SESSION AGENDA

- Introduction to Elimination Reactions
- Types of elimination reactions: 1,1; 1,2 elimination
- General mechanism of E1, E2 and E1cB reactions
- Mechanism of E2 Reaction with evidences
- Hofmann and Saytzeff orientation

LEARNING OBJECTIVES

Students should understand

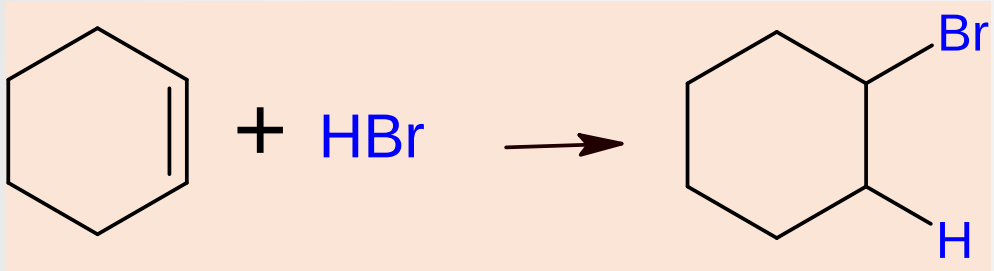
- 1,1 and 1,2 Elimination reactions
- General mechanism of E1, E2 and E1cB Elimination
- Hofmann and Saytzeff rules
- Factors affecting Saytzeff and Hofmann orientation

RECAP

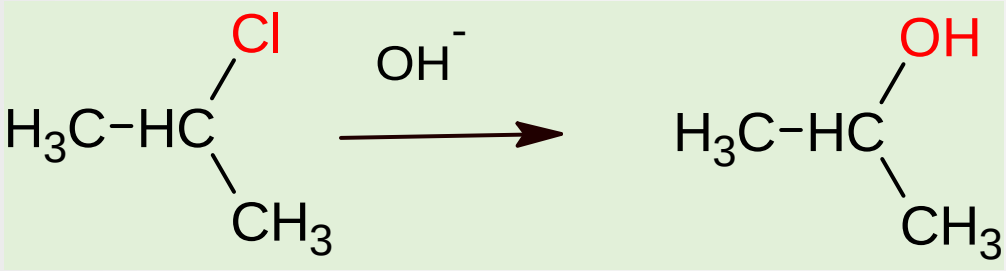
Types of Organic Reactions

- Addition Reactions

$$HCl + CH_2 = CH_2 \rightarrow CH_3CH_2Cl$$



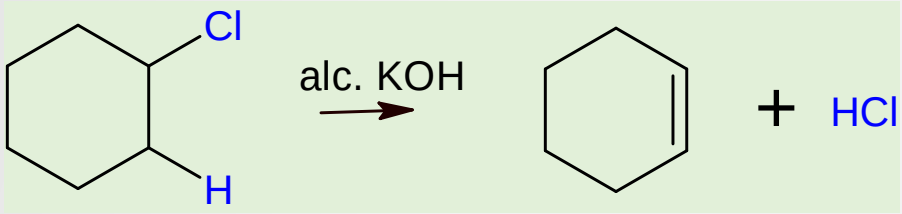
- Substitution Reactions



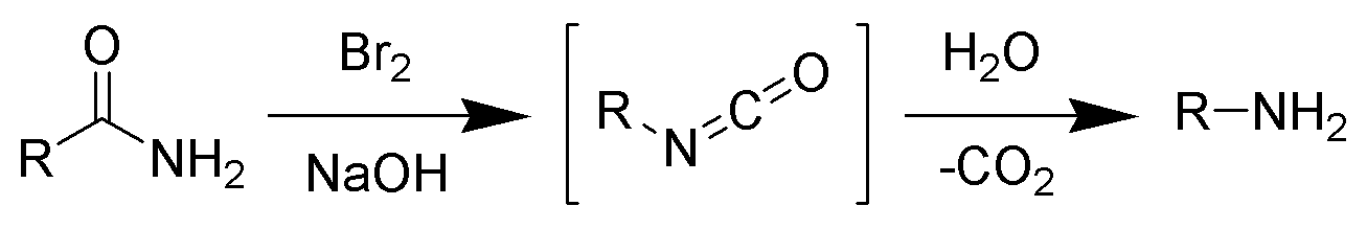
RECAP

Types of Organic Reactions

- Elimination Reaction

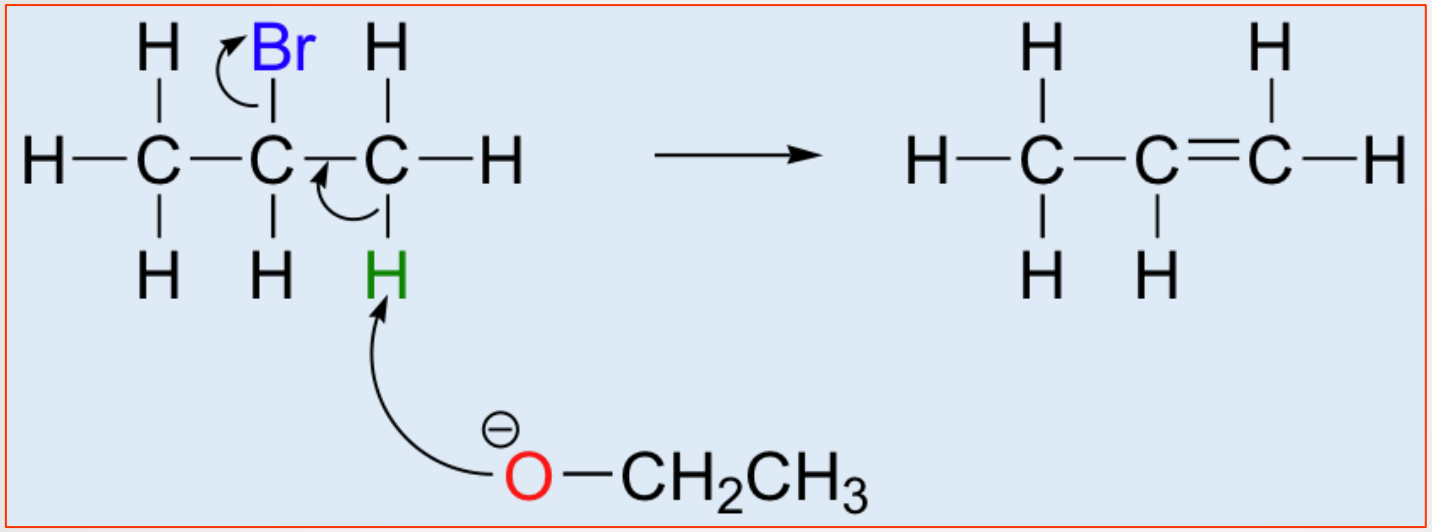


- Rearrangement Reactions



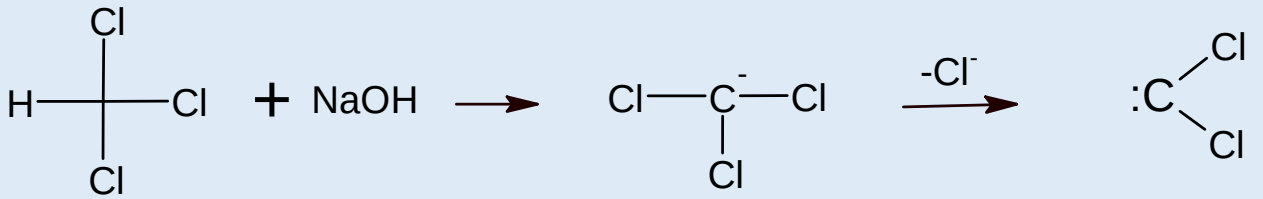
Elimination reactions

A reaction in which two atoms or groups are removed from reactant to form a product with higher degree of unsaturation.



1,1 Elimination

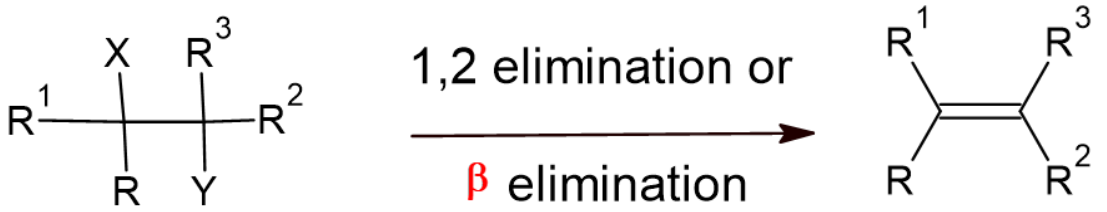
1,1 Elimination (α-elimination)
Elimination reaction in which an organic compound loses two atoms or groups from the same atom.

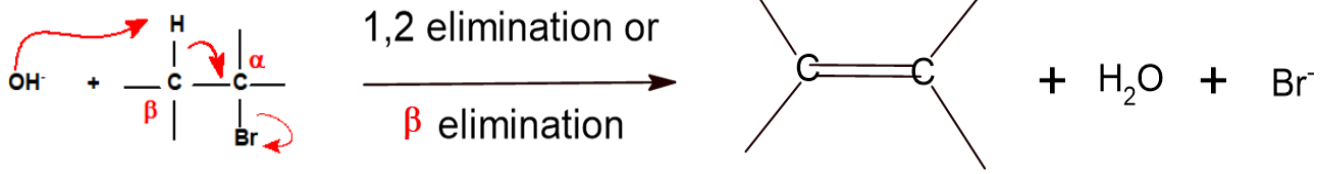


- 1,1 or α elimination is less common
- Mechanism is similar to E1cB.
- First step is generates carbanion
- Second step involve loss of leaving group

1,2 Elimination

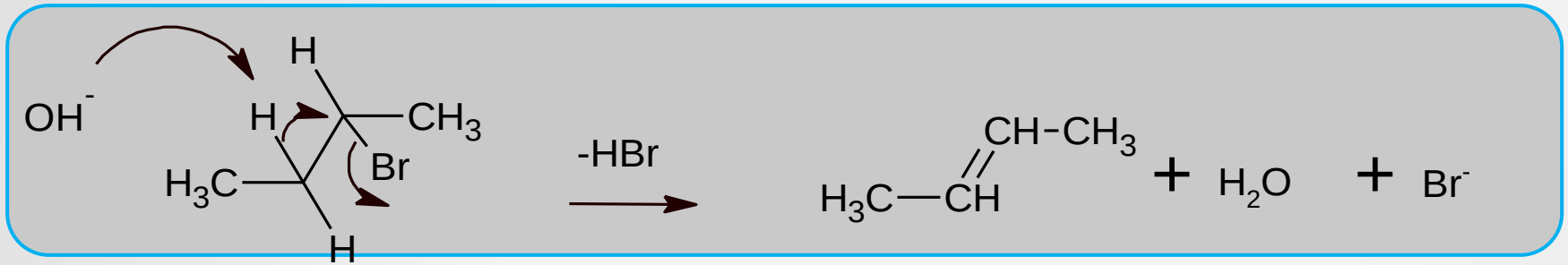
1,2 Elimination or β elimination : In this elimination loss of two atoms/groups from adjacent carbon atom take place.



