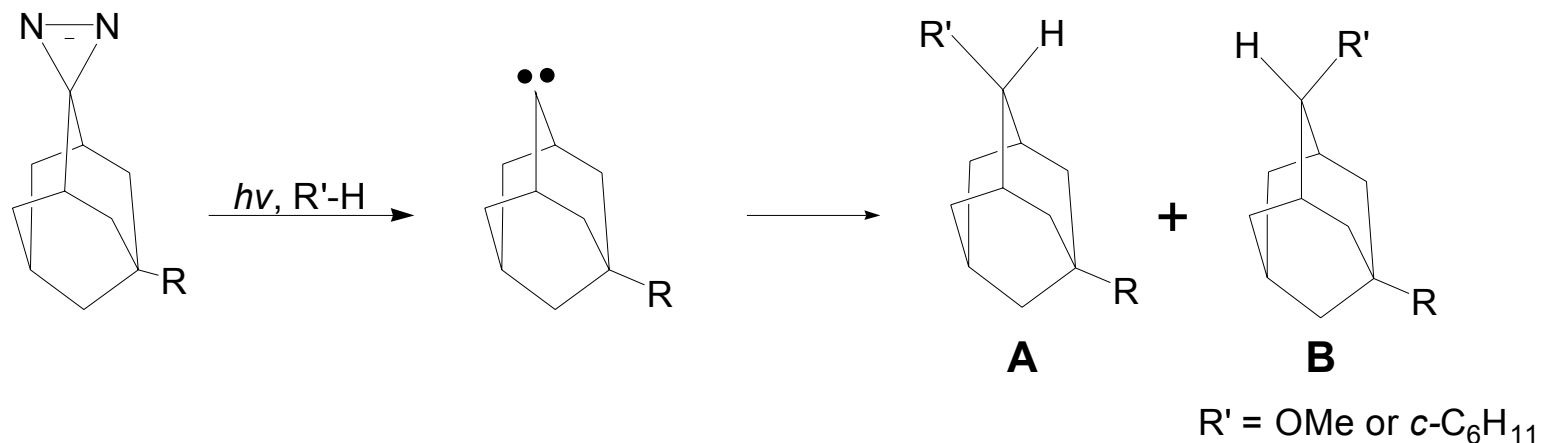


R	Ratio A : B
OH	90 : 10
NH ₂	80 : 20
Si(CH ₃) ₃	26 : 74

Note: the exact mechanism of carbene insertion is not known, but above results appear to contradict Cieplak's Model

