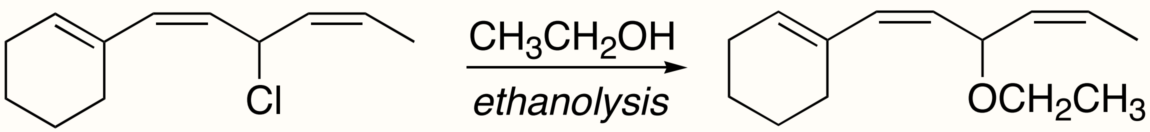
Lecture 21
Organic Chemistry 1

Professor Duncan Wardrop

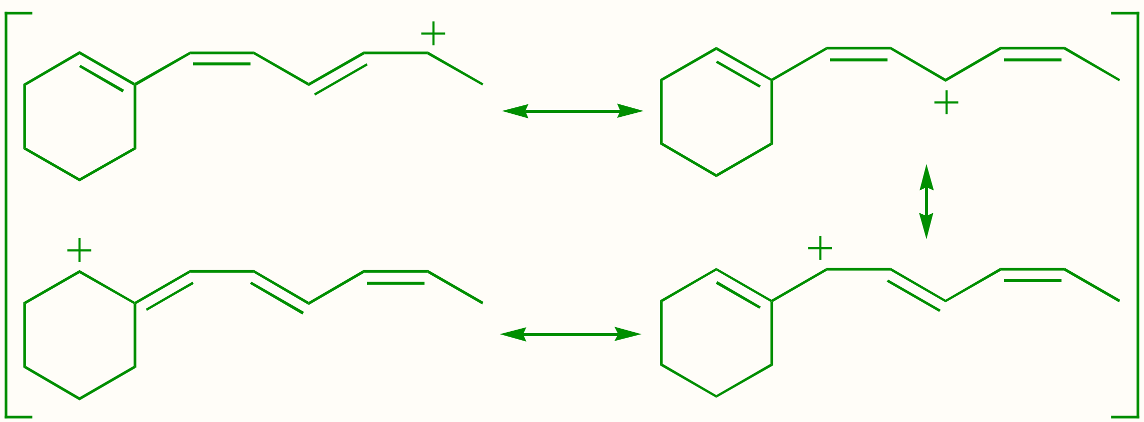
March 30, 2010

Self Test Question

Ethanolysis of alkyl halide **1** gives ether **2** as one product; however, several other constitutional isomers of **2** are also isolated. Which of the following structures can not be one of those products? *Hint: The carbocation intermediate is stabilized by resonance. Draw all possible resonance structures to determine which carbons are electrophilic.*



1 **2**



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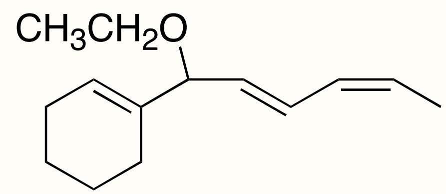

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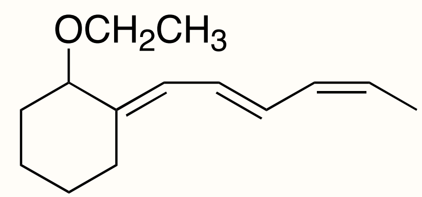

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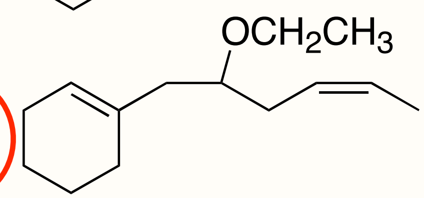

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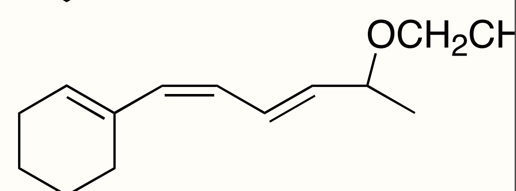

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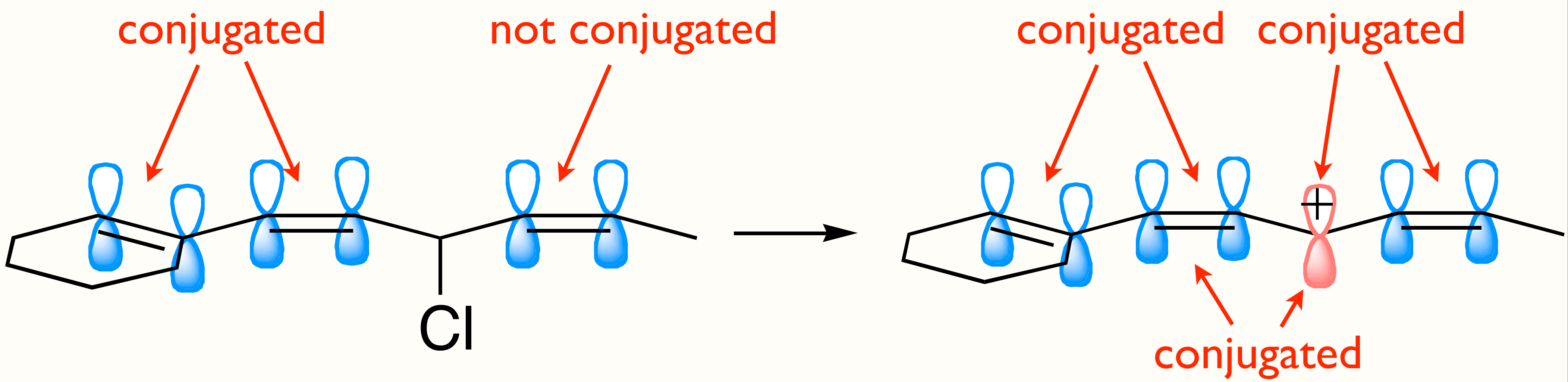
Chapter 10
Conjugation in Alkadienes & Allylic Systems

Sections Sections 10.1-10.2

Conjugation

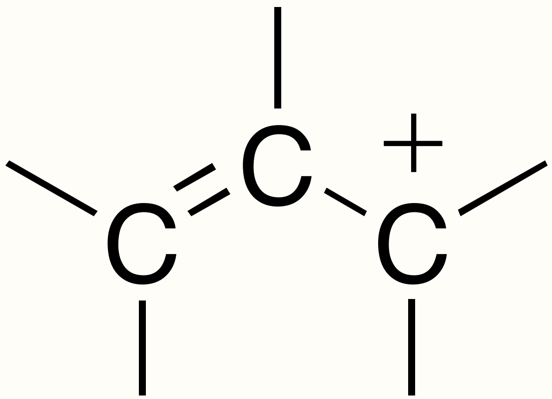
conjugare = latin verb: to link or yoke together



- π-system = contains p-orbitals
- conjugation: overlap between adjacent π-systems
- π-systems must be adjacent in order to overlap

Conjugated π-Systems

allylic carbocation: carbocation adjacent to a vinyl group



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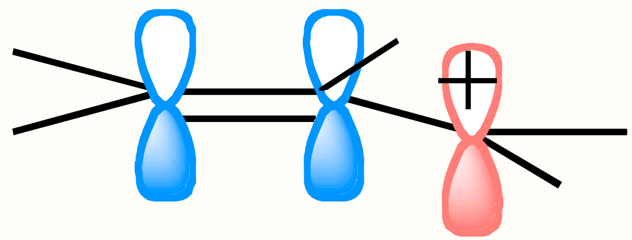
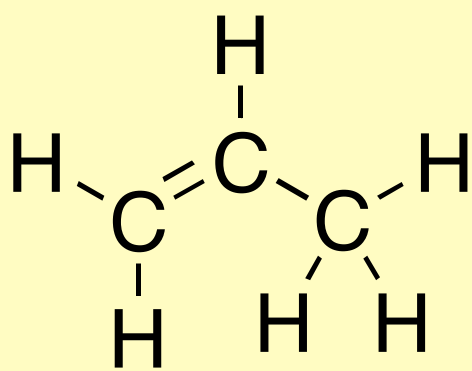


Review: Allyl Group



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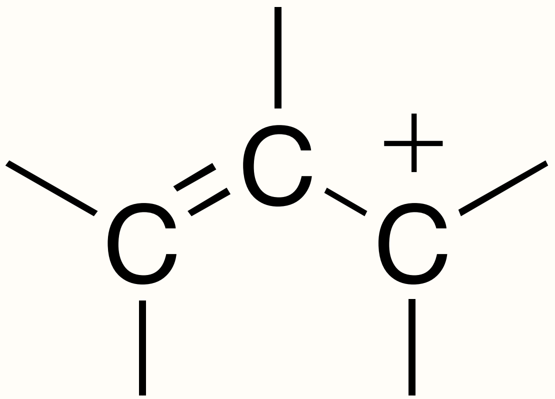

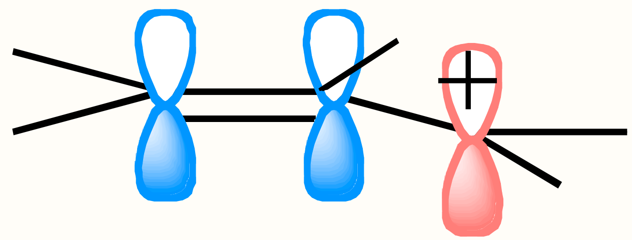

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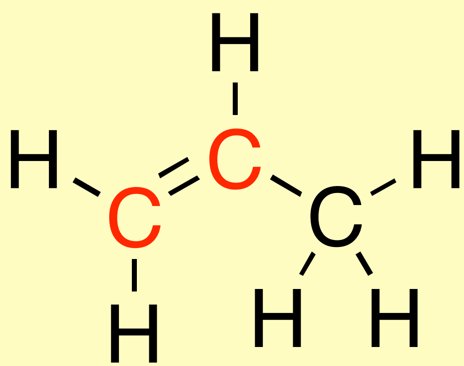

vinylic carbons

Conjugated π-Systems

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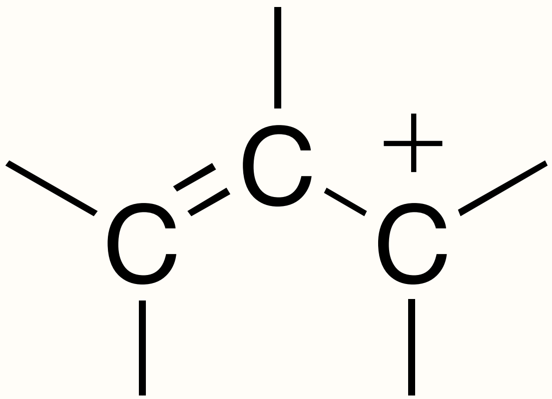

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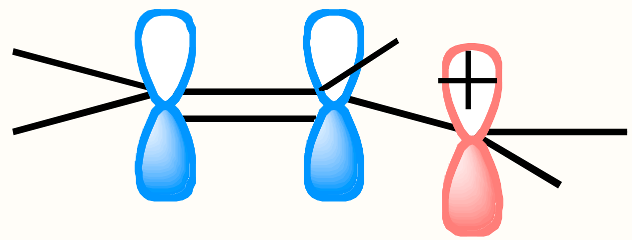

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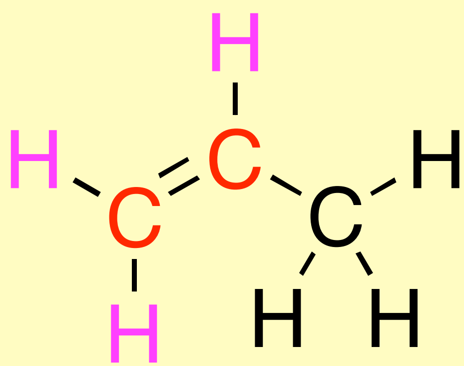

vinylic carbons

vinylic hydrogens

Conjugated π-Systems

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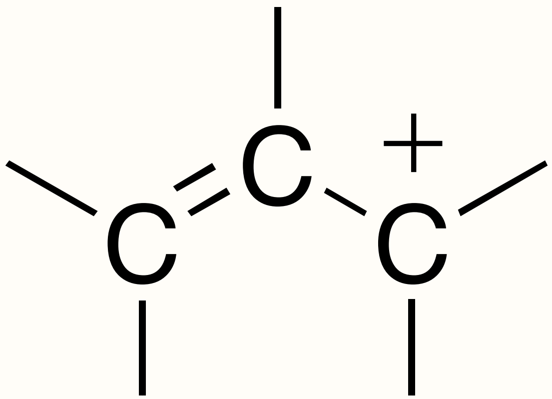

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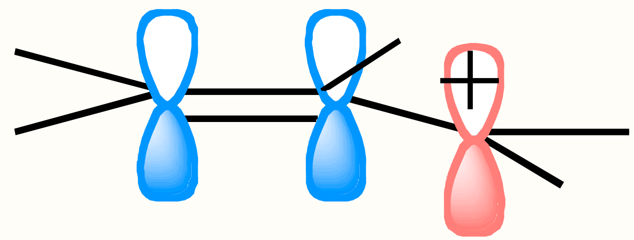

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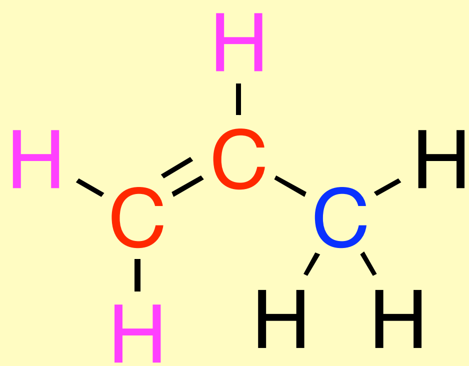