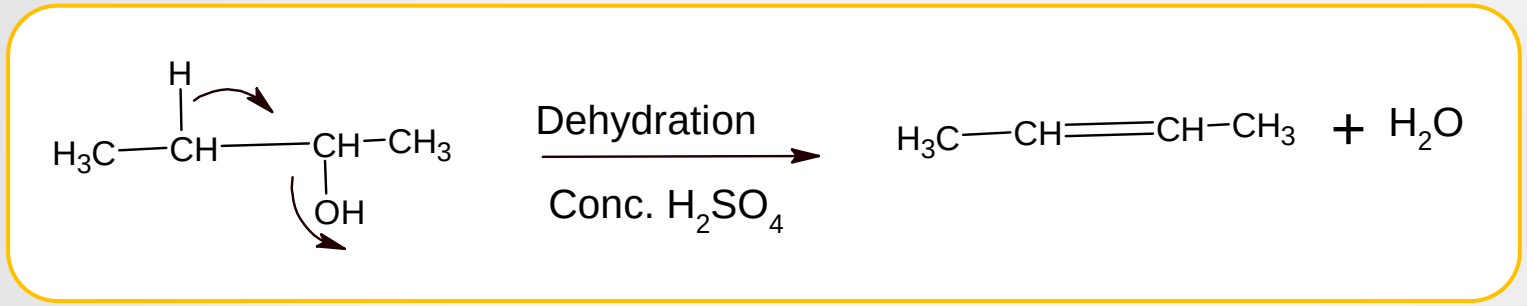


1,2 Elimination

1,2 Elimination Examples:
1) Dehydrohalogenation



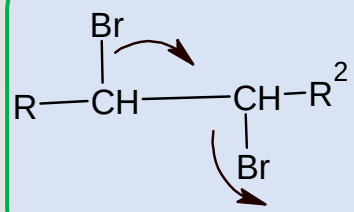
2) Dehydration



Dehydrating Agents like Al_2O_3, Conc H_2SO_4, H_3PO_4 can be used

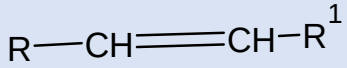
1,2 Elimination

1,2 Elimination Examples:
3) Dehalogenation



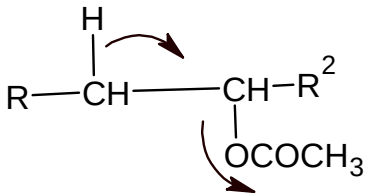
Dehalogenation

I^- or Zn



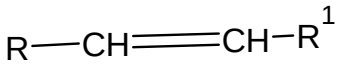
+ $ZnBr_2$

4) Pyrolytic Elimination



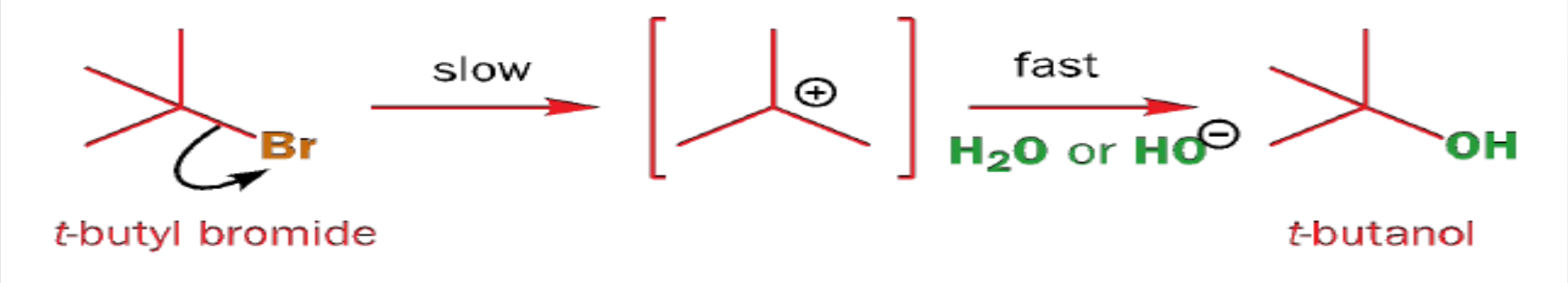
△

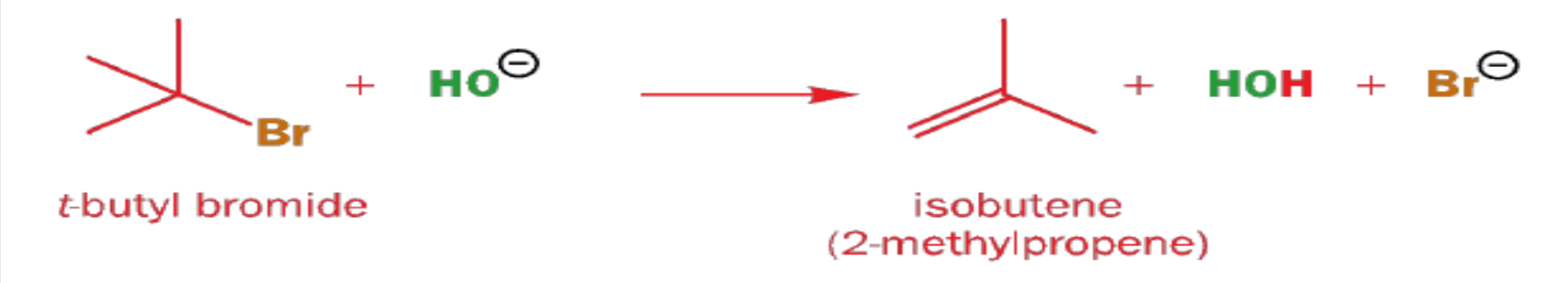
Pyrolytic elimination



+ CH_3COOH