The Cieplak Model: Alternate Explanation

Carbenes: Experimental Results



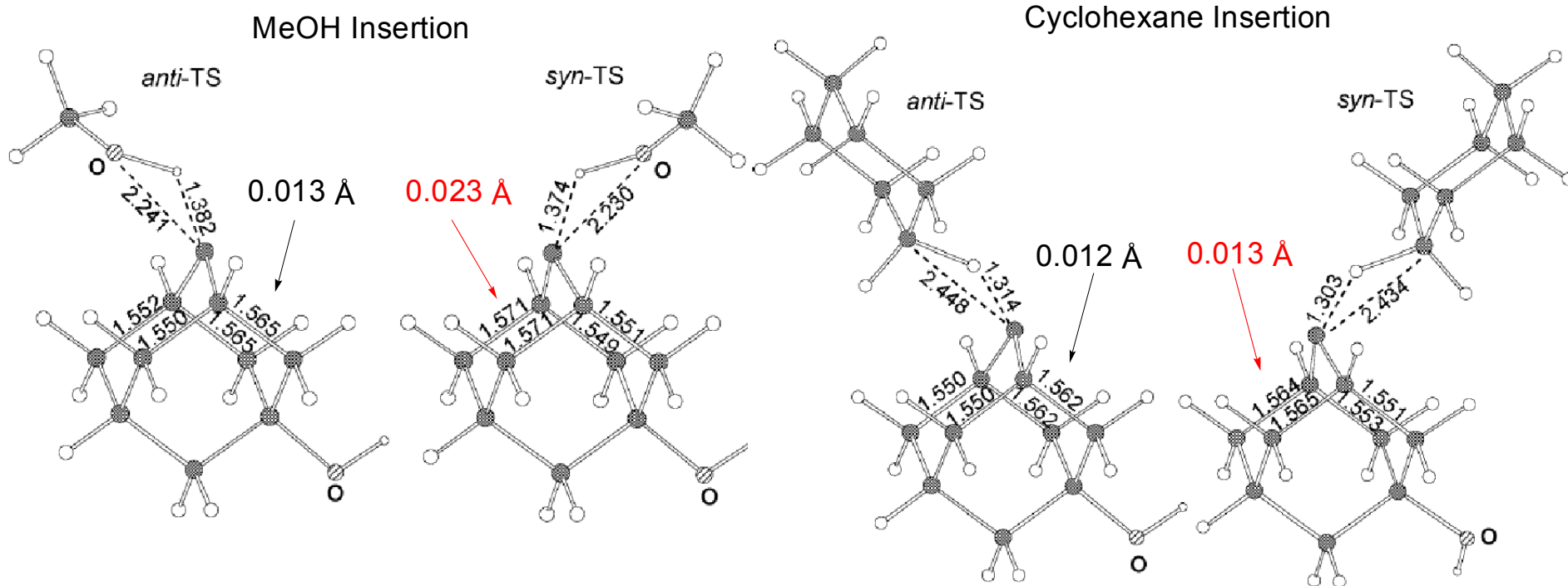
R	Solvent	Ratio A : B
OH	MeOH	15 : 85
NH ₂	MeOH	15 : 85
Si(CH ₃) ₃	MeOH	69 : 31
OH	<i>c</i> -C ₆ H ₁₂	15 : 85
NH ₂	<i>c</i> -C ₆ H ₁₂	15 : 85
Si(CH ₃) ₃	<i>c</i> -C ₆ H ₁₂	69 : 31

Similar results with polar and nonpolar solvents discount electrostatic control of substrate's orientation

The Cieplak Model: Alternative Explanation

Carbenes: Tomoda's Calculations

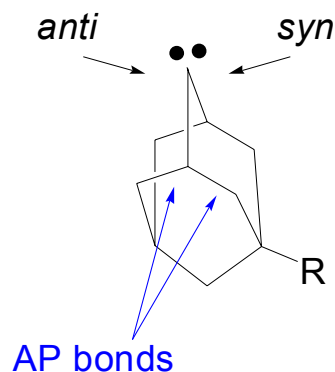
Tomoda's Calculated Transition States:



- Numbers show the difference in bond length from the indicated bonds and the corresponding bonds on the opposite side of the molecule
- Longer bond lengths correspond to greater anti-periplanar anomeric effect
- Support Cieplak's Model??

The Cieplak Model: Alternate Explanation

Carbenes: Tomoda's Calculations



AP Bond Lengths and Bond Populations

R	TS	Bond Elongation (Å)			Bond Population (e)		
		GS	TS	%BE	GS	TS	ΔBP
<i>Methanol</i>							
H	NA	1.580	1.571	-0.55	1.924	1.932	+0.008
OH	anti	1.571	1.565	-0.35	1.924	1.934	+0.005
	syn	1.582	1.571	-0.68	1.919	1.930	+0.011
TMS	anti	1.587	1.577	-0.59	1.920	1.928	+0.008
	syn	1.576	1.568	-0.49	1.927	1.933	+0.007
<i>Cyclohexane</i>							
H	NA	1.580	1.565	-0.92	1.924	1.944	+0.020
OH	anti	1.571	1.562	-0.55	1.929	1.942	+0.012
	syn	1.581	1.565	-1.06	1.920	1.943	+0.023
TMS	anti	1.586	1.568	-1.15	1.919	1.942	+0.023
	syn	1.577	1.562	-0.94	1.924	1.944	+0.020