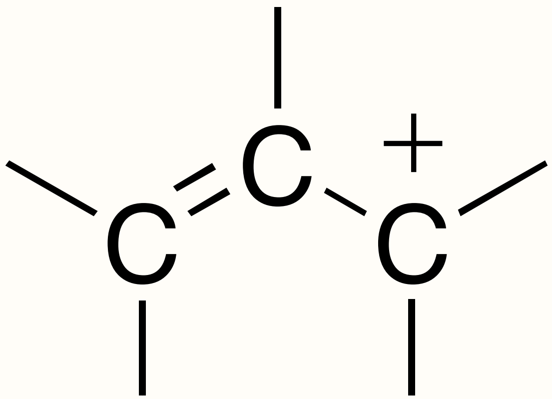
vinylic carbons

vinylic hydrogens

allylic carbon

Conjugated π-Systems

allylic carbocation: carbocation adjacent to a vinyl group



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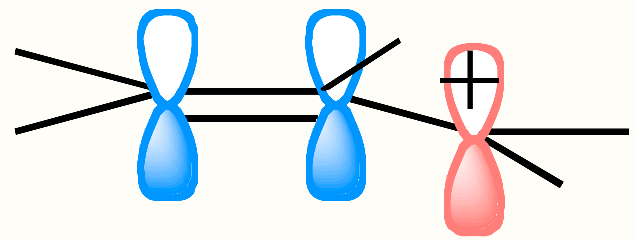

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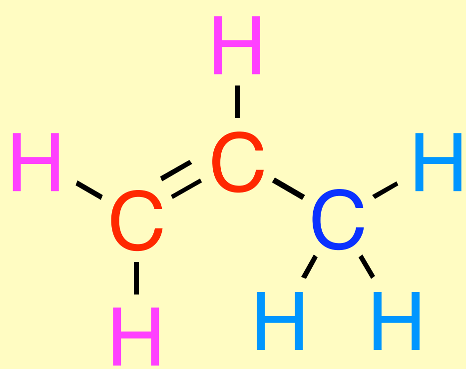


vinylic carbons

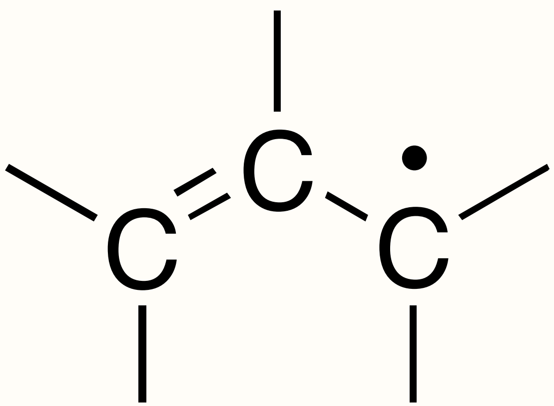
vinylic hydrogens

allylic carbon

allylic hydrogens

Conjugated π-Systems

allylic radical: radical adjacent to a vinyl group



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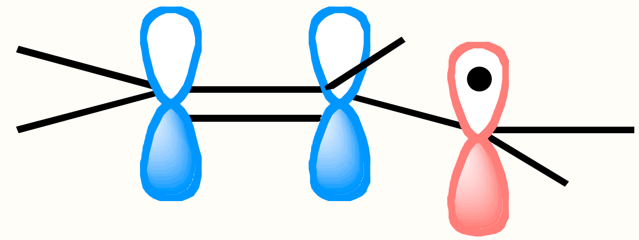
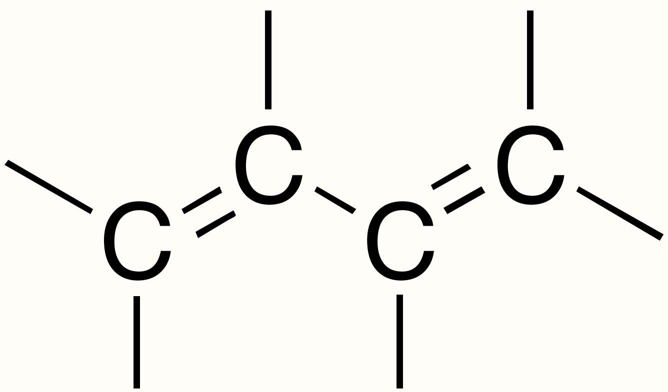


Conjugated π-Systems

conjugated alkadienes: two adjacent vinyl groups (alkenes)



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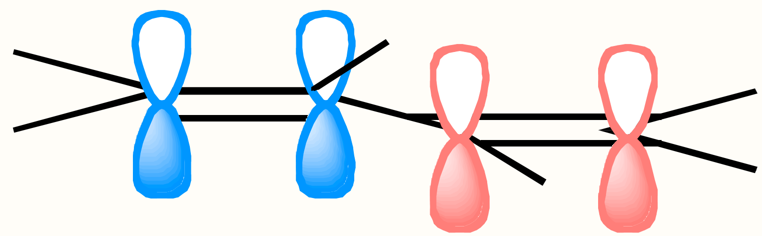
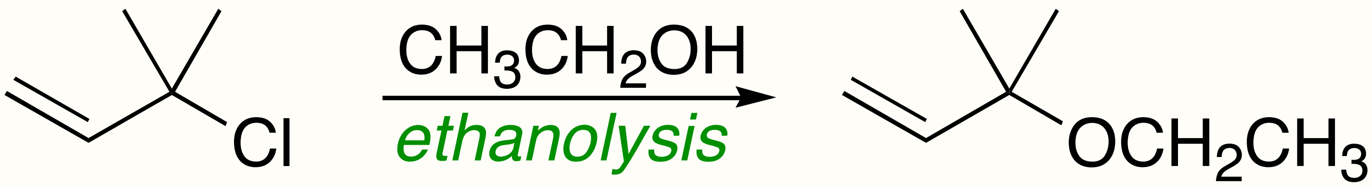
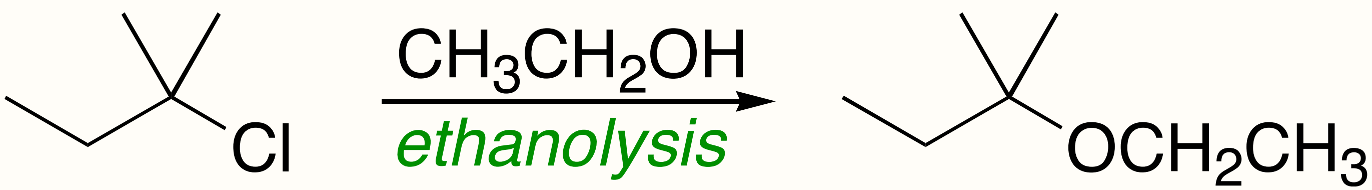


Allylic alkyl chlorides undergo S_N1 substitution faster than saturated alkyl chlorides



$k_{rel} = 123$

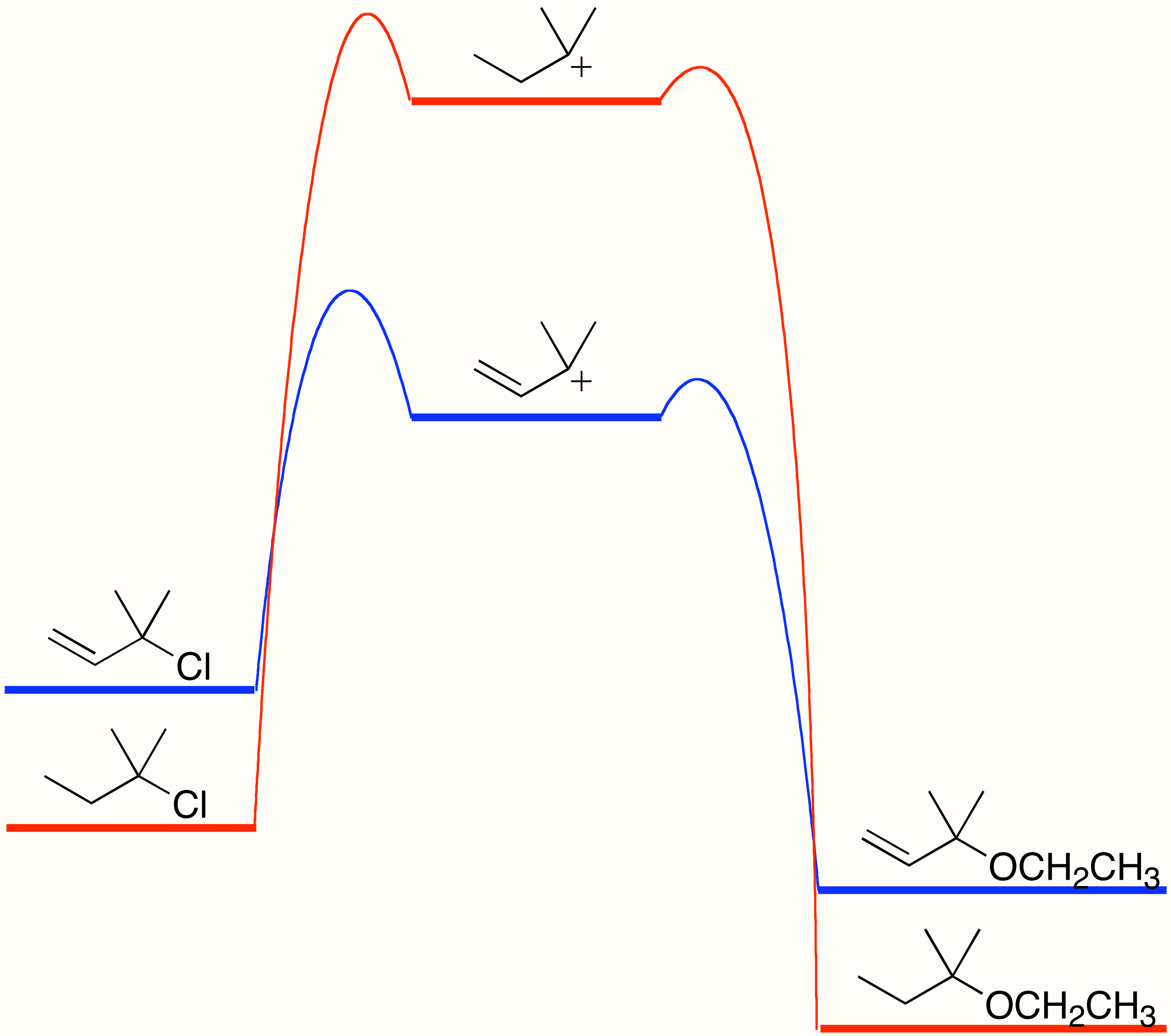


$k_{rel} = 1$

Chapter 10
Allylic Effects on Reactivity

Sections: 10.3-10.6
You are responsible for section 10.7.

Allylic S_N1

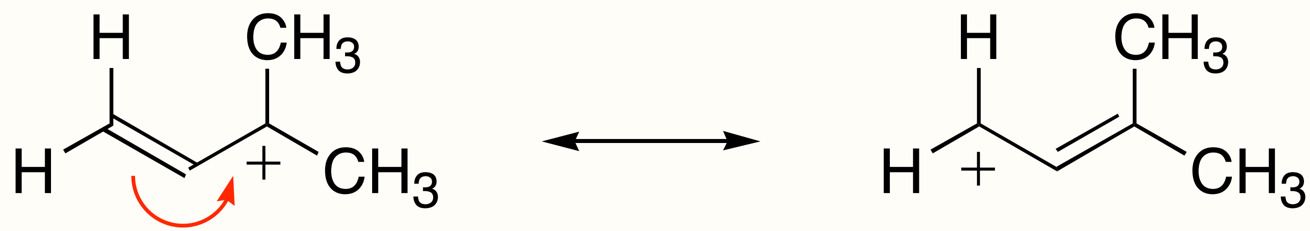


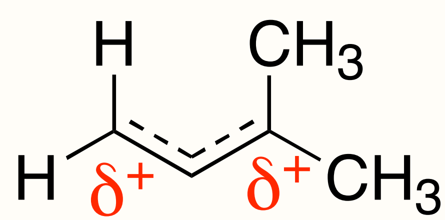
- allylic carbocations are more stable (lower energy) than non-conjugated carbocations
- lower energy intermediate = lower energy transition state (TS)
- lower energy TS = lower Ea = faster reaction
- differences in ground state energies have no effect since they are present in both carbocations and products

Stabilization of Allylic Carbocations

Allylic carbocations are stabilized by delocalization of the positive charge. Two models can explain delocalization:

1. Resonance model
2. Orbital overlap model





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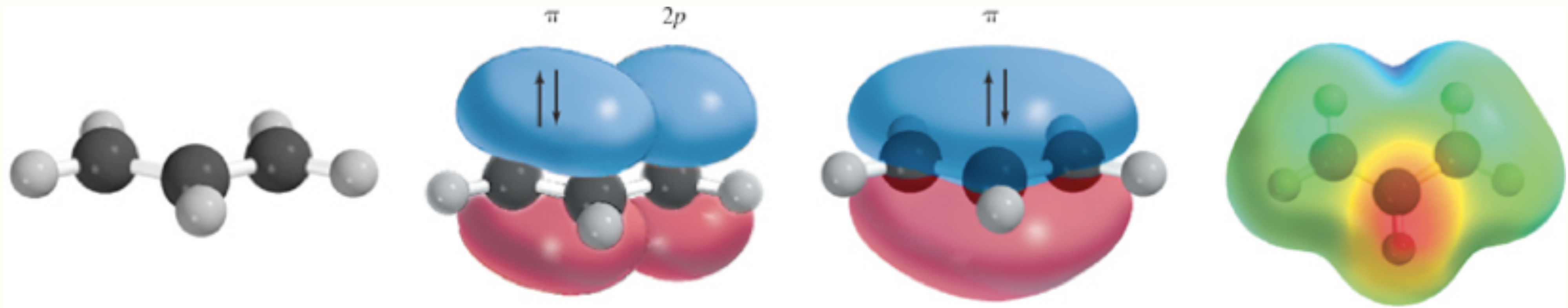