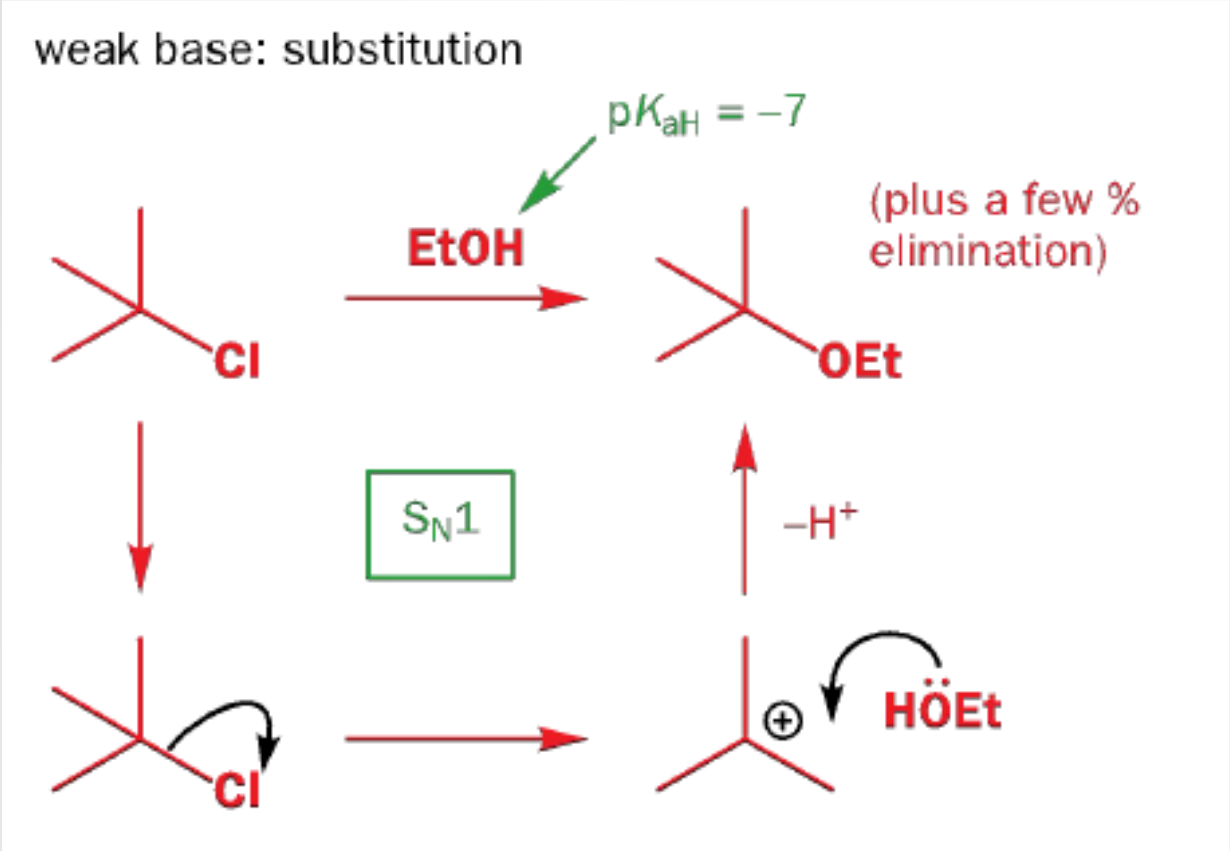
Substitution vs Elimination

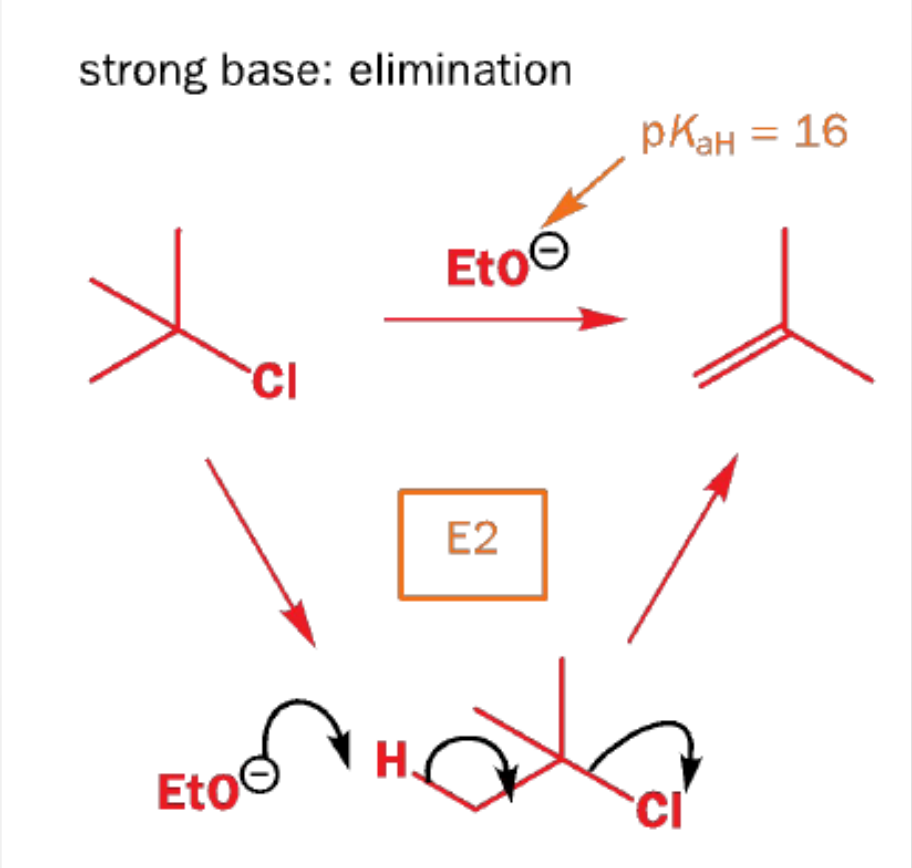




Substitution vs Elimination

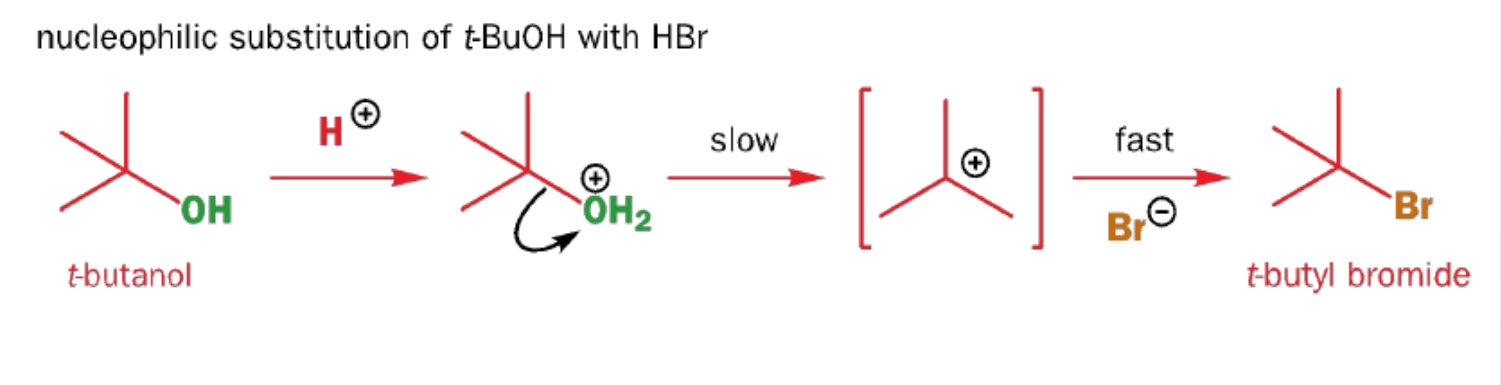
1) Strength of base

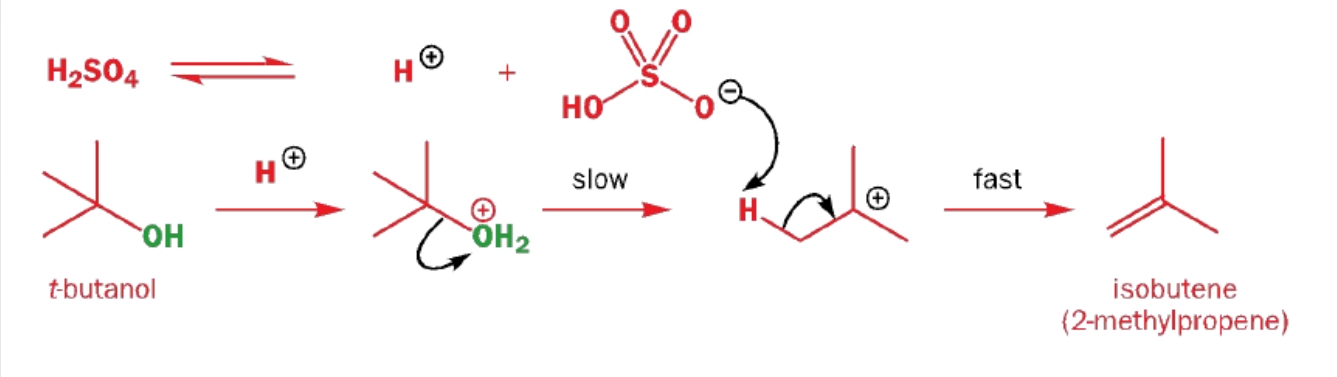




Substitution vs Elimination

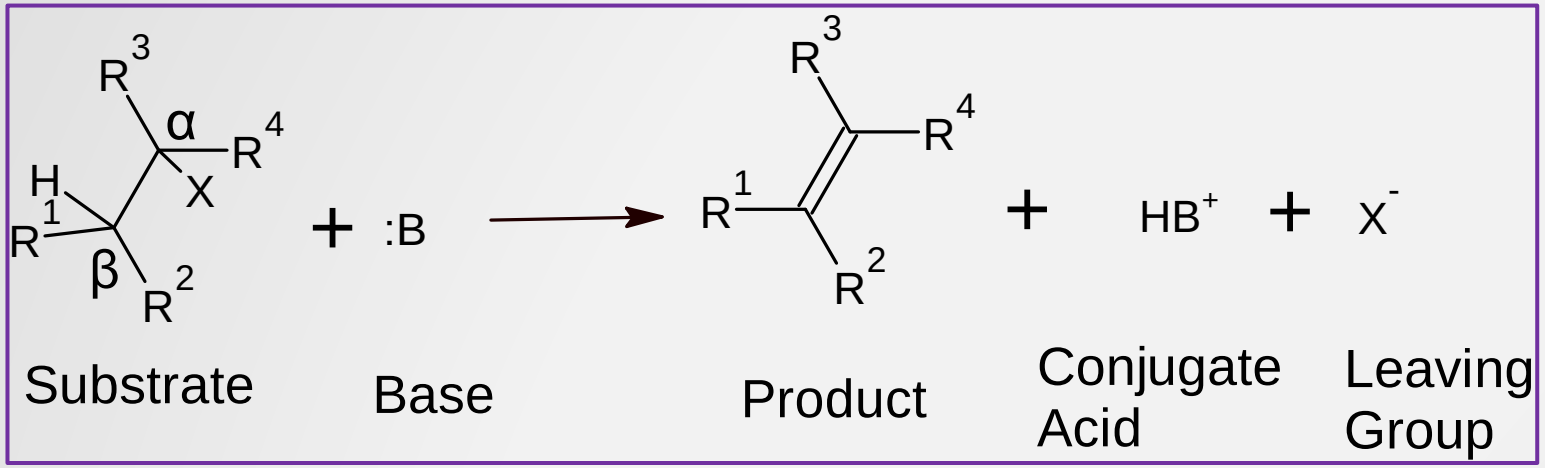
2) Bulky Base/ Nucleophile Favour elimination





3) High temperature Favour elimination

Mechanism of 1,2 elimination (β-elimination)



a) Breaking of Cα -X bond

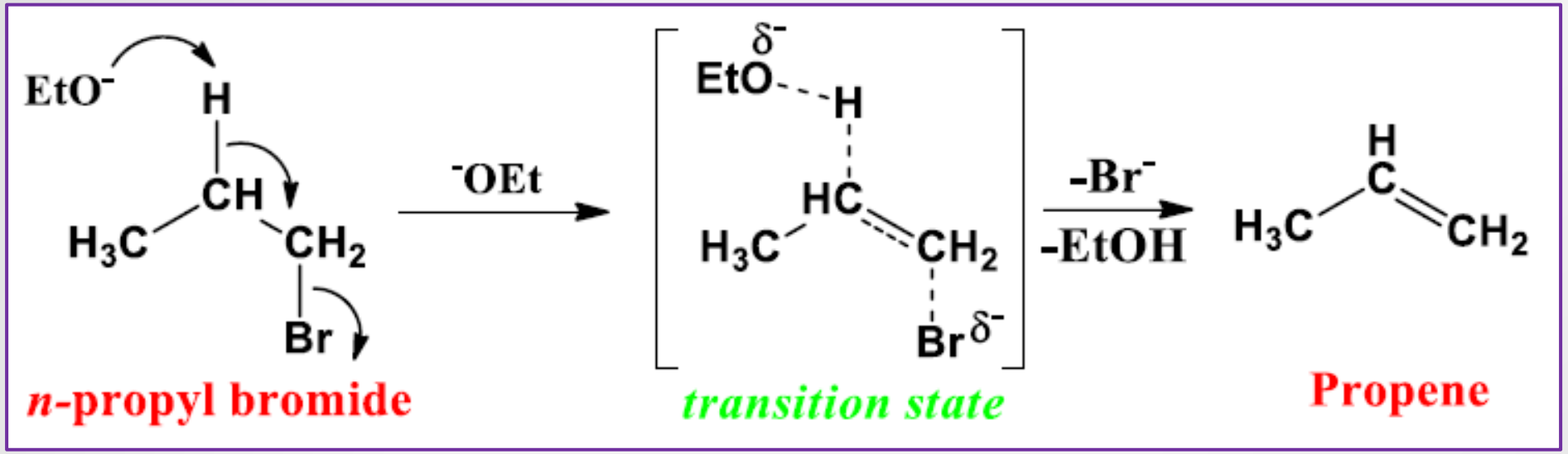
b) Breaking of Cβ -H bond

c) Formation of π bond between Cα - Cβ

Types of 1,2 Elimination (β-elimination)