-Bond lengths *decrease* and bond populations *increase* from going from GS to TS

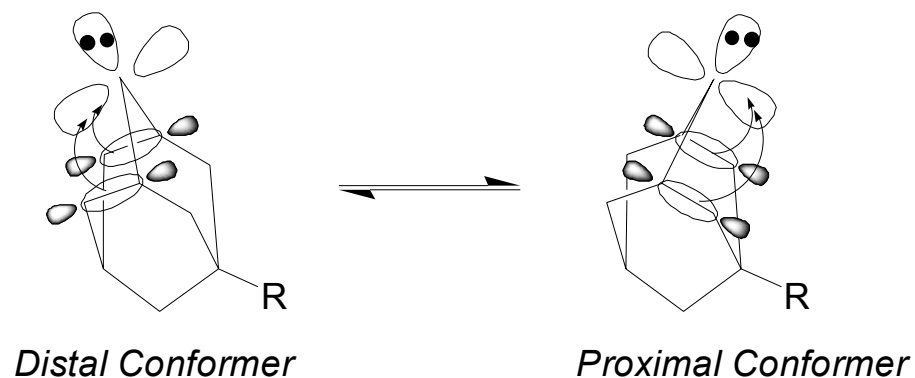
-The analysis shows that the AP effect actually *decreases* in the TS, and the AP effect *destabilizes* the TS