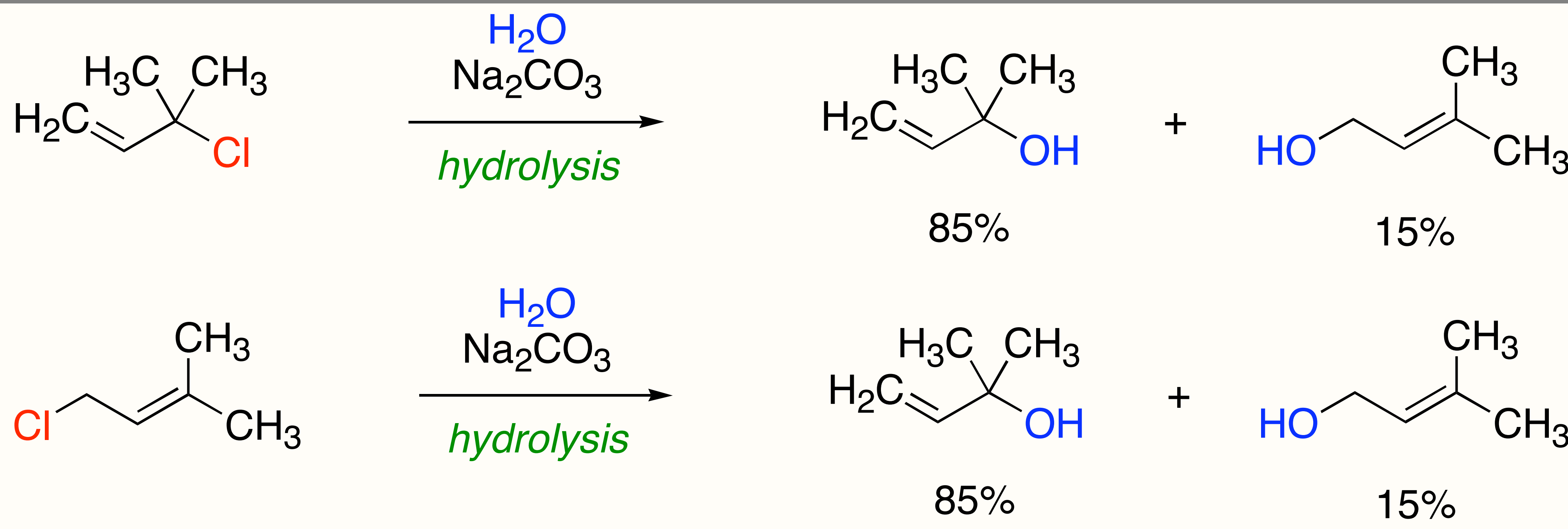
- geometry = planar
- bond angles = 120°

- all C atoms sp2
- hybridized
- 2 conj. p-systems:
- p-bond & 2p orbital

- overlap = new MO
- two electrons delocalized over 3 carbon atoms

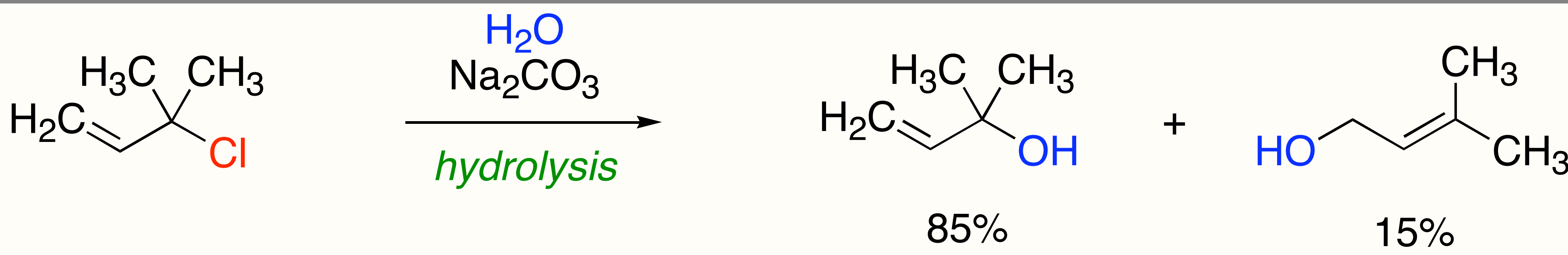
- positive charge shared equally between terminal C atoms

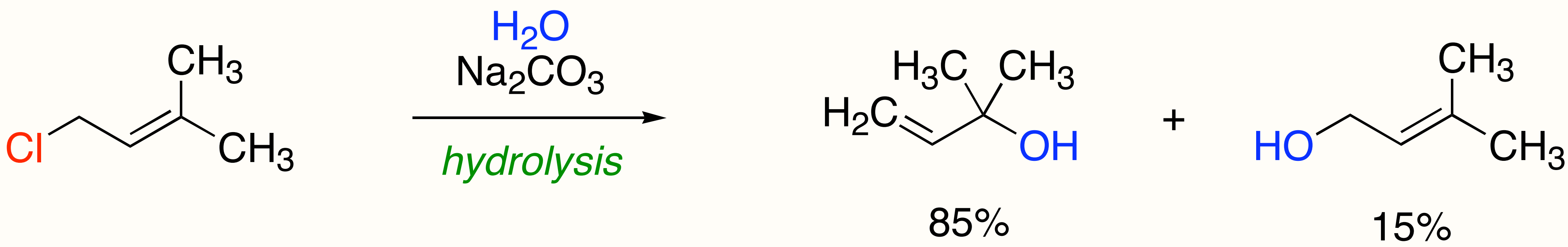
Allylic Carbocation: Unequal Charge Distribution

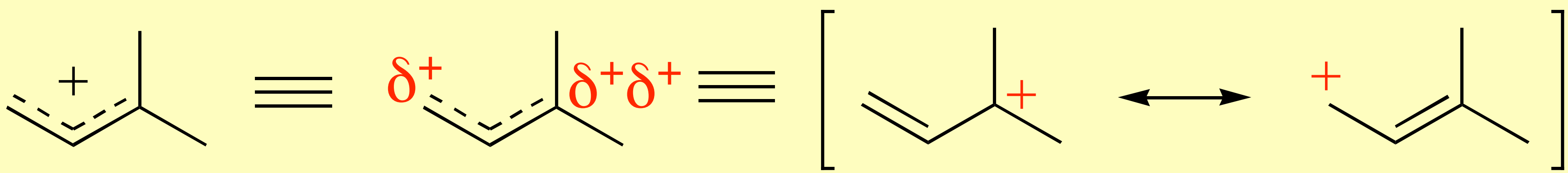


The same products are isolated from each reaction since both proceed through the same carbocation intermediate.

Allylic Carbocation: Unequal Charge Distribution

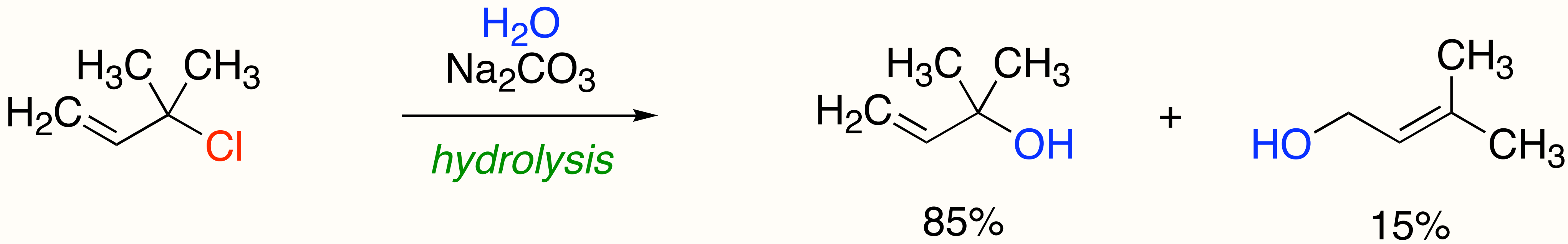


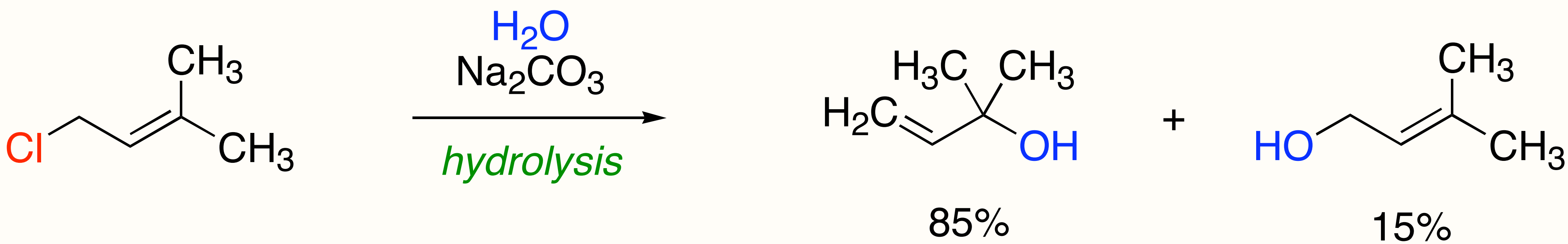


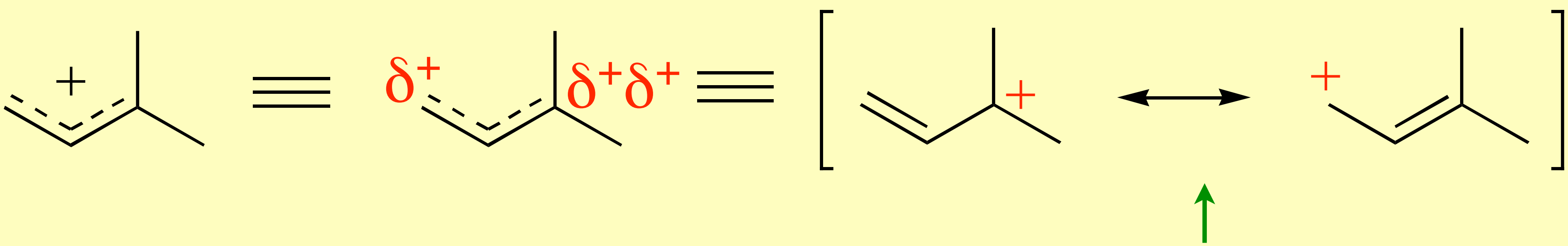


most substituted carbon = most positive charge = most electrophilic = lowest Ea upon nucleophile capture

Allylic Carbocation: Unequal Charge Distribution

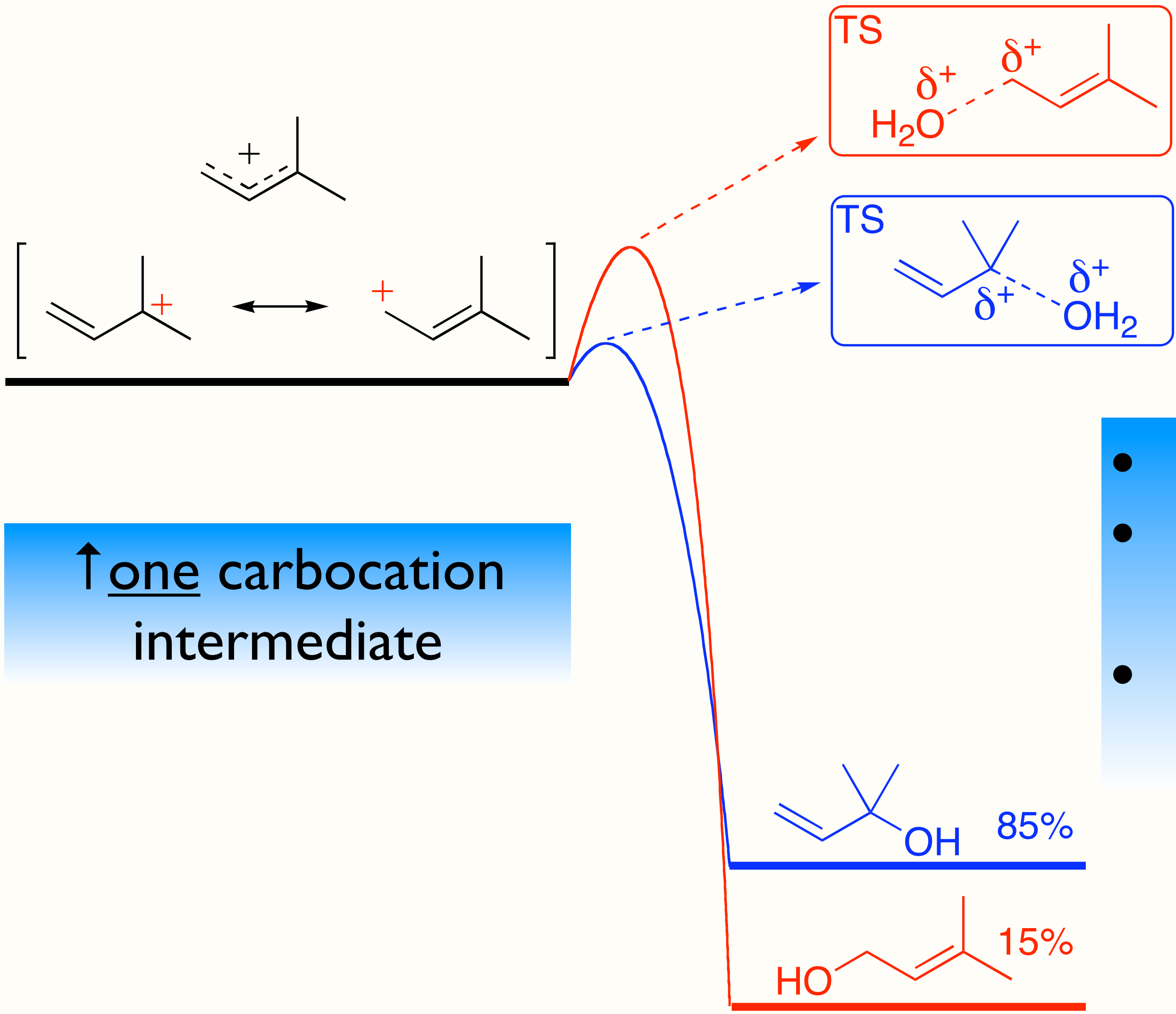






these are only resonance structures = neither actually exists; this does not represent two carbocation intermediates in equilibrium with each other

Unequal Charge Distribution = Unequal Product Distribution

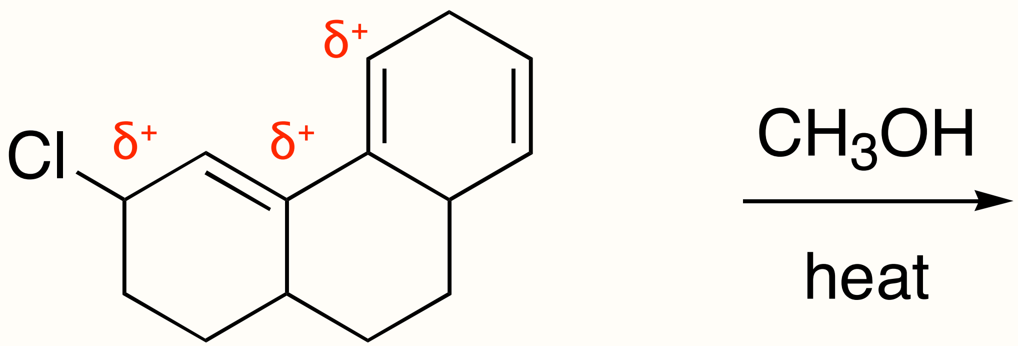


↑ one carbocation intermediate

- ↖ two transition states (TS)
- lower energy TS = ∂+ on most substituted C
- lower energy TS = lower Ea = faster rxn

Self Test Question

Predict the *major* product for the following reaction.