- E2 (Elimination Bimolecular)
- E1 (Elimination Unimolecular)
- E1cB (Elimination Unimolecular via Conjugate Base)

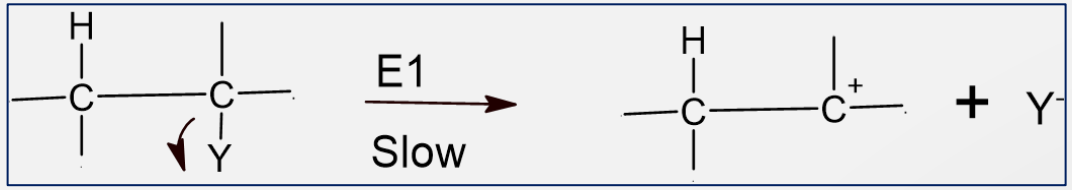
E2 Elimination



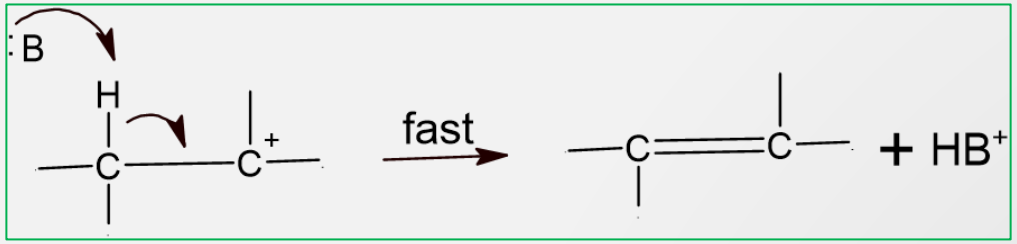
- It is bimolecular elimination
- All bond breaking and bond formation are concerted
- Proceed through single transition state
- It is one step process

E1 Elimination

Step I Formation of Carbocation



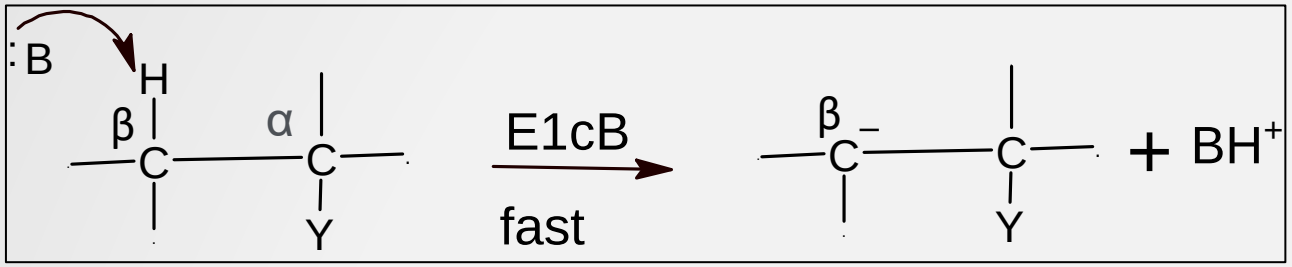
Step I Formation of Alkene



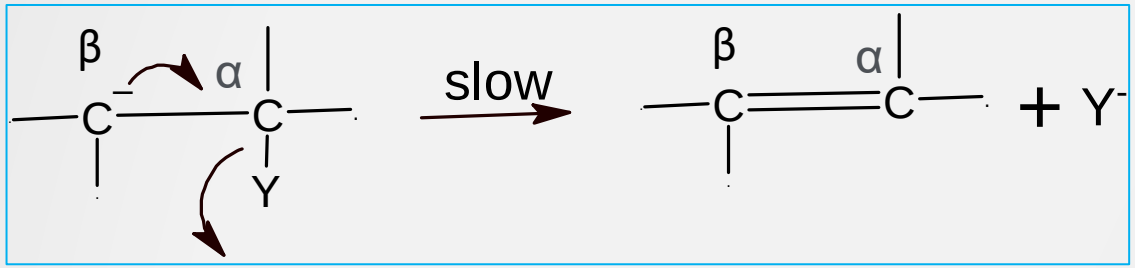
- It is unimolecular elimination
- Stable carbocation is formed in RDS (slow step)
- Rearrangement may take place
- It is two step process.
- Reactivity order of RX is 3°>2°>1°

E1cB Elimination

Step I: Formation of Carbanion

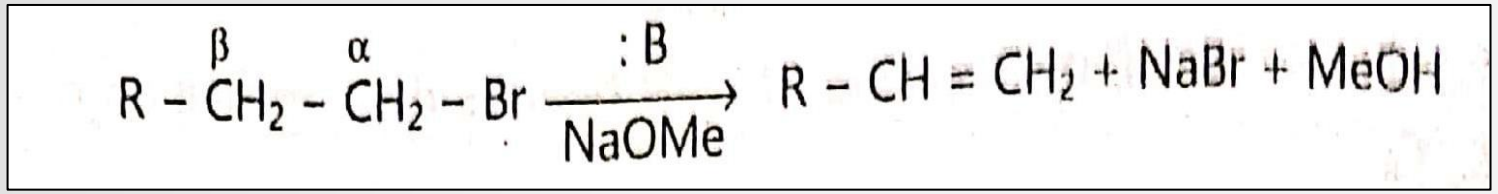


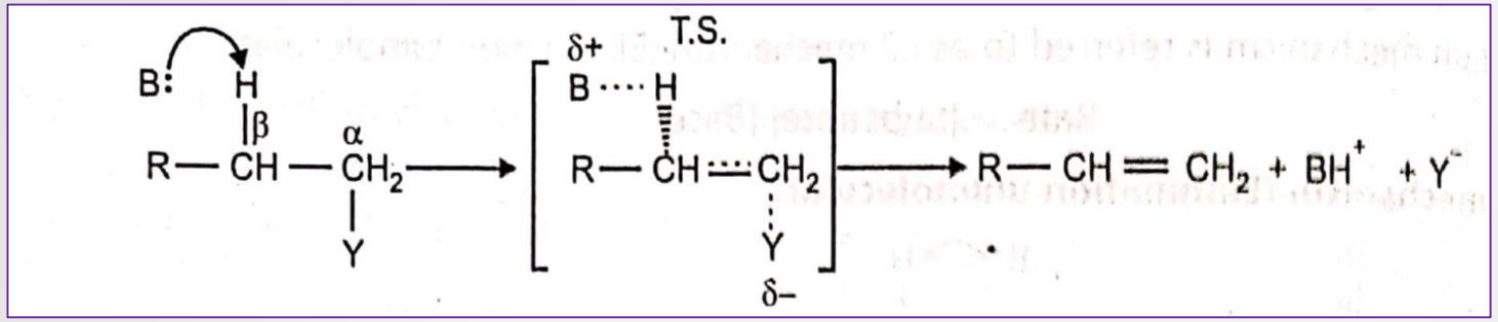
Step II: Formation of Alkene



- a) It is unimolecular elimination
- b) Intermediate carbanion form in fast step
- c) It is two step process.
- d) This mechanism is less common as compare to E1 and E2 mechanism

Mechanism of E2 Elimination





- Base abstracts β hydrogen
- Leaving group simultaneously leaves the molecule
- Formation of multiple bond between Cα and C β carbon atoms.

Mechanism of E2 Elimination

Kinetic

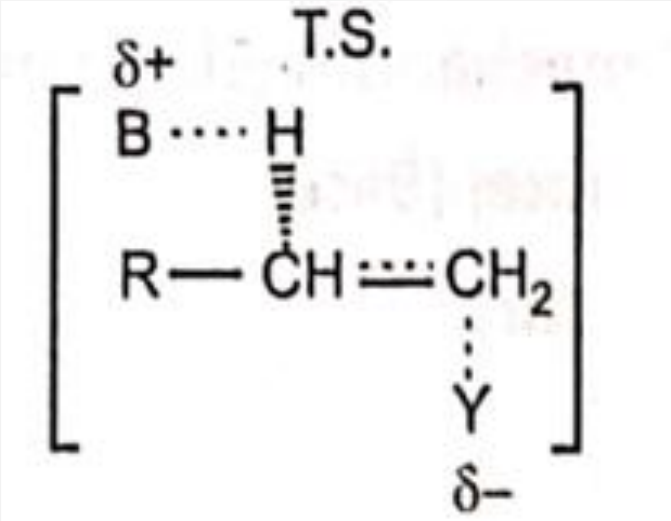
Rate ∝ [R-CH_2-CH_2-Br] [NaOMe]

Rate = K [R-CH_2-CH_2-Br] [NaOMe]

Rate of reaction depends on the concentration of substrate and concentration of base.