-These results are *inconsistent* with Cieplak's and Anh's models

The Cieplak Model: Alternative Explanation

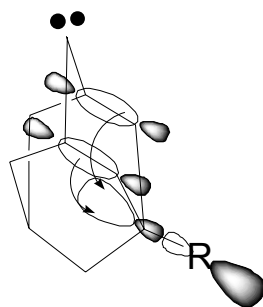
Carbenes: Bending of the Carbene carbon

The bending Model



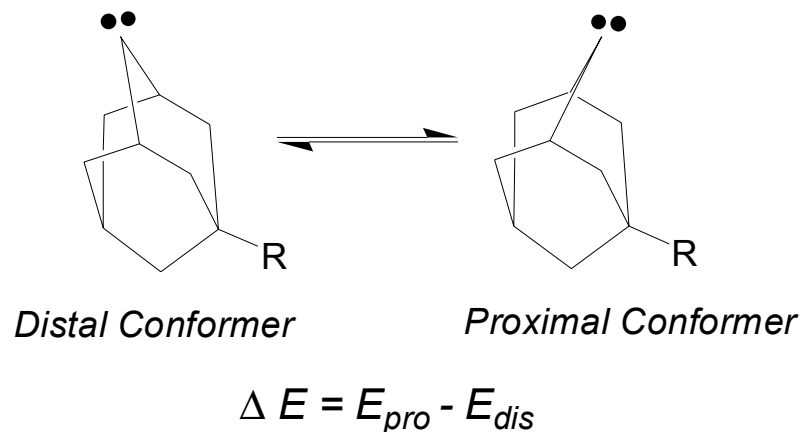
The substituent Role

- a) induction
- b) hyperconjugation



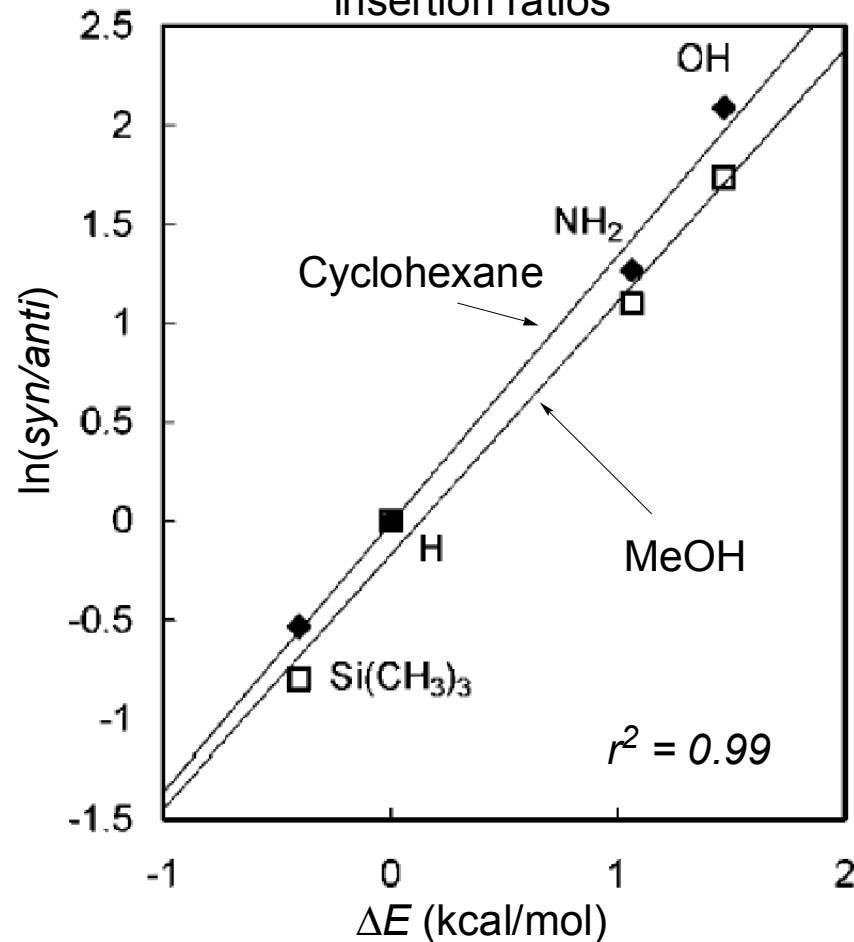
The Cieplak Model: Alternative Explanation