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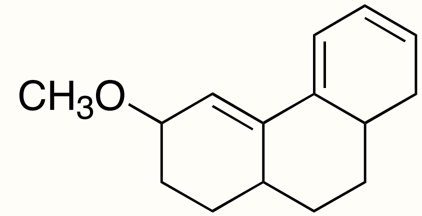

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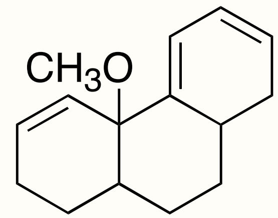

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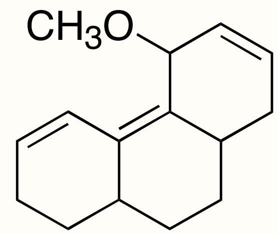

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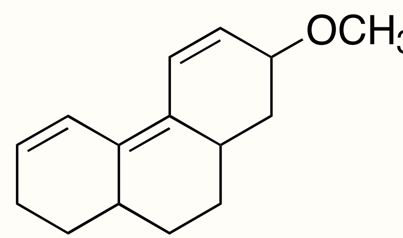

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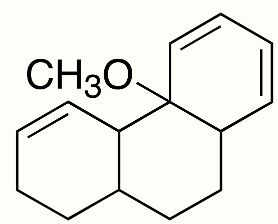
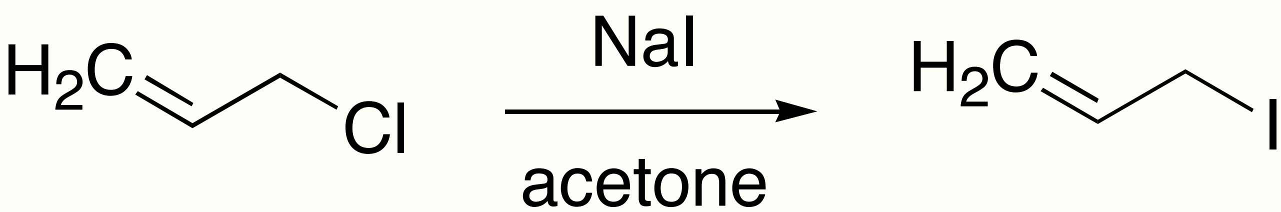
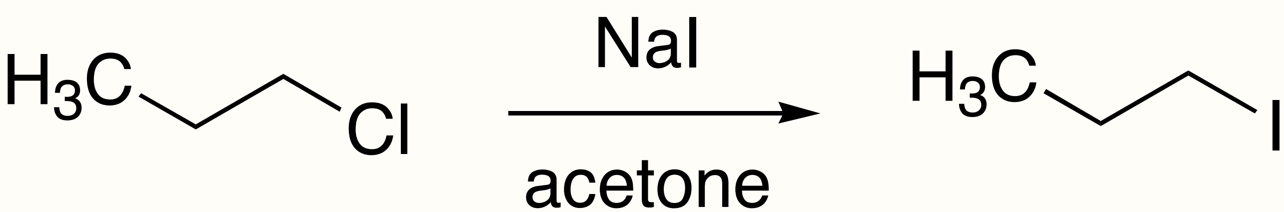


S_N2 Reactions of Allylic Halides

Allylic halides undergo S_N2 faster than nonallylic halides



$k_{rel} = 80$

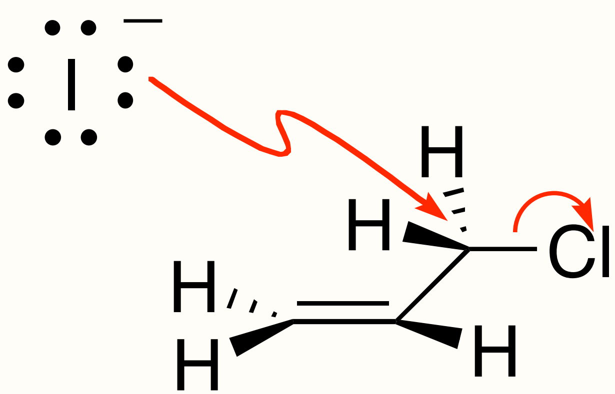


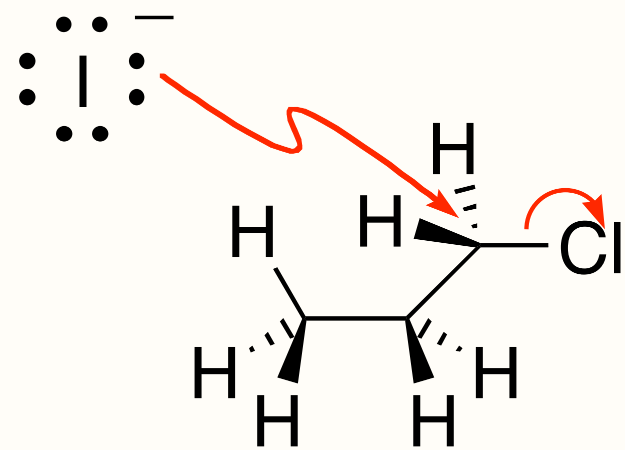
$k_{rel} = 1$

Since their are no carbocation intermediates in either reaction, how can we explain this observation?

Allylic S_N2 is Faster: Two Arguments

1. steric hinderance (VWF)
2. molecular orbital interactions

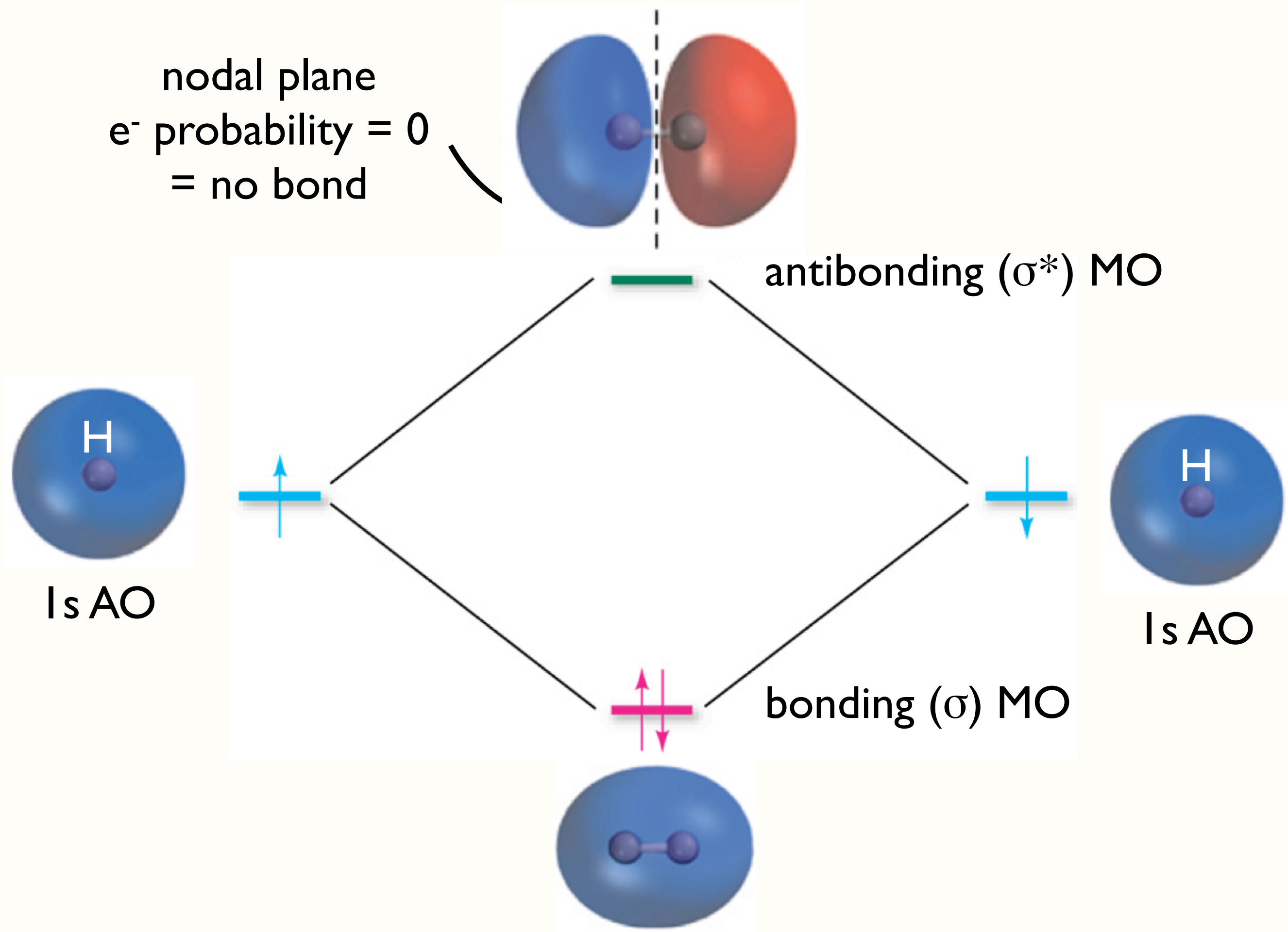




since backside attach is required, the nucleophile is less sterically hindered when adjacent carbon is sp^2-hybridized

1. steric hinderance (VWF)

2. molecular orbital interactions



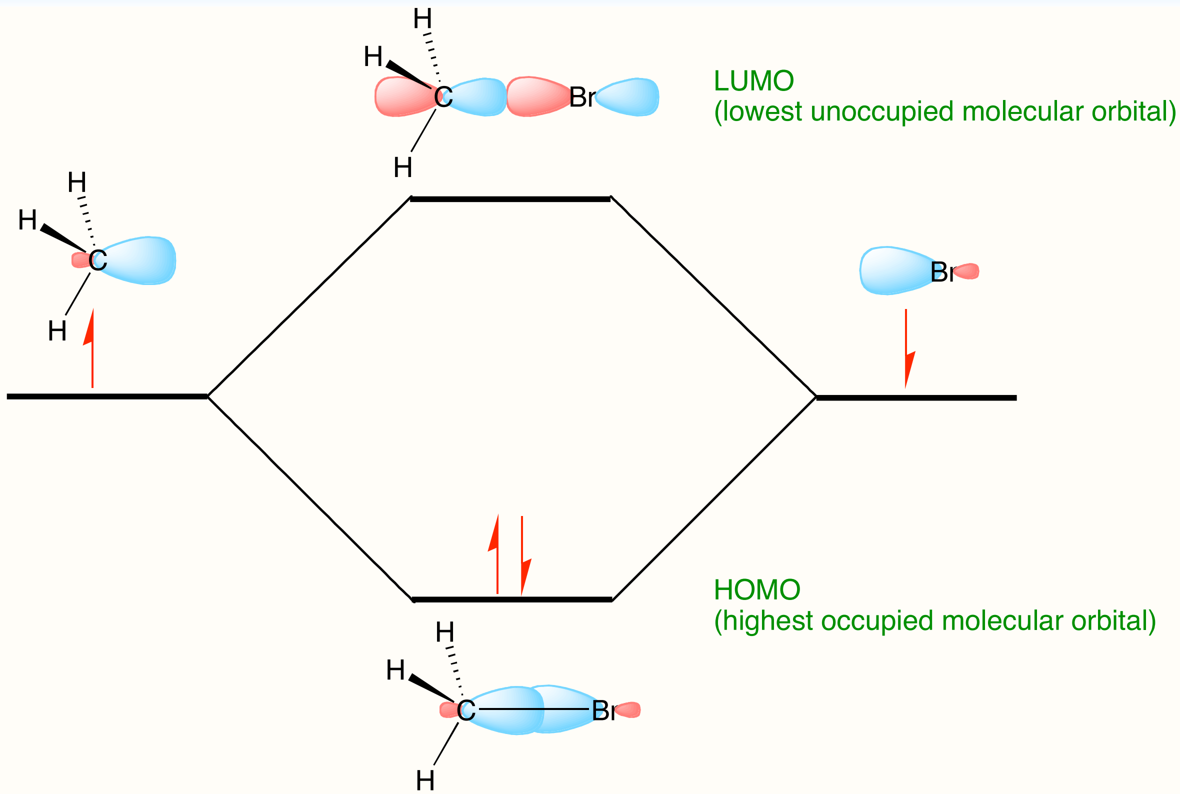
molecular orbitals (MOs) are formed by mixing atomic orbitals (AOs)

Allylic S_N2 is Faster: Two Arguments

1. steric hinderance (VWF)