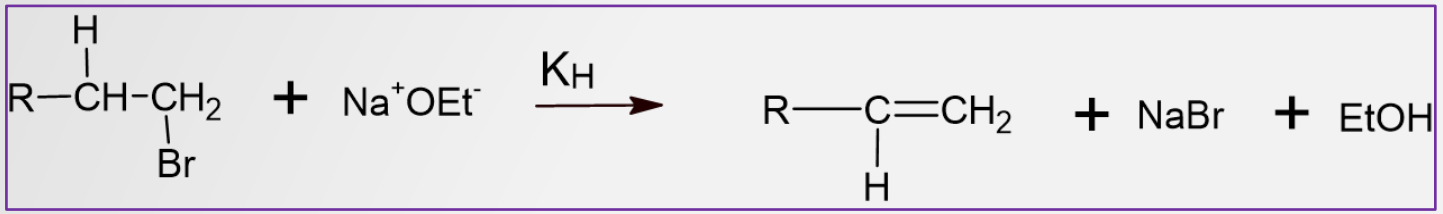
Transition state:

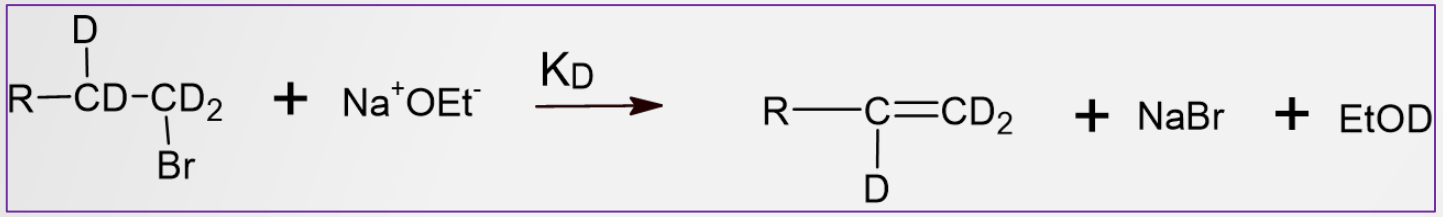
In transition state two bonds (C-H and C-Y) are broken and two new bonds (BH and C=C) are formed



Evidences of E2 Mechanism

1) Kinetic isotopic effect:





KH/ KD = 7
Breaking of C-D bond is difficult than Breaking of C-H bond,

KH/ KD = 7 indicate breaking of these bond take place in slow (RDS) step.

Evidences of E2 Mechanism

2) Nature of leaving group:

$$R\text{-}CH_2\text{-}CH_2\text{-}X \xrightarrow[E2]{Base} R\text{-}CH{=}CH_2$$

Substrate	Relative Rate
$Ph\text{-}CH_2\text{-}CH_2\text{-}F$	1
$Ph\text{-}CH_2\text{-}CH_2\text{-}Cl$	70
$Ph\text{-}CH_2\text{-}CH_2\text{-}Br$	4.2×10^3
$Ph\text{-}CH_2\text{-}CH_2\text{-}I$	3.7×10^4

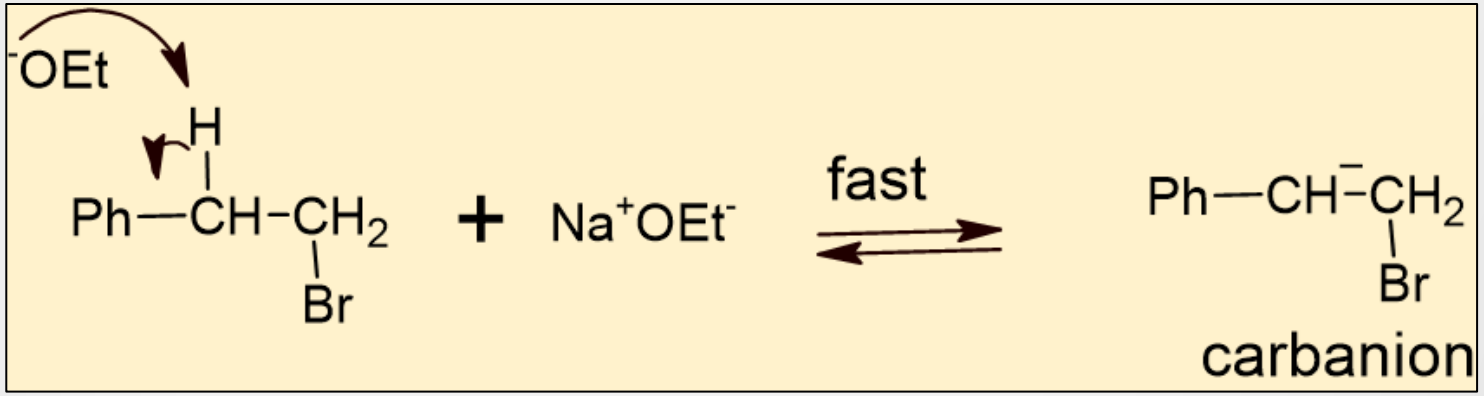
- Leaving group ability of halogen family is I > Br > Cl > F
- Relative rate in above substate indicate that breaking of C –X bond take place in slow (RDS) step.

Evidences of E2 Mechanism

3) Absence of Hydrogen exchange:

- In order to prove that the reaction follows E2 mechanism and not E1cB, hydrogen exchange experiment is performed.

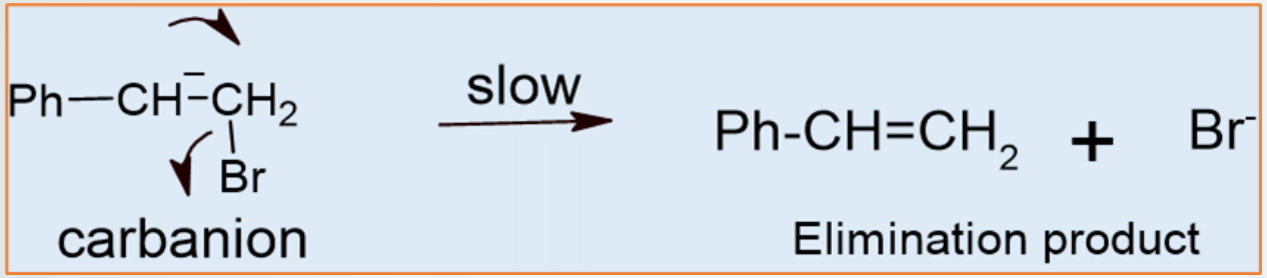
- 2-phenyl ethyl bromide is allowed to react with sodium ethoxide in presence of EtOD. Reaction is allowed to proceed until half and then arrested.

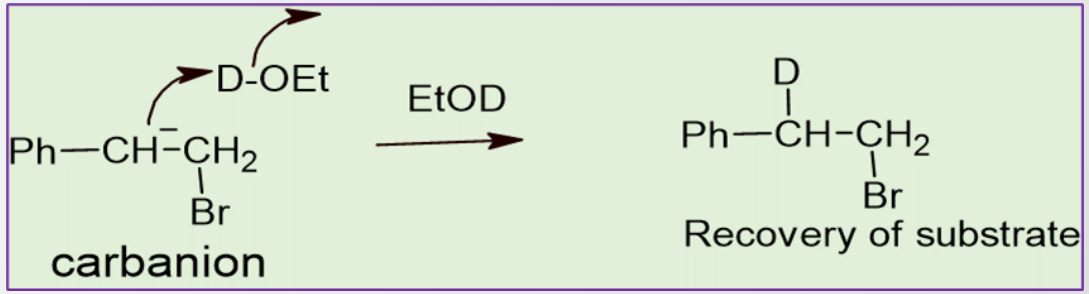


Evidences of E2 Mechanism

3) Absence of Hydrogen exchange:

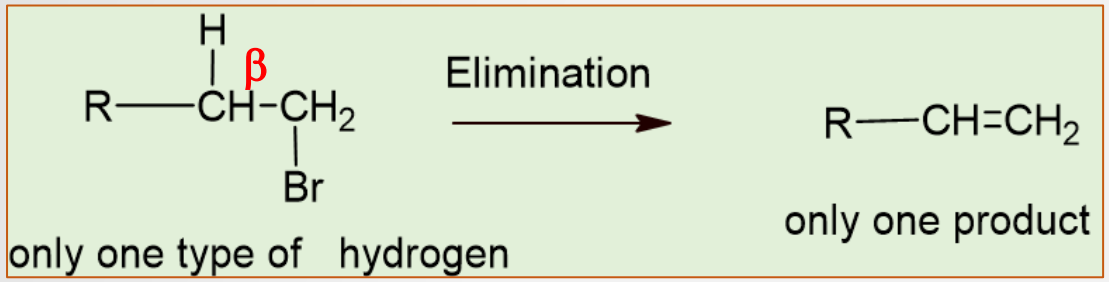
- If reaction follows E1cB mechanism then unreacted substrate should contain deuterium.
- In actual experiment unreacted substrate did not contain deuterium. i.e. there is no hydrogen exchange.

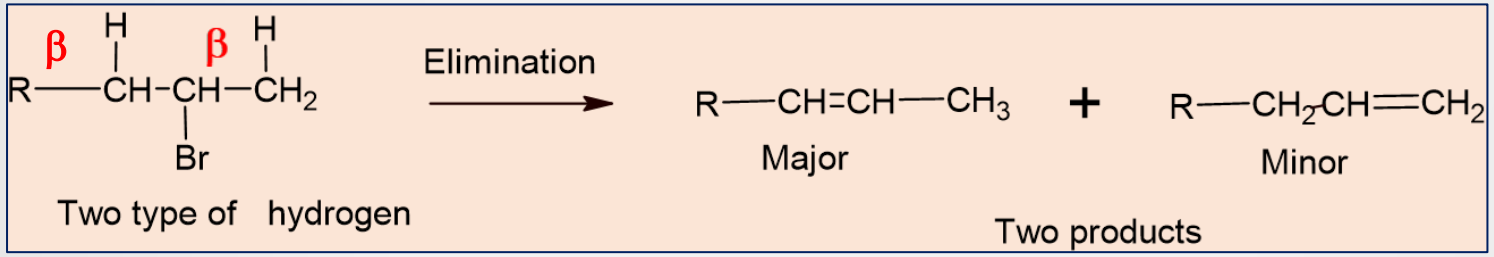




Orientation and reactivity in E2

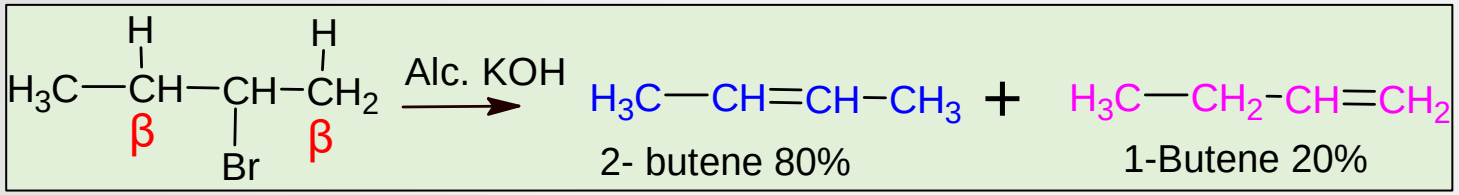
Saytzeff Rule:
In an elimination reaction more substituted alkene is obtained as the major product.