Carbenes: Bending of the Carbene Bridge



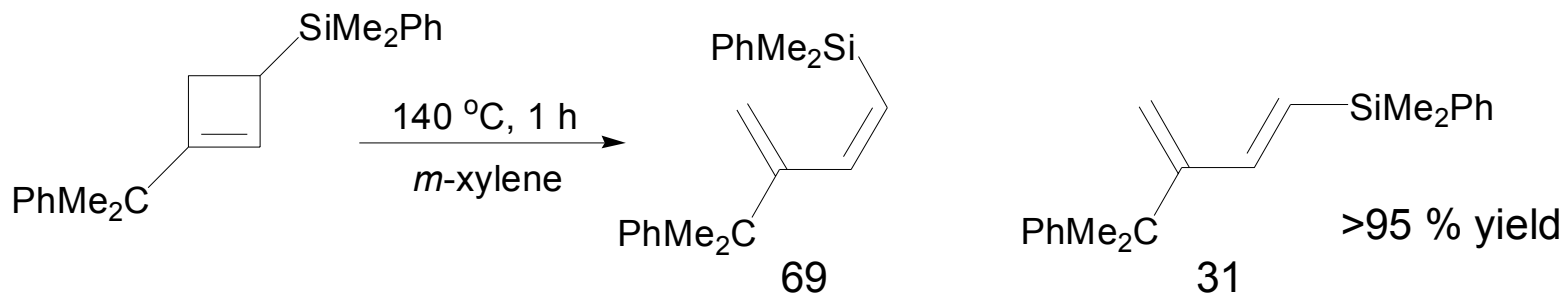
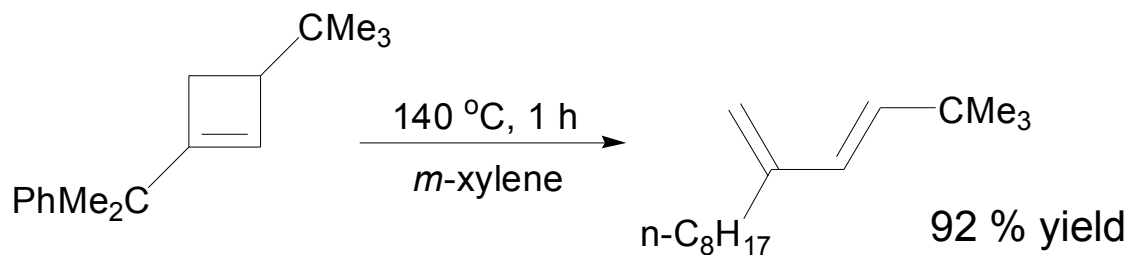
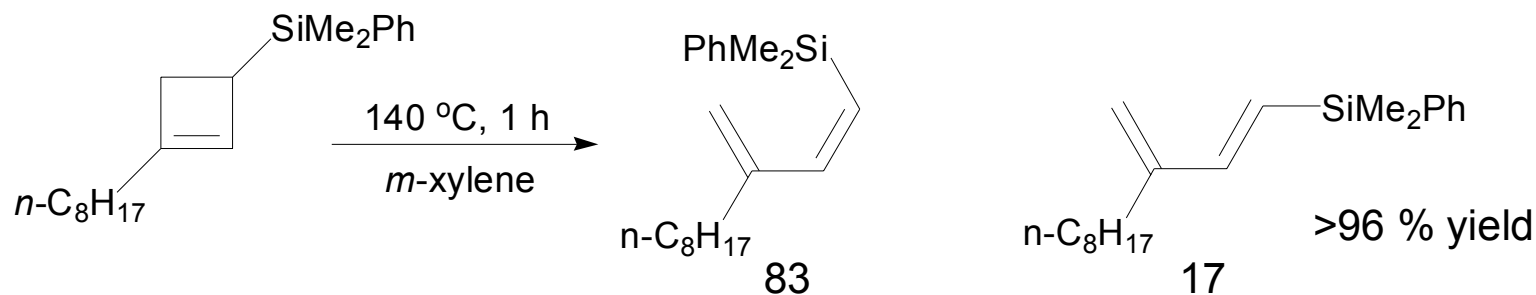
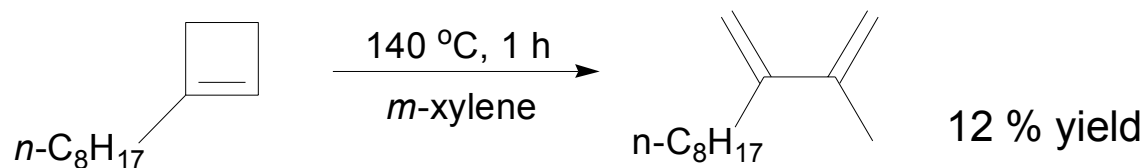
- Calculations performed on *Gaussian 98*

Plot of Difference in Energy of the Proximal and Distal conformers vs Ln of the observed insertion ratios