2. molecular orbital interactions

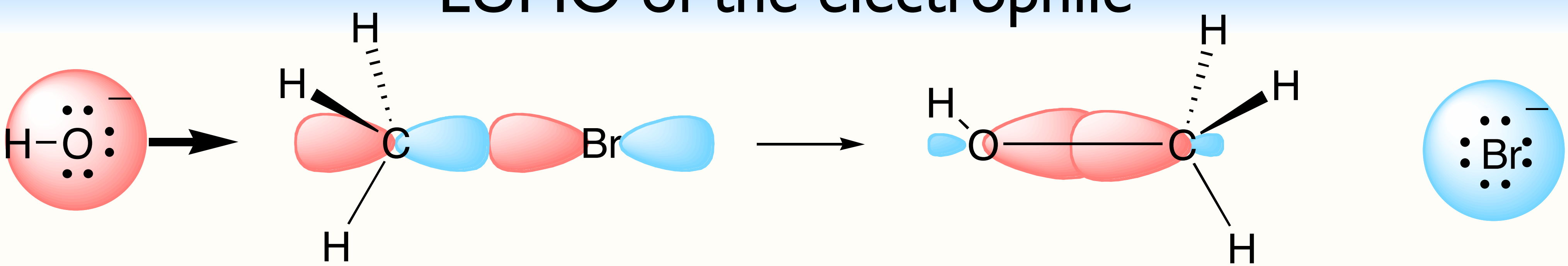
Generalization: New bonds are formed by overlap between LUMO of electrophile and HOMO of nucleophile



Allylic S_N2 is Faster: Two Arguments

1. steric hinderance (VWF)
2. molecular orbital interactions

Electrons in HOMO of nucleophile flow into the empty LUMO of the electrophile



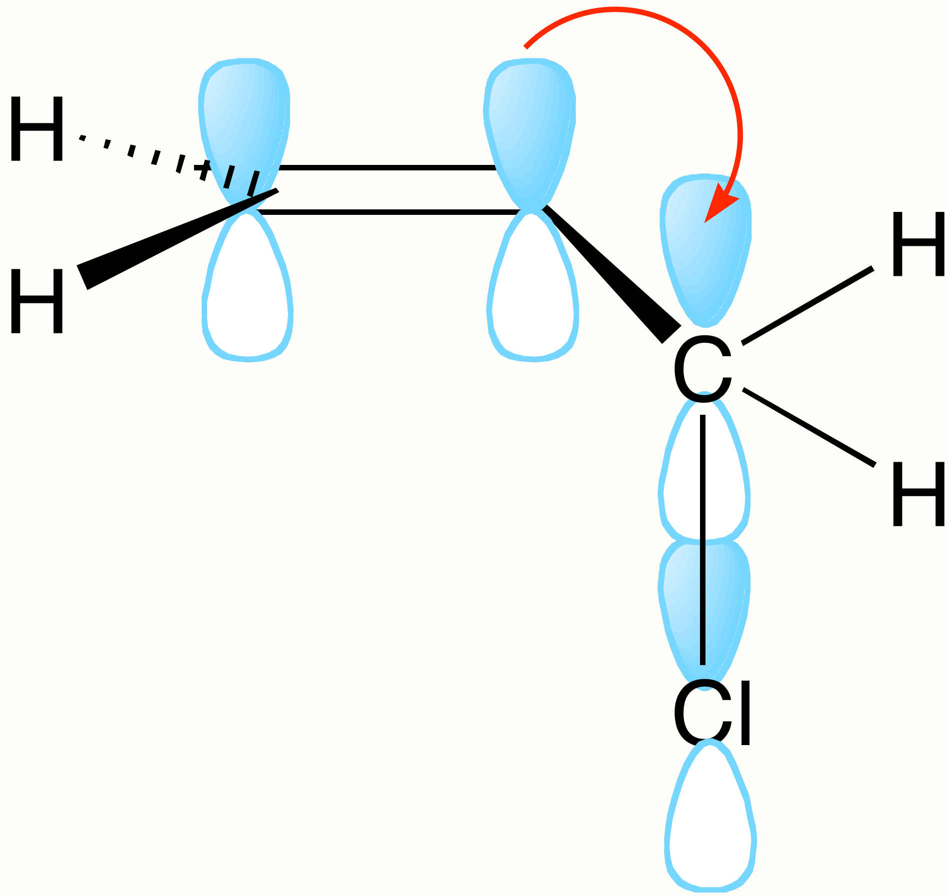
Nucleophile (HOMO)

electrophile (LUMO)

- since the LUMO is an antibonding orbital (σ^*), adding electrons to this orbital weakens the C–Br bond until it breaks
- bonding overlap (constructive interference) of HOMO must be from side opposite to C–Br bond to form C–O bond

Allylic S_N2 is Faster: Two Arguments

1. steric hinderance (VWF)
2. molecular orbital interactions



- LUMO of C-X bond can adopt a coplanar arrangement with p-orbitals of p-bond =
- electron delocalization over three orbitals =
- lower energy LUMO =
- lower activation energy =
- faster reaction
- *Why does lower energy LUMO result in lower activation energy?*

Allylic S_N2 is Faster: Two Arguments

1. steric hinderance (VWF)

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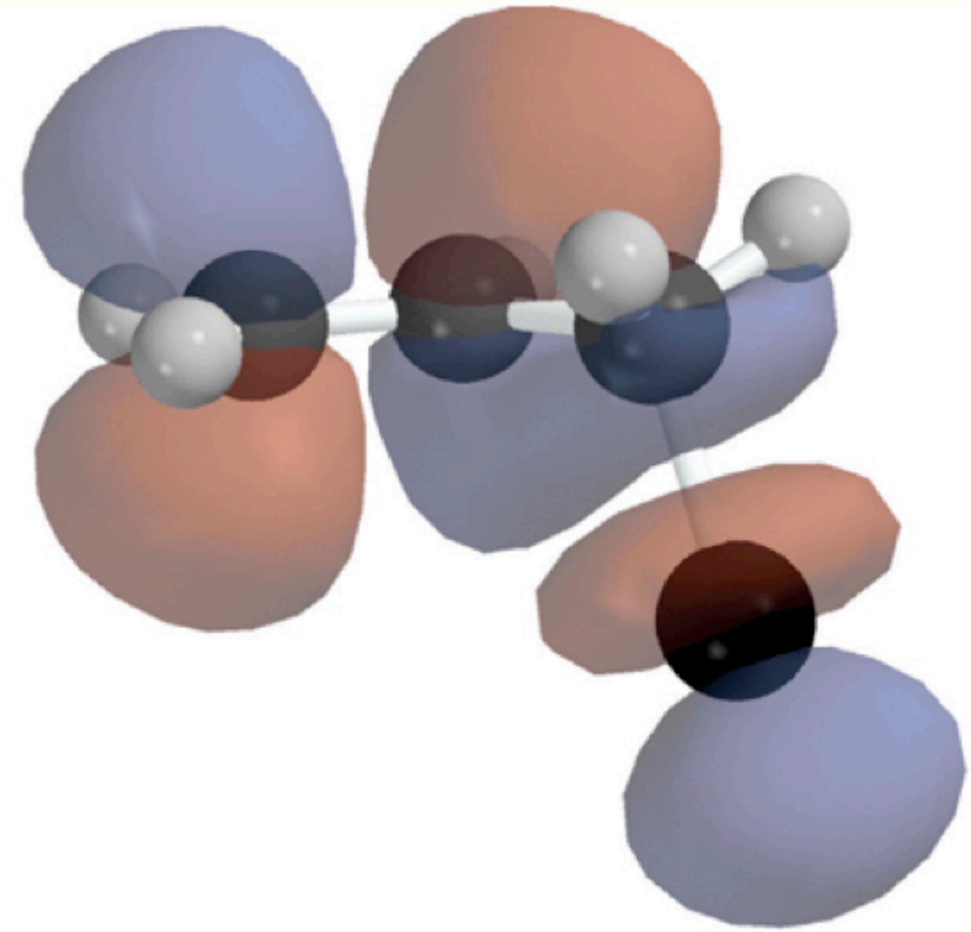

- LUMO of C-X bond can adopt a coplanar arrangement with p-orbitals of p-bond =
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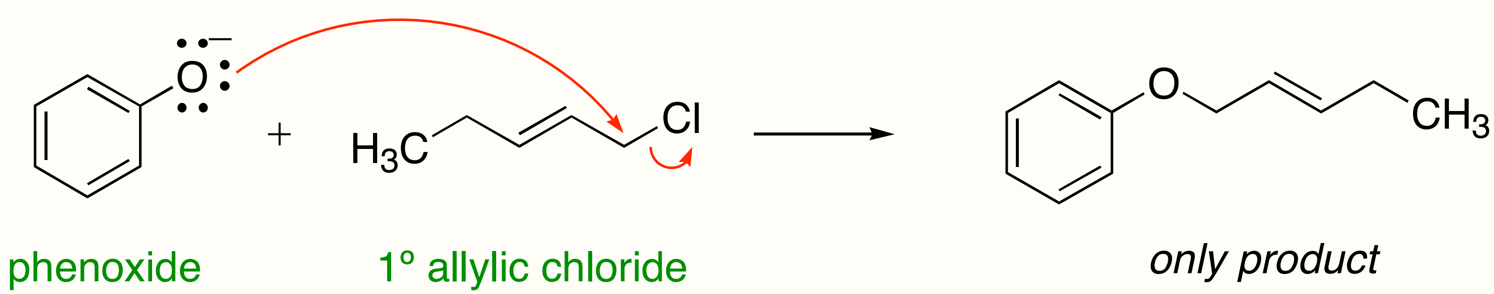
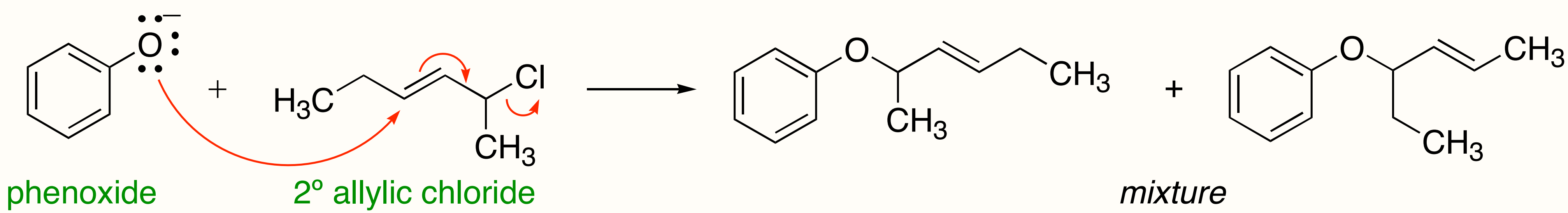
- lower energy LUMO =
- lower activation energy =
- faster reaction
- *Why does lower energy LUMO result in lower activation energy?*

S_N2 Usually of 1° Allylic Halides

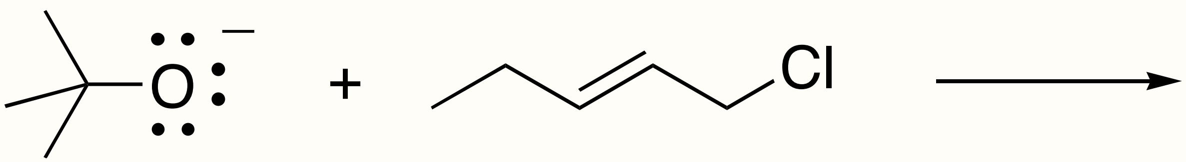
S_N1 competes with S_N2 when electrophile is a 2° or 3° alkyl halides.





Self Test Question

Unlike phenoxide (pKa of phenol = 10), *tert*-butoxide (pKa of *tert*-butanol = 18) does not give S_N2 as major products. What is the major product?



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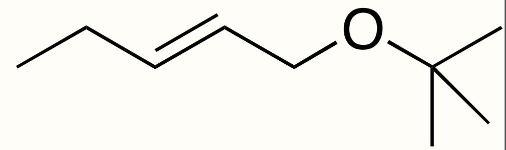

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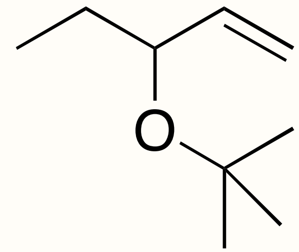

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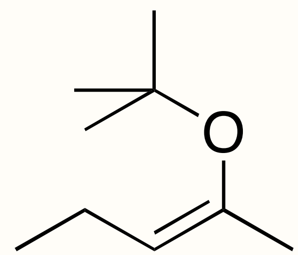

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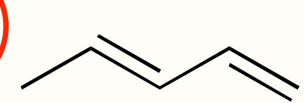

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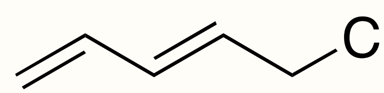
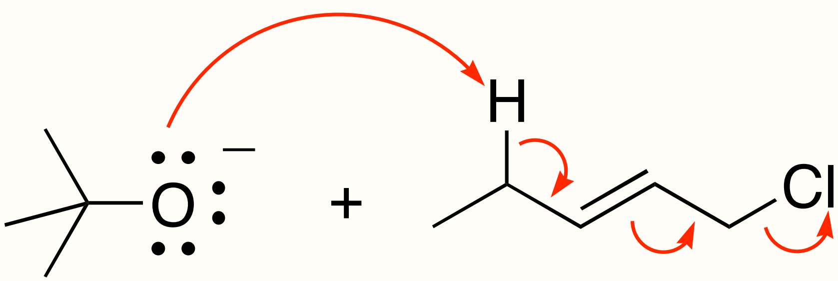
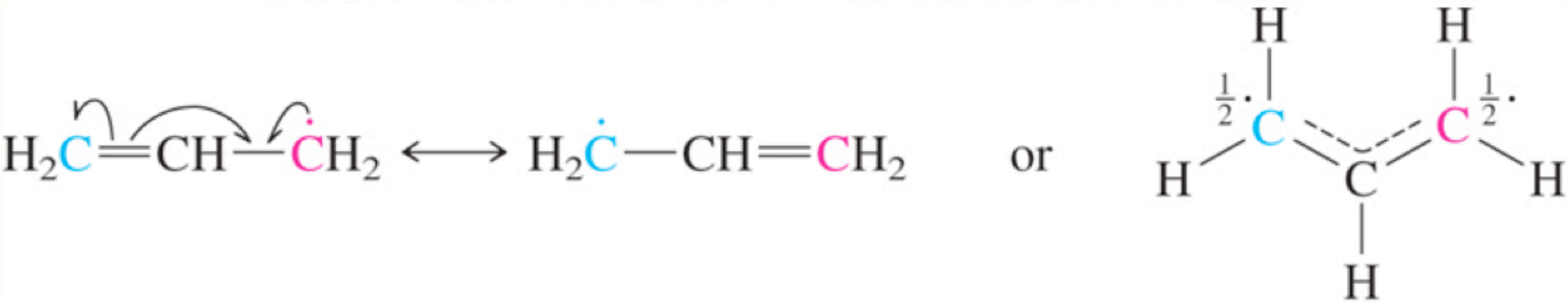




elimination predominates when nucleophiles are stronger bases than hydroxide (pK_a of H_2O = 15.7)