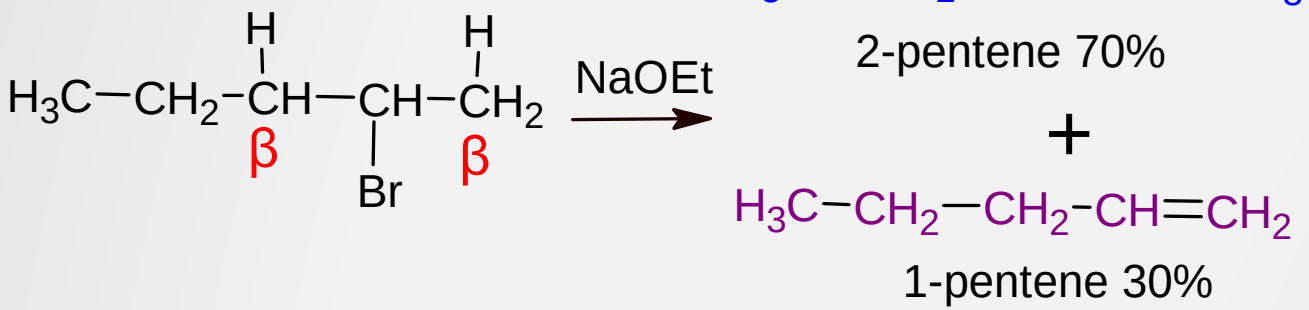


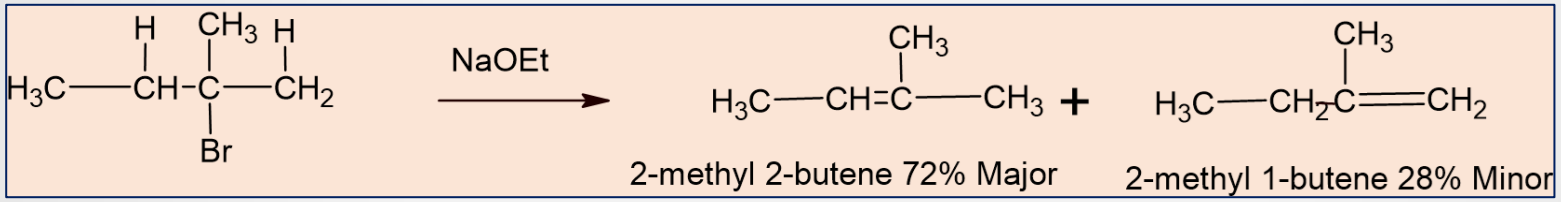


Orientation and reactivity in E2

Saytzeff Rule:







Justification of Saytzeff Rule

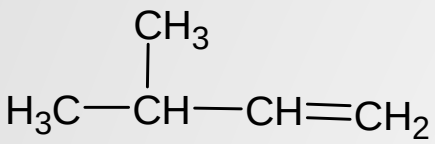
1) **Stability of alkene:**

Alkene	**Order of substitution**	**Heat of hydrogenation**
CH_3-CH_2-CH=CH_2	Monosubstituted	30.3 kcal
CH_3-CH=CH-CH_3	Disubstituted	28.6 kcal (cis) and 27.6 kcal (trans)
CH_3-CH_2-CH_2-CH_2-CH=CH_2	Monosubstituted	30.1 kcal
CH_3-CH_2-CH_2-CH=CH-CH_3	Disubstituted	28.6 kcal (cis) and 27.6 kcal (trans)

- As no of substituent increases stability of alkene increases.
- Stability of alkene depends on heat of hydrogenation.(heat liberated during addition of hydrogen to double bond)
- Lower the heat of hydrogenation more is the stability of alkene.

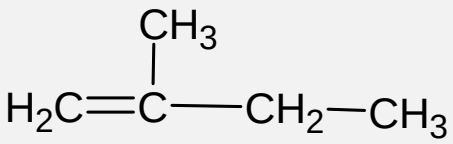
Justification of Saytzeff Rule

1) Stability of alkene:



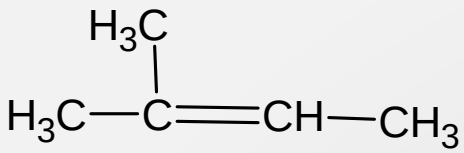
Monosubstituted

30.3 kcal



Disubstituted

28.5 kcal



Trisubstituted

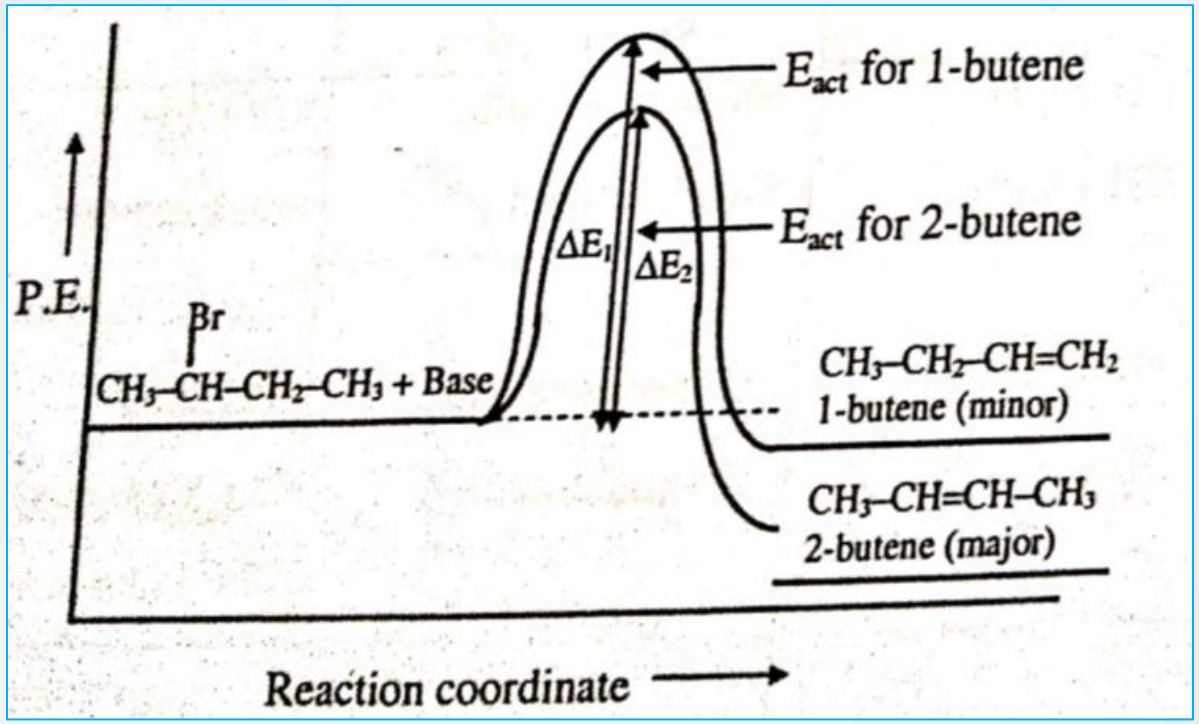
26.7 kcal

General order of stability of alkene is

$R_2C{=}CR_2 > R_2C{=}CH\text{-}R > R_2C{=}CH_2 > R\text{-}CH{=}CH\text{-}R > RCH{=}CH_2 > CH_2{=}CH_2$