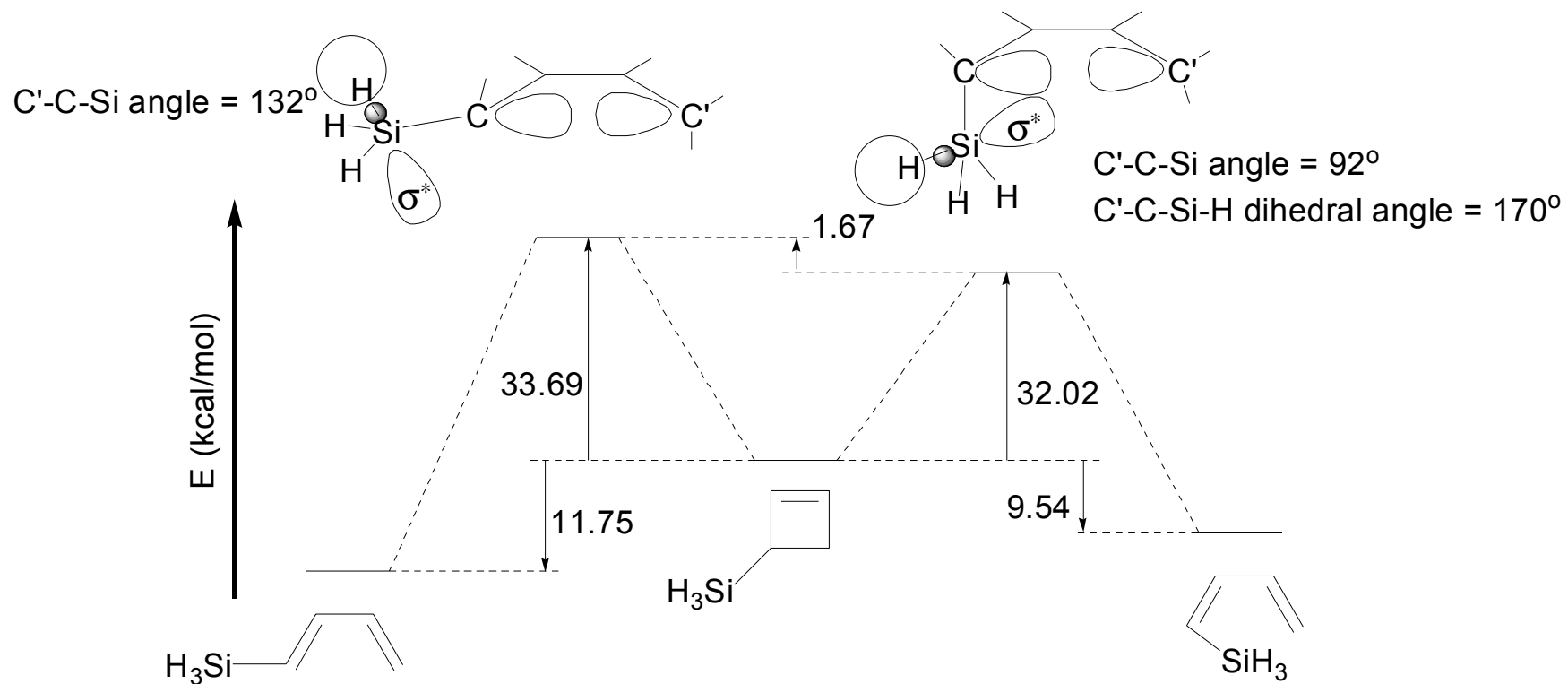
Recent Stereoelectronic Effects

Silyl Effects on Ring-Opening Reactions of Cyclobutenes



Recent Stereoelectronic Effects

Silyl Effects on Ring-Opening Reactions of Cyclobutenes



Cautions with using FMO

Anh's Warnings

- FMO gives good predictions in ~80 % of the cases studied by Anh
- FMO should only be applied when the following conditions are met:
 - Only apply FMO to the transition states (in most cases)
 - Apply FMO only to systems in which the FMO are well separated from other MO
 - Apply FMO to systems that can be described by a single electronic configuration
 - Only compare systems that are similar and undergoing the same reaction
(Ethane and ethene acceptor orbital abilities are different)
- Almost all violations of FMO theory occur when these restrictions are not met

Conclusions

-The hyperconjugative interactions due to σ -bonds are relevant.

These interactions have shown importance in bond lengths, NMR coupling constants, appear to be involved in conformational energies, and transition state energies

-All three terms of the Fock matrix equation need to be considered to account for the hyperconjugation interactions.

F_{ij} (orbital orientation and proximity and polarizations) and ΔE (HOMO and LUMO energy levels separation)

-NBO analysis ($E(\text{del})$ or $E(2)$ methods) provides an estimate of the hyperconjugative interactions allowing one to quantitatively unravel their relative importance.

-Hyperconjugative interactions due to σ -bonds are relatively weak. These interactions should be considered but other interactions can be more important