Allylic Free Radicals

Allylic radicals are also stabilized by electron delocalization through resonance



Allylic Free Radicals

Free radical stabilities are related to bond dissociation energies (BDE) or bond strength

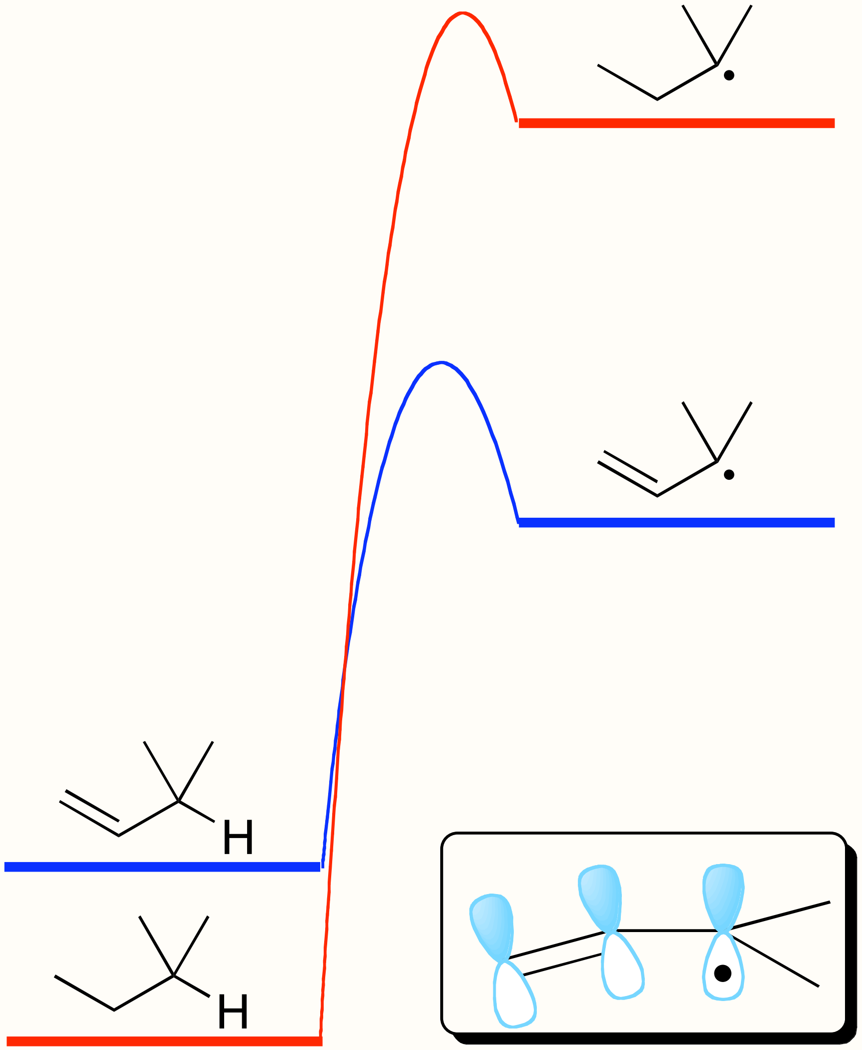
$$CH_3CH_2CH_2{:}H \longrightarrow CH_3CH_2\dot{C}H_2 + \cdot H \qquad \Delta H^\circ = +410\ \text{kJ}\ (+98\ \text{kcal})$$

Propane — Propyl radical — Hydrogen atom

$$H_2C{=}CHCH_2{:}H \longrightarrow H_2C{=}CH\dot{C}H_2 + \cdot H \qquad \Delta H^\circ = +368\ \text{kJ}\ (+88\ \text{kcal})$$

Propene — Allyl radical — Hydrogen atom

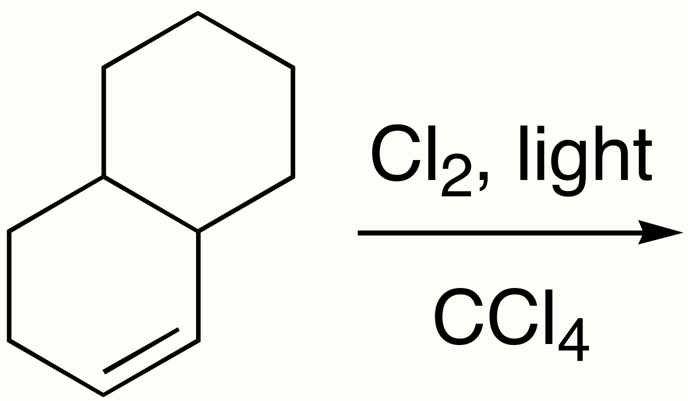
Allylic Free Radicals



- allylic C-H bonds are weaker than non-conjugated C-H =
- less endothermic homolysis of allylic C-H bonds
- because allylic free radical intermediate is more stable
- reactions that for allylic free radical happen faster than those that generate non-conjugated free radicals

Self Test Question

Based on what you've learned about conjugated carbocation, predict the major product of the following free-radical chlorination.



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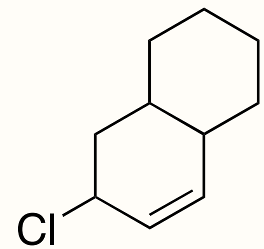

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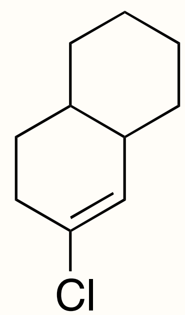

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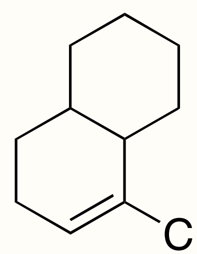

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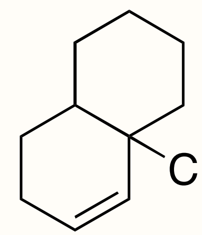

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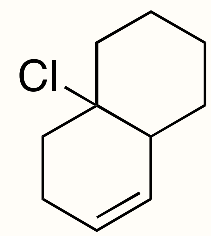
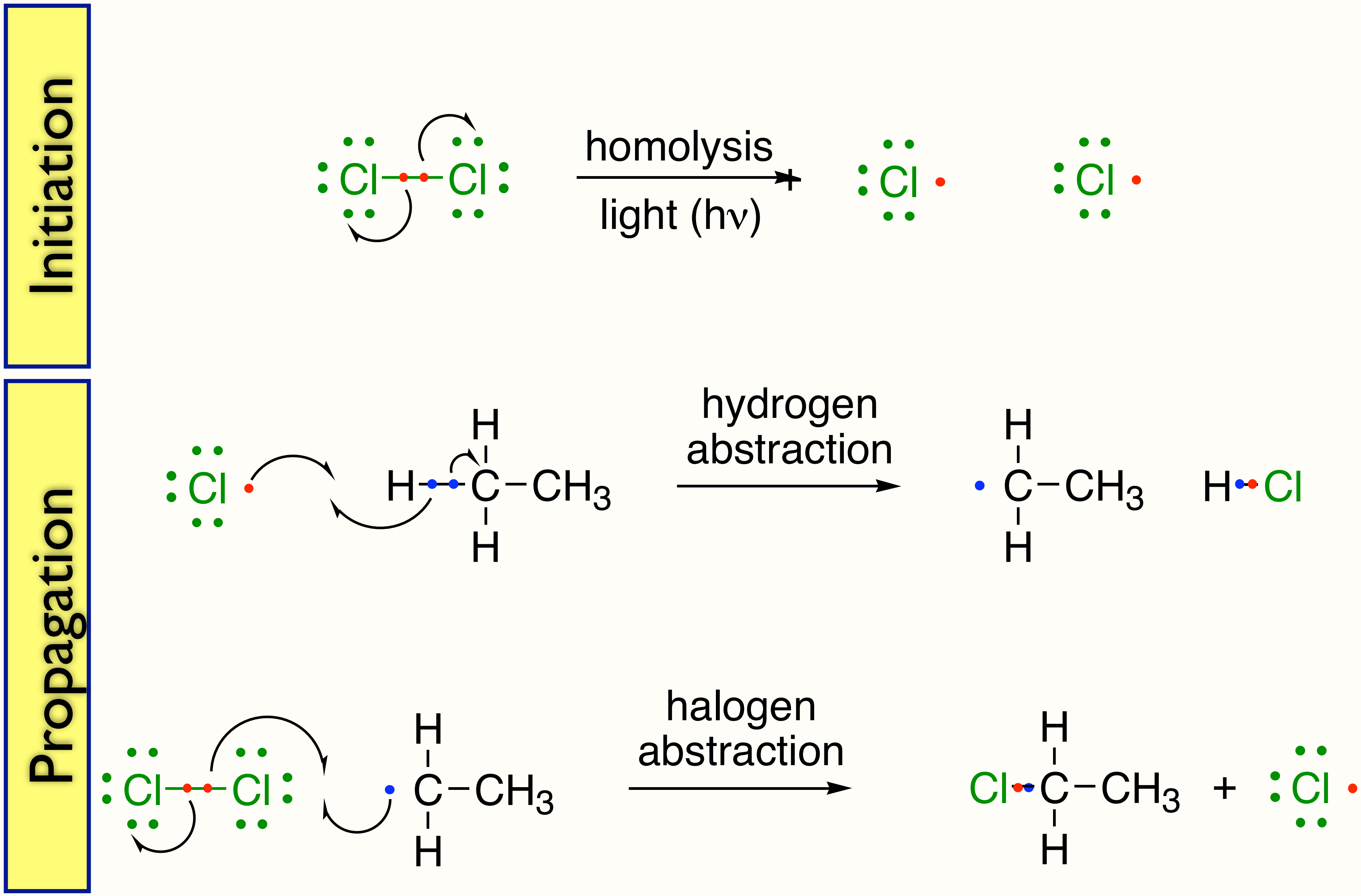
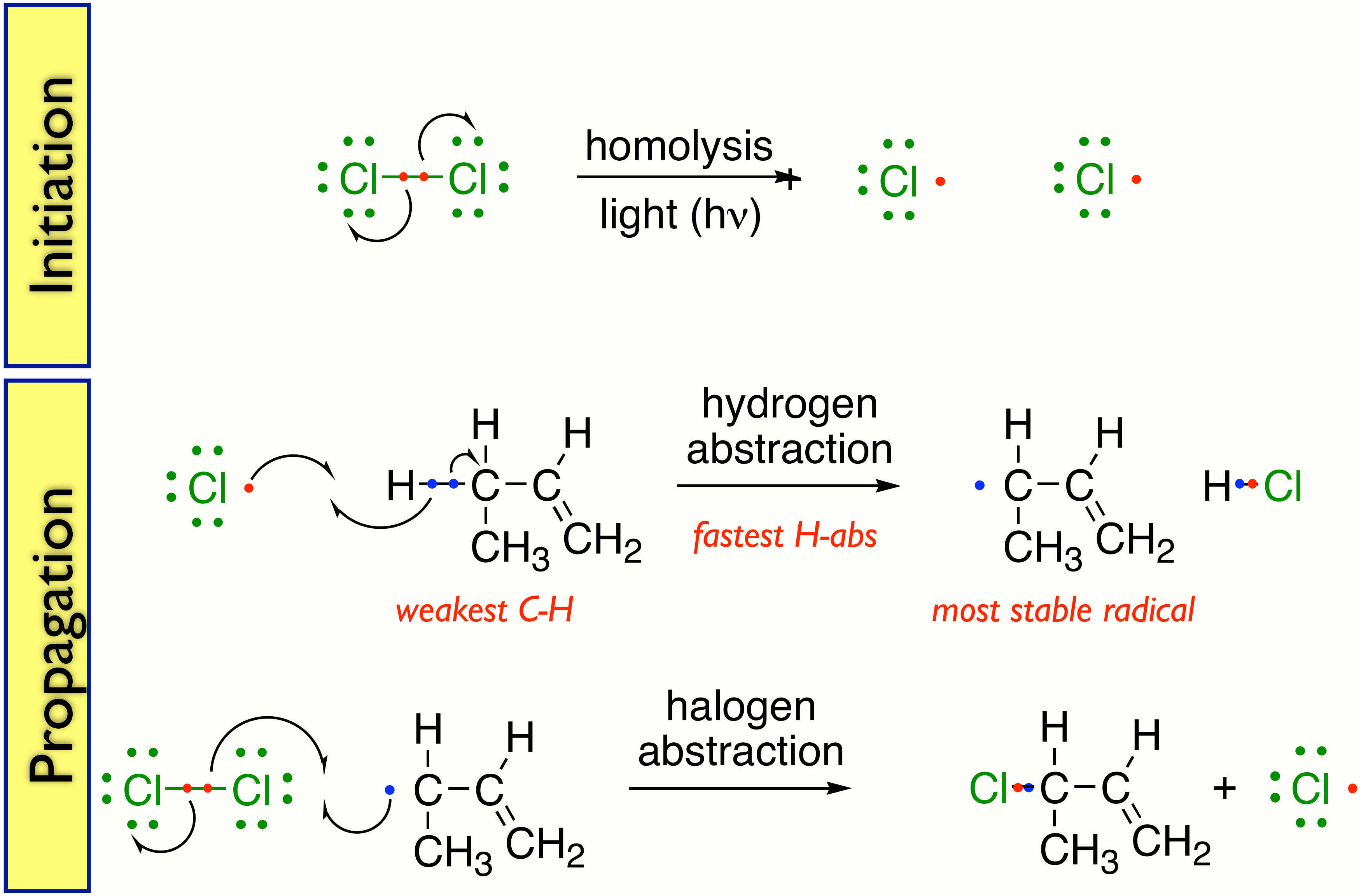