Justification of Saytzeff Rule

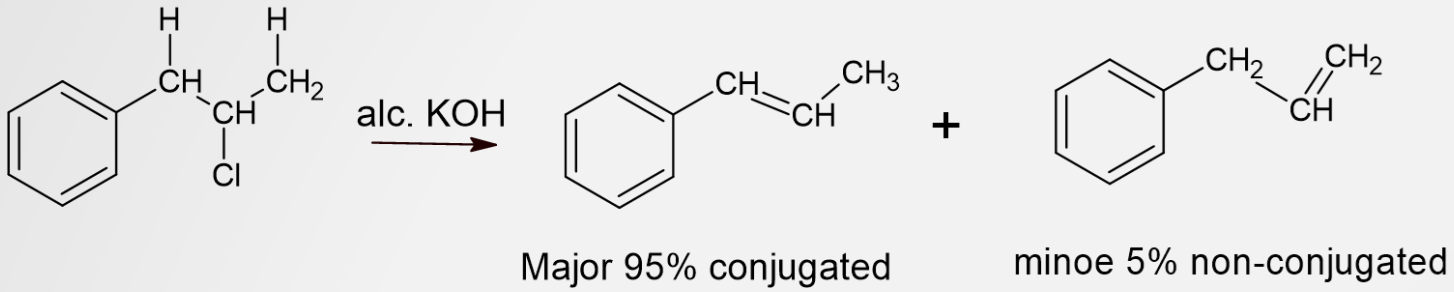
2) Lower energy of activation

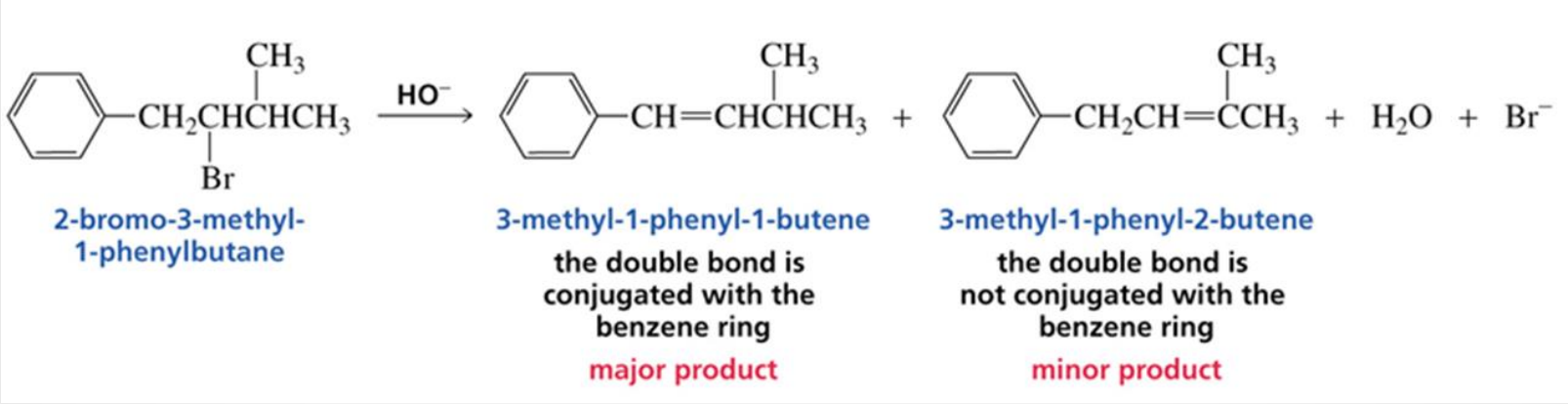


- As number of substituents attached to double bonded carbon atom increases, energy of T.S. goes on decreasing.
- Thus more substituted alkene form with faster rate

Justification of Saytzeff Rule

3) Stability due to resonance effect

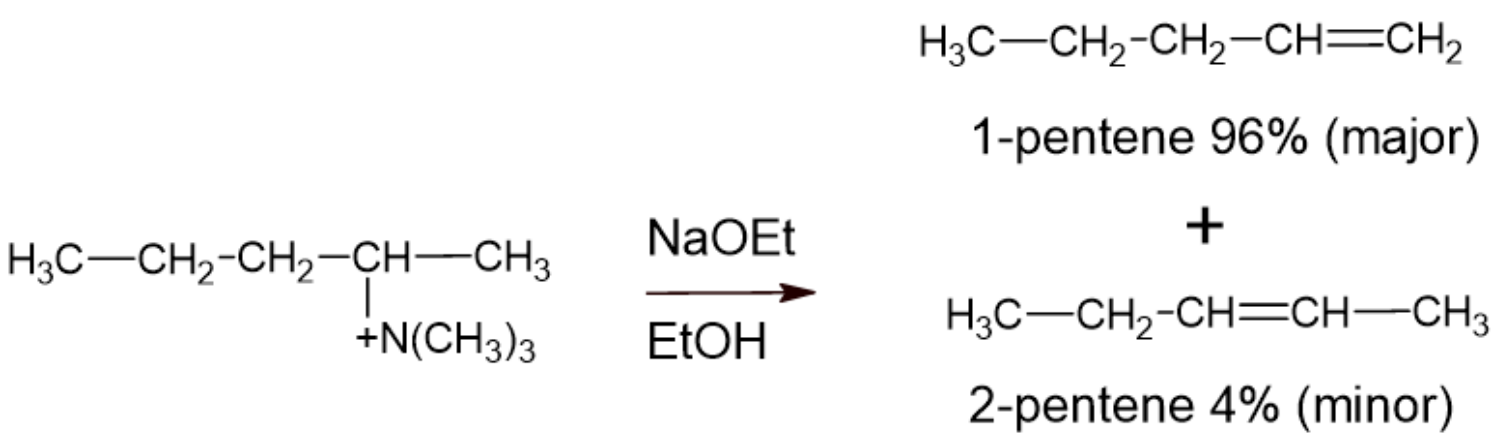




In conjugated alkene extra stabilization by resonance delocalization is possible.

Hofmann Elimination

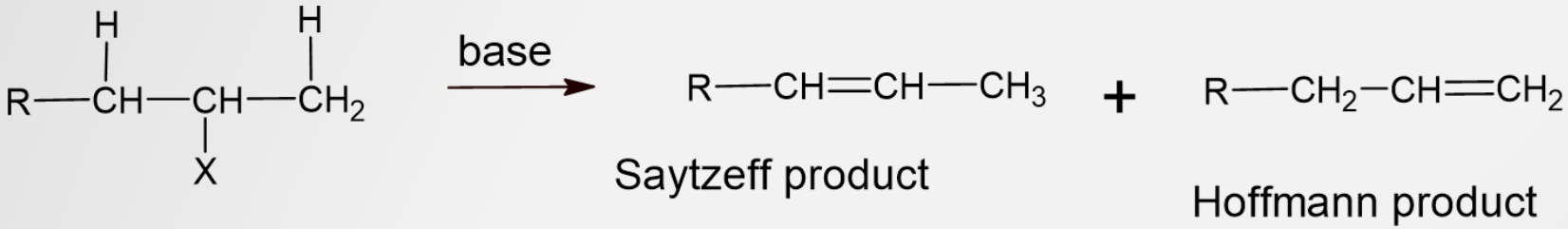
- Hofmann rule: In an elimination reaction less substituted alkene is obtained as the major product.
- When substrate contains more than one type of β hydrogens, then more than one products are formed



Saytzeff and Hofmann orientation

Factors affecting Saytzeff and Orientation

1) The effect of leaving group

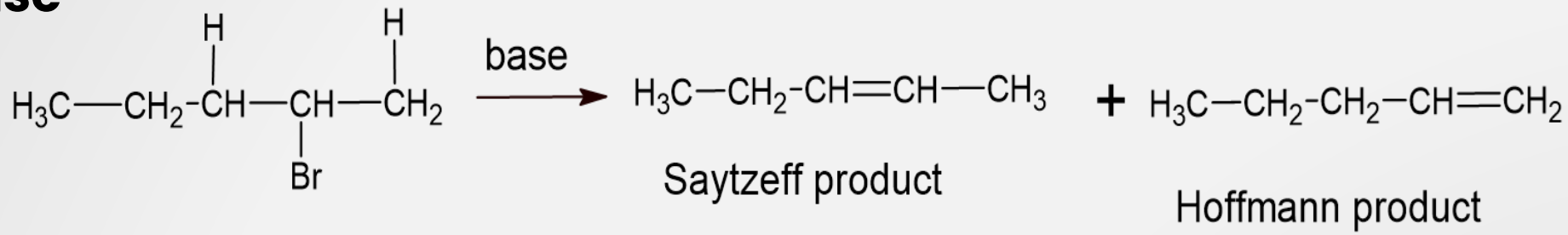


Leaving group	Saytzeff product	Hofmann product
-Br	80%	20%
-OTs	60%	40%
$-^{+}S(CH_3)_2$	25%	75%
$-+N(CH_3)_3$	5%	95%

As size of leaving group increases percentage of Hofmann product increases

Saytzeff and Hofmann orientation

2) Effect of base

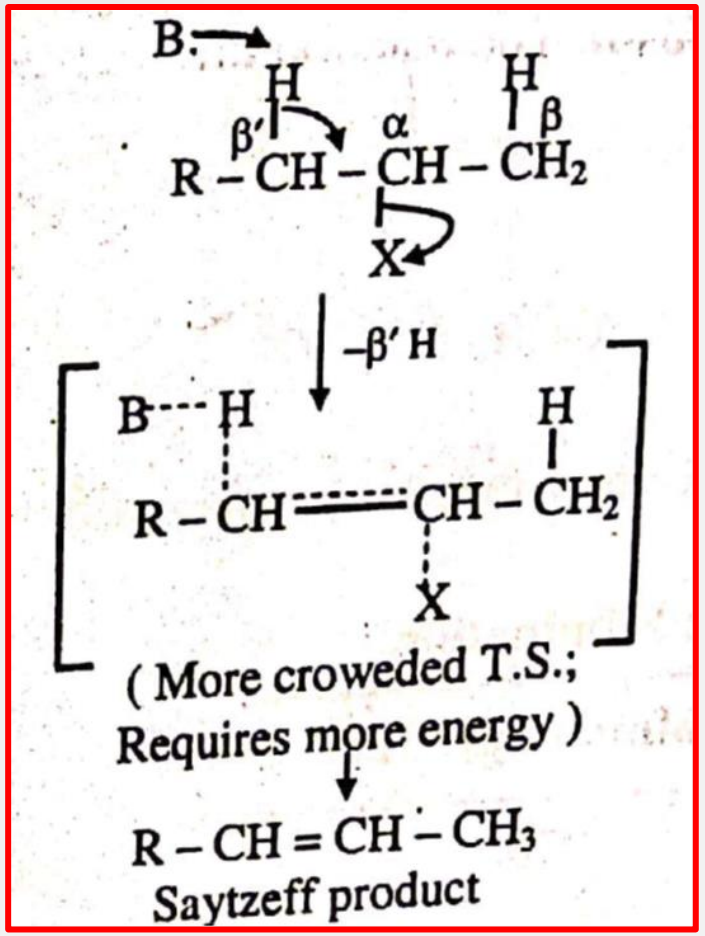


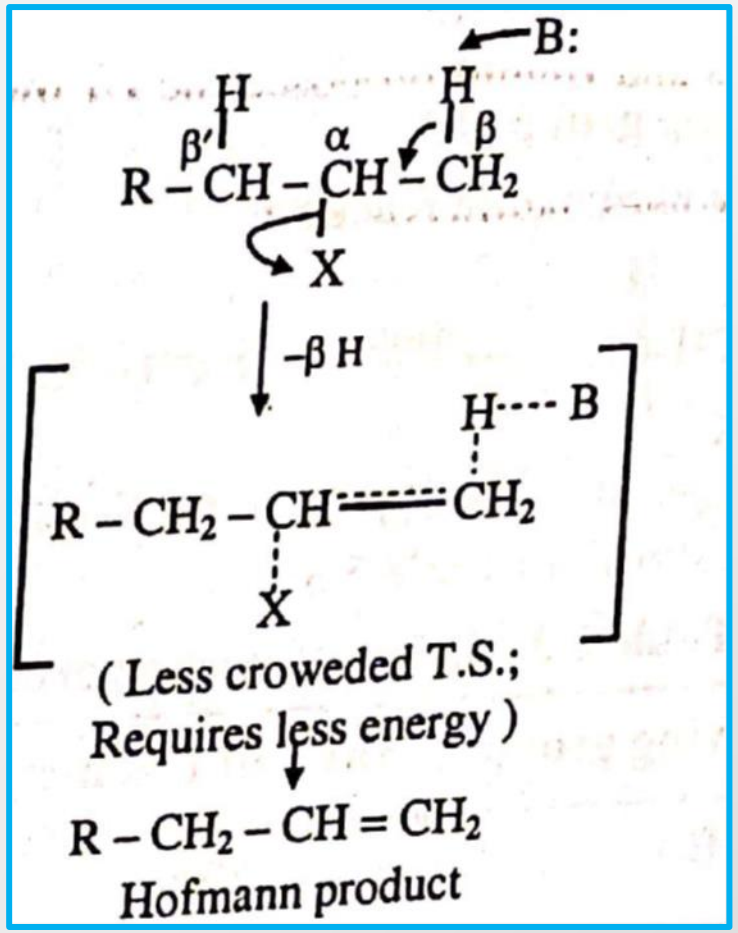
Base	Saytzeff product	Hofmann product
$C_2H_5O^-$	70 %	30 %
$(CH_3)_3C\text{-}O^-$	28 %	72 %
$(C_2H_5)_3C\text{-}O^-$	20 %	80 %

As the size of attacking base increases the transition state for Saytzeff elimination become more crowded than Hofmann elimination .
Thus percentage of Hofmann product increases.

Saytzeff and Hofmann orientation

Transition state in Saytzeff and Hofmann elimination





Student Assessment

1) 2- Bromohexane on treatment with sodium ethoxide gives 2-hexene, since it follows the .....

   a) Markownikoff's b) Saytzeff's rule

   b) Hofmann elimination rule d) None of these

2) Percentage of cis isomer is less than trans isomer in the elimination reactionism explained by .....

   a) heat of hydrogenation b) steric effect

   c) inductive effect d) resonance effect

Student Assignment

1. What is E2 elimination? Discuss the mechanism of E2 elimination
2. Define Saytzeff and Hofmann rule
3. Discuss the kinetic isotopic effect in E2 elimination reaction

SUMMARY

- 1,1 and 1,2 Elimination reactions
- General mechanism of E1, E2 and E1cB Elimination
- Hofmann and Saytzeff rules
- Factors affecting Saytzeff and Hofmann orientation

PRECAP

- Mechanism of E1 elimination
- Stereochemistry of E1 and E2 elimination
- Orientation and reactivity in E1 elimination.

References

- R.T. Morrison & R.N. Boyd: Organic Chemistry, 7th edition, Prentice Hall.
- Reference: J. Clayden Organic Chemistry
- Organic Chemistry: Graham Solomons


Thank You so Much

T.Y. B.Sc. Chemistry

CH-507 Organic Chemistry

Elimination Reactions

RECAP

Types of Elimination Reactions

General mechanism of E1, E2 and E1cB reactions

Mechanism of E2 elimination

Orientation in elimination reaction

Saytzeff and Hofmann elimination

SESSION AGENDA

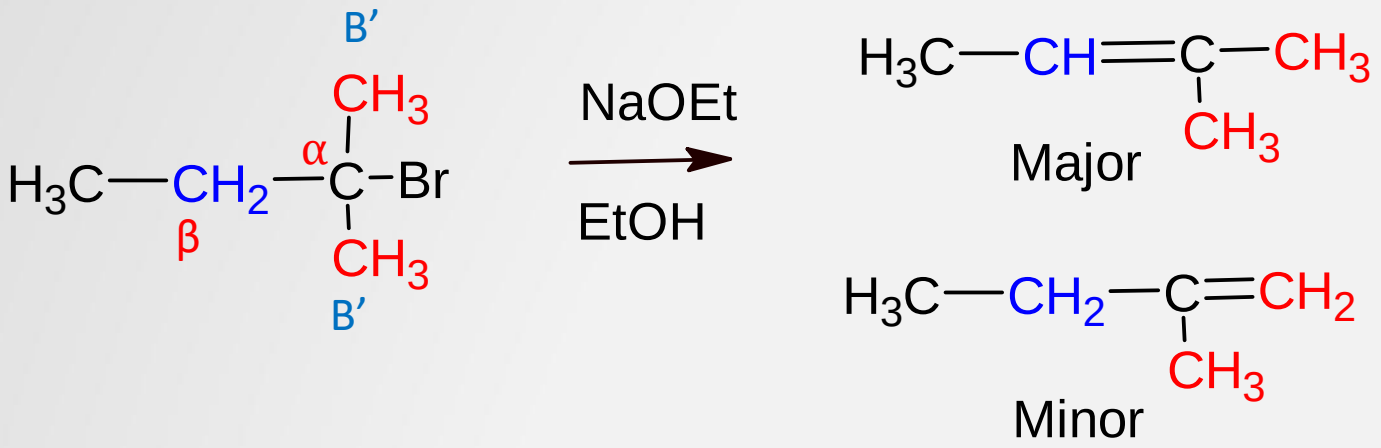
- Mechanism of E1 Reaction
- Evidences in E1 mechanism
- Orientation and reactivity in E1 elimination.
- Mechanism of E1cB elimination

LEARNING OBJECTIVES

Students should understand

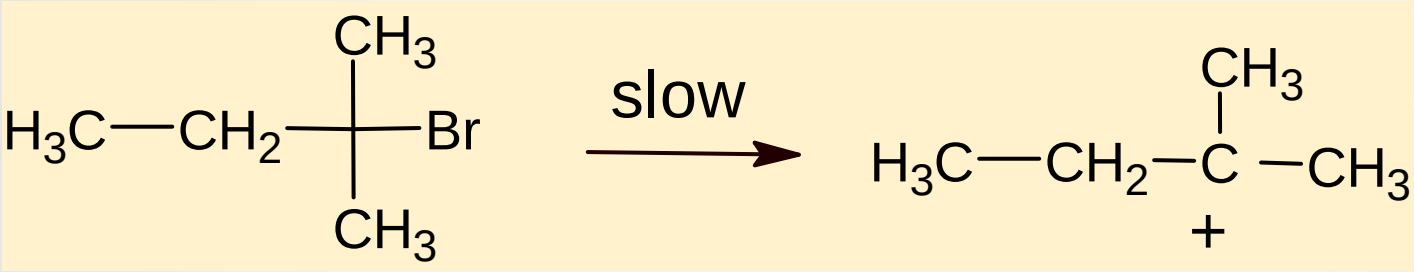
- Mechanism of E1 elimination.
- Rearrangements involved in E1 elimination
- Orientation and reactivity in E1 Elimination
- Differentiation of E1, E2 and E1cB elimination.

E1 Elimination



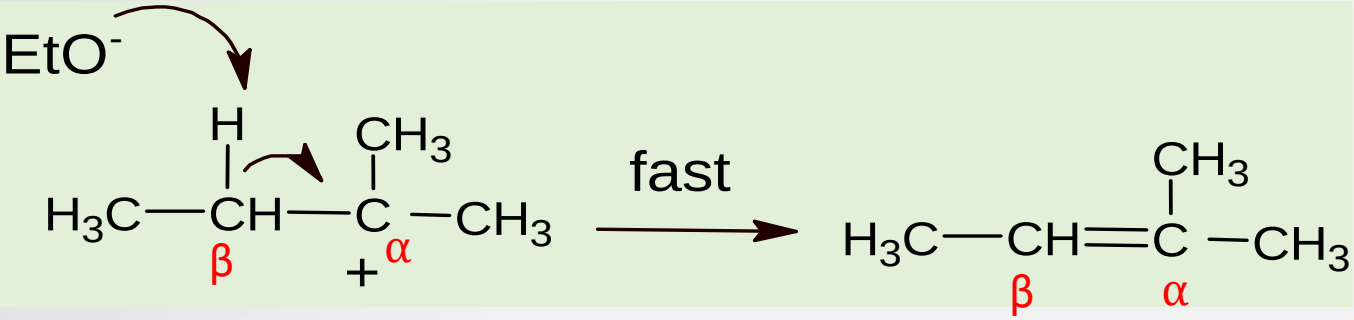
Mechanism

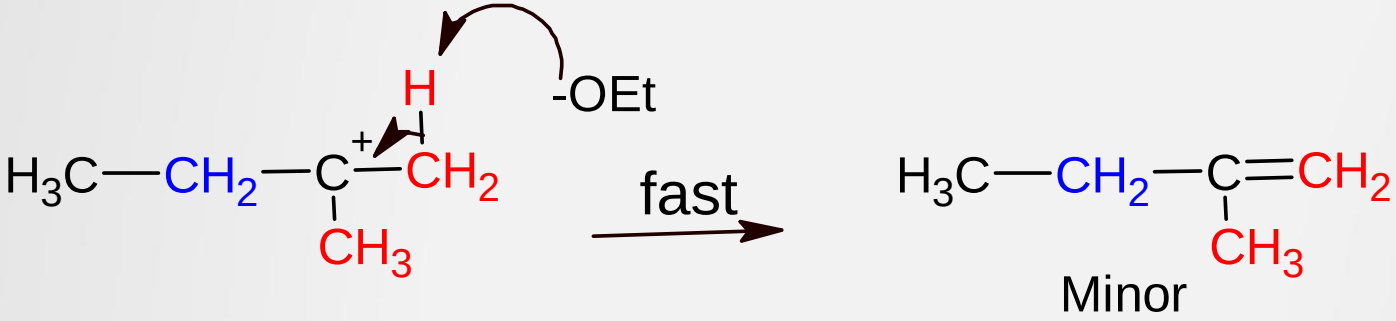
Step I : loss of leaving group



E1 Elimination

Mechanism
Step II : abstraction of proton