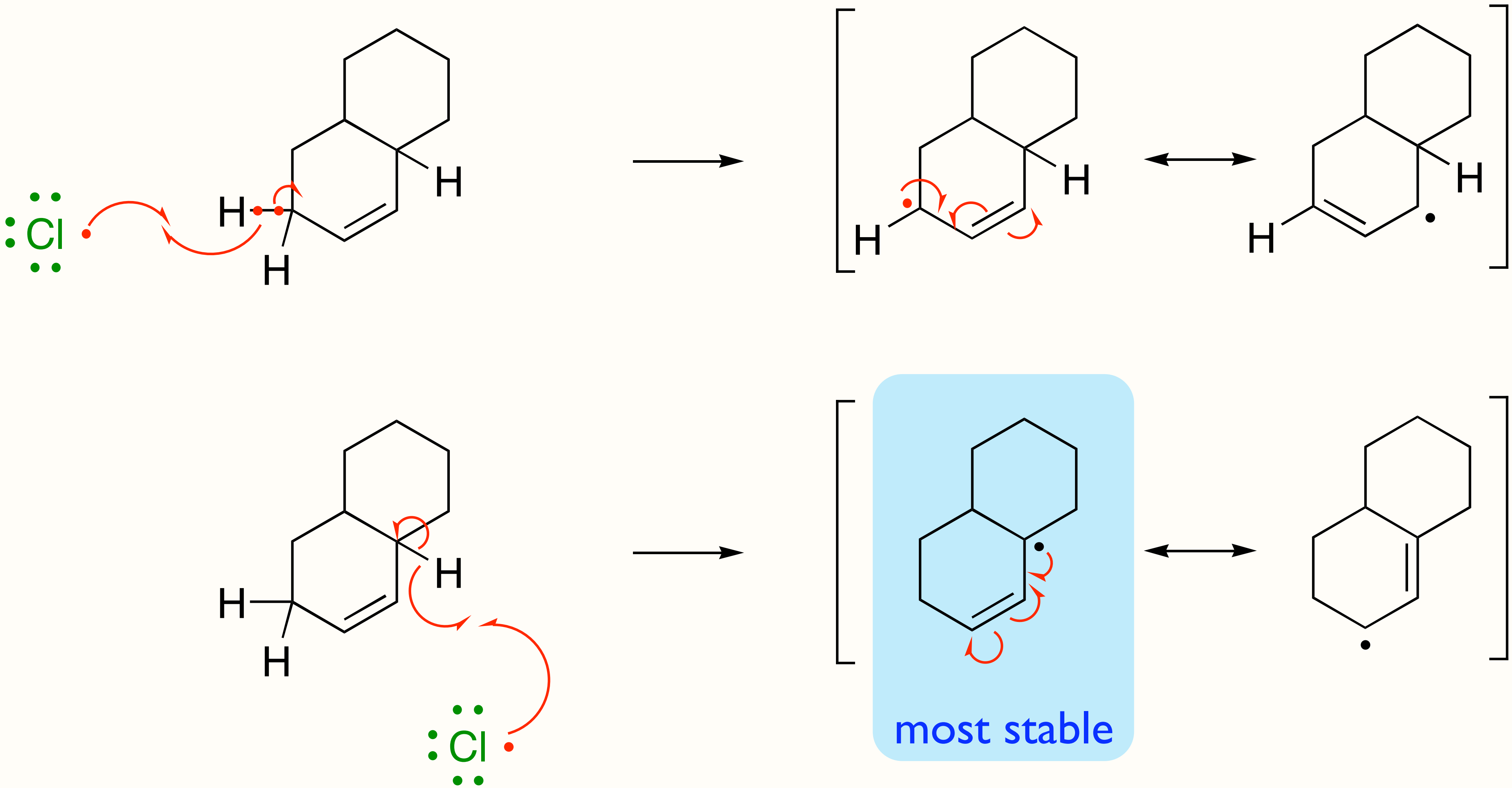
Halogenation



Allylic Halogenation



Allylic Halogenation

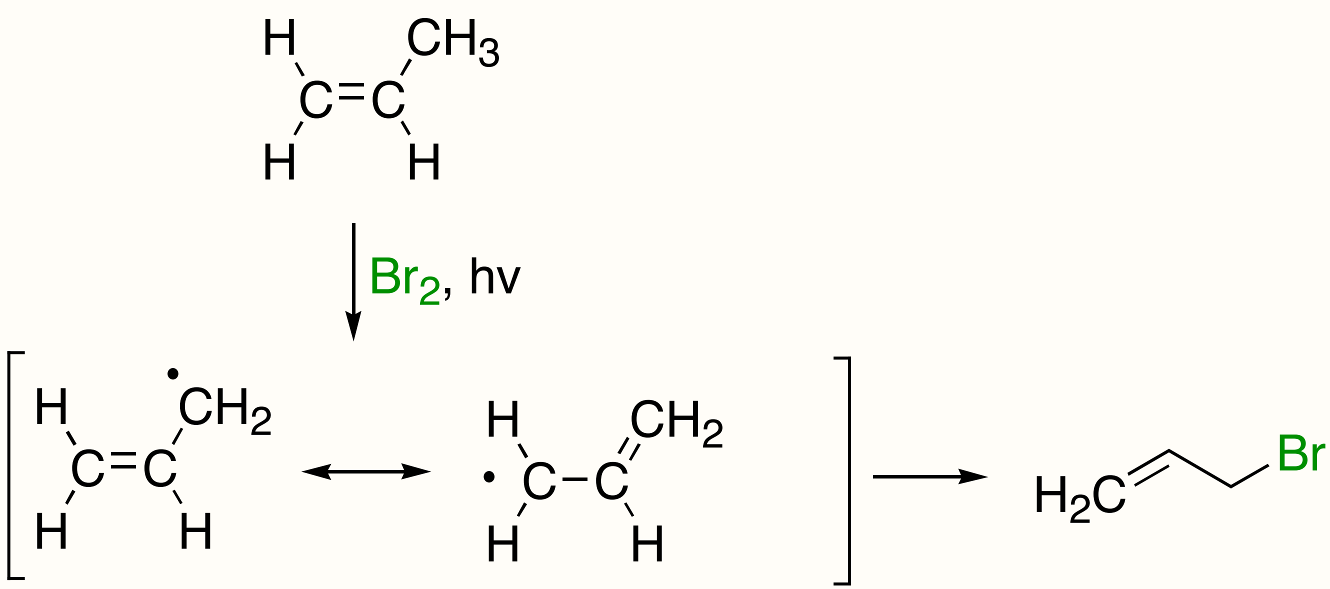


Allylic Halogenation in Synthesis

Although halogenation of allylic carbons can be regioselective, large mixtures are still obtained when there are more than one set of allylic hydrogens. Therefore, this method should only be in synthetic problems when the following conditions are met:

1. All the allylic hydrogens in the starting alkene must be equivalent.

2. Both resonance forms of the allylic radical must be equivalent.



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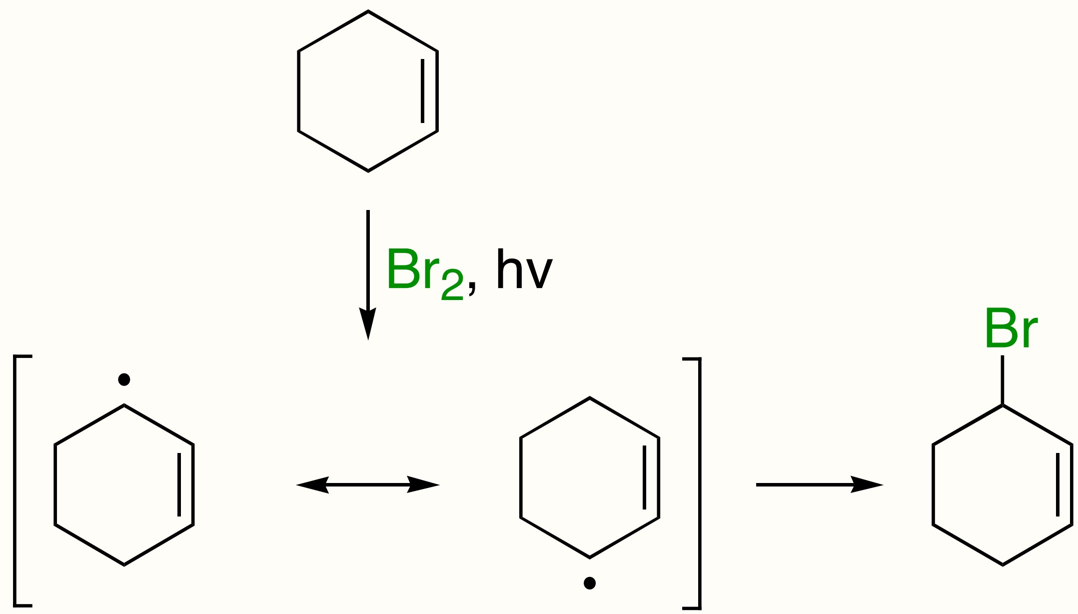

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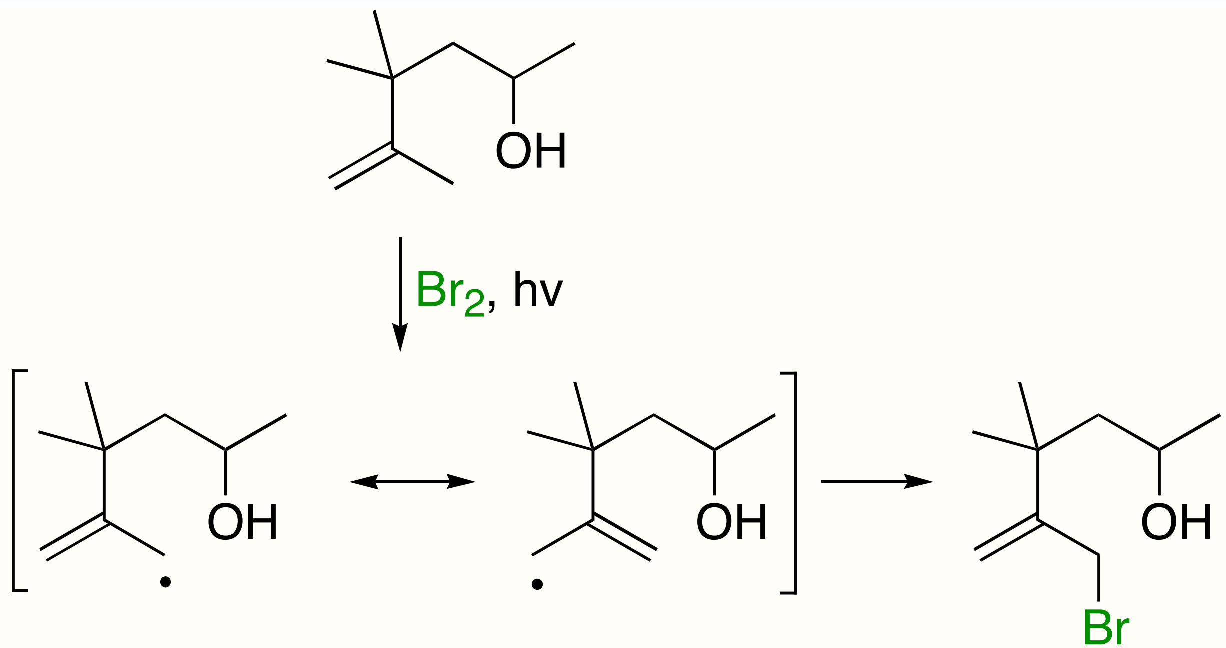
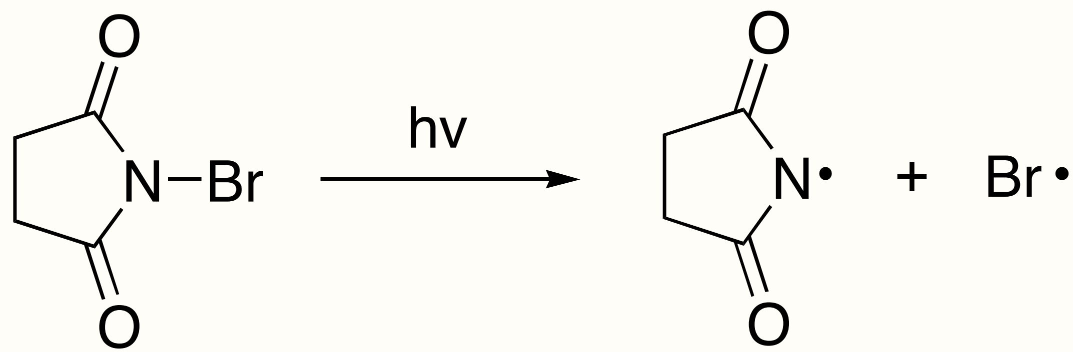
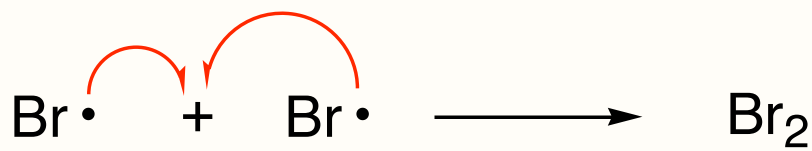


NBS: Another Radical Bromination Reagent

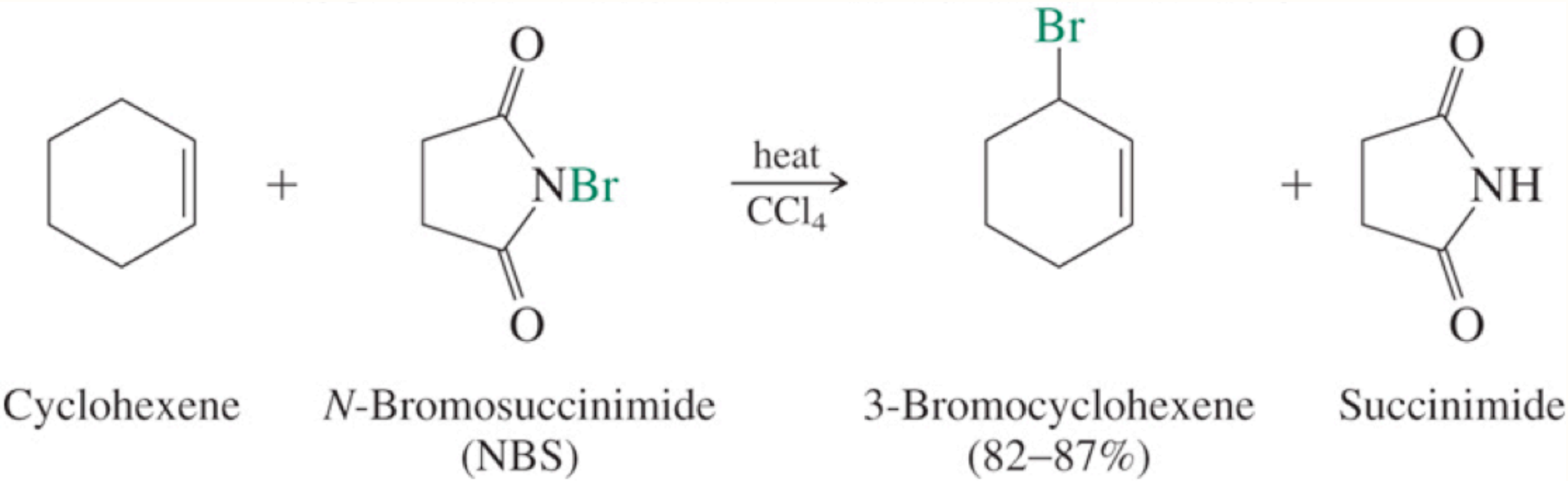


N-bromosuccinimide (NBS)



- *N*-bromosuccinimide (NBS) also causes allylic radical bromination
- only used for radical <u>bromination</u>
- advantages: NBS generates the radical initiator (Br•) and maintains low concentration of Br2
- low [Br2] = suppresses competing addition across alkene

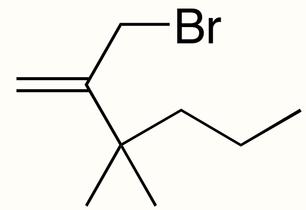
NBS: Another Radical Bromination Reagent

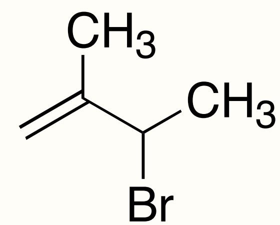


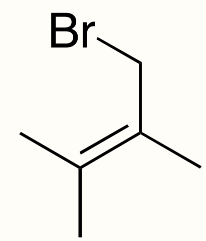
- NBS is a substitute for Br2/hv
- NBS generates radical initiator (Br•) and maintain a low concentration of Br2
- prevents addition of Br across alkene to give vicinal dihalide

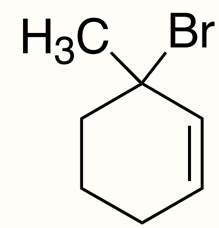
Self Test Question

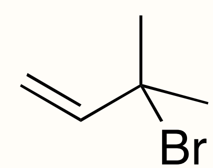
Which allylic bromide could be prepared as the sole product by radical bromination of an alkene ?

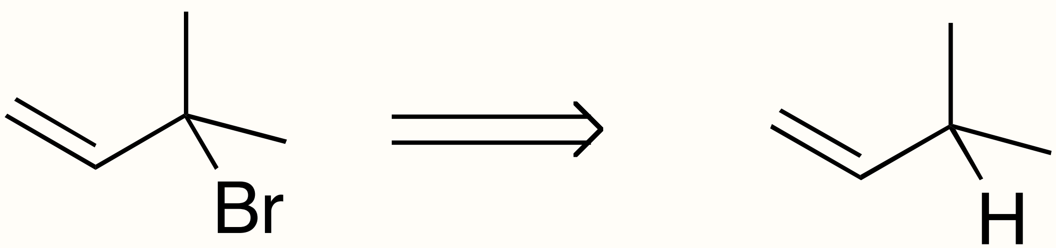
A 

B 

C 

D 

E 



√ only 1 set allylic Hs

X more than one resonance form

Self Test Question

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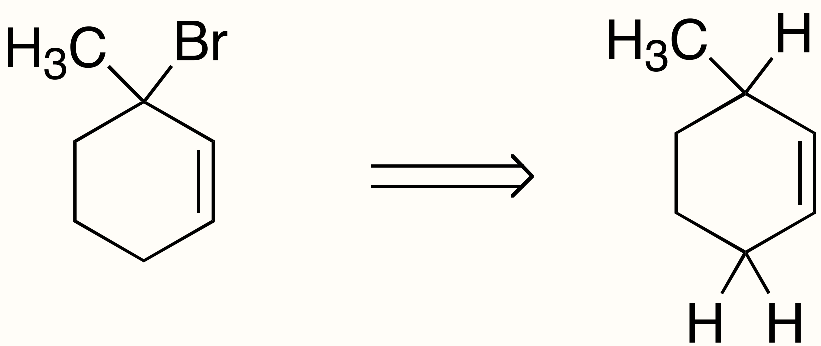
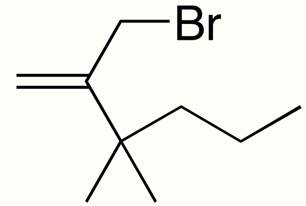


X more than 1 set allylic Hs

X more than one resonance form for each

A



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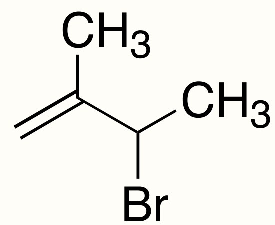

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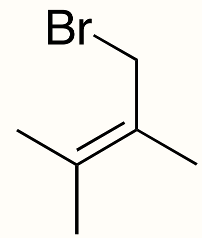

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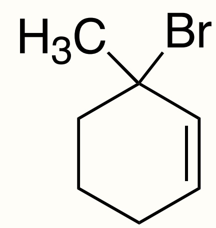

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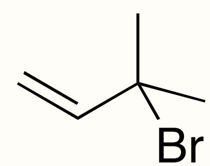

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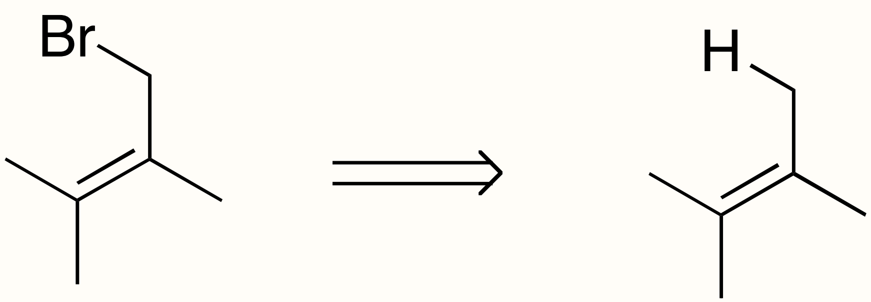
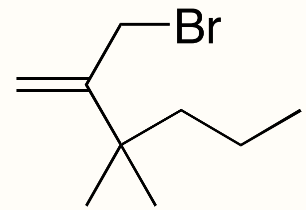


√ only 1 set of allylic Hs

X more than one resonance form

A


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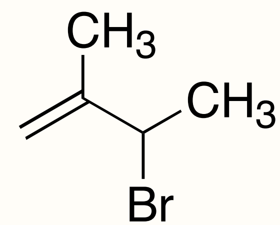

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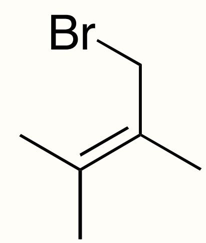

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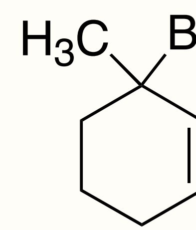

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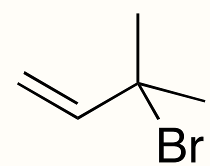

Self Test Question

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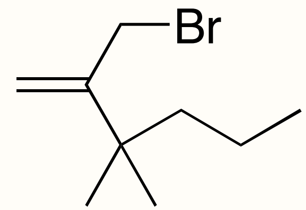

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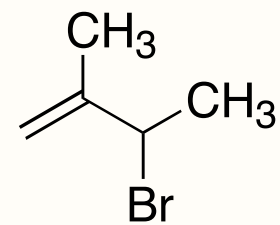

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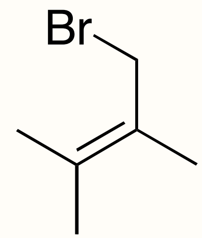

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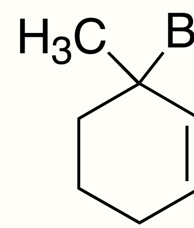

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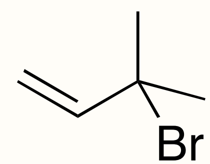

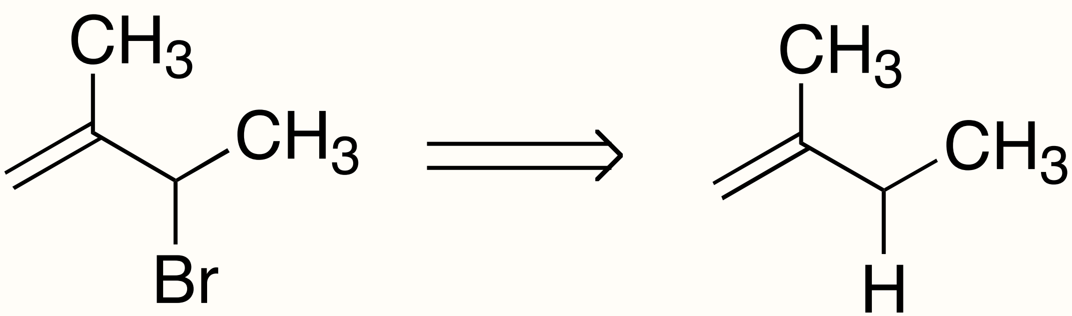

X more than 1 set allylic Hs
X more than one resonance form for each

Self Test Question

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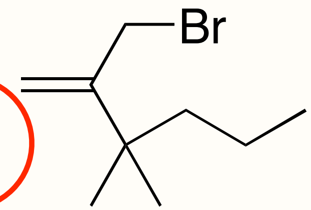
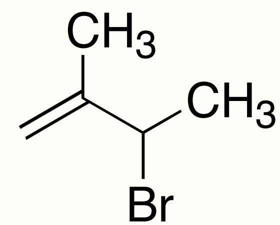
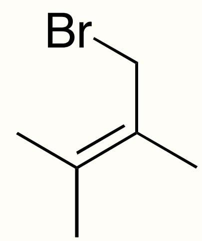
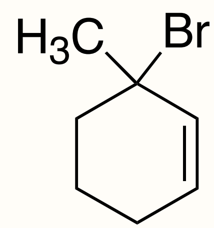
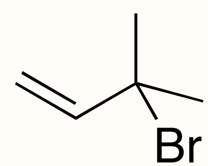
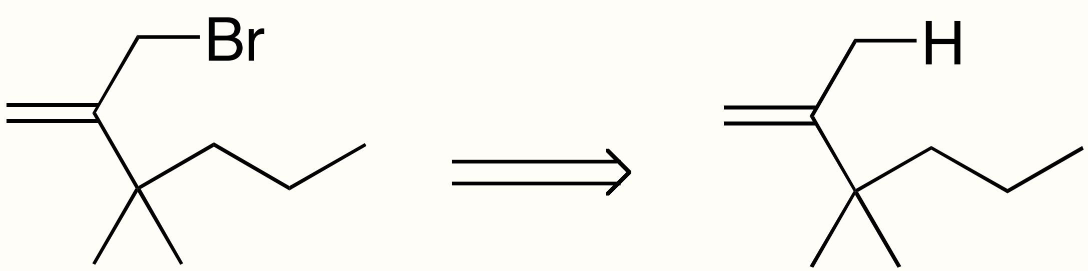
A 

B 

C 

D 

E 



√ only 1 set of allylic Hs

√ only one resonance form

Next Lecture...

Chapter 10: Sections 10.8-10.17

Quiz This Week. . .

Chapter 9 & Synthesis Problems

Exam Two

- Monday, April 5
- 6:00-7:15 p.m.
- 250 SES
- Chapters 6-10 (everything!)
- Makeup Exam: Monday, April 12th, time t.b.a.

Makeup policy: There are no makeup exams without **prior** approval. Only students showing proof of a class conflict will have the option to take a makeup exam. To be added to the makeup list, you must email me no later than Friday, Feb. 12.

Exam One Grade Distribution

Q1. Ranking (50 points)

Q2. Predict the Products (50 points)

Q3. Arrow-Pushing Mechanism (50 points)

Q4. Nomenclature (20 points)

Q5. Drawing & Conformational Analysis (50 points)

Q6. Functional Groups (30 points)

Exam One Policies

- Non-scientific calculators allowed only
- No cell phones, ipods or others electronic devices
- No molecular models
- Periodic table will be provided
- Seating will be assigned
- **Bring Your I.D.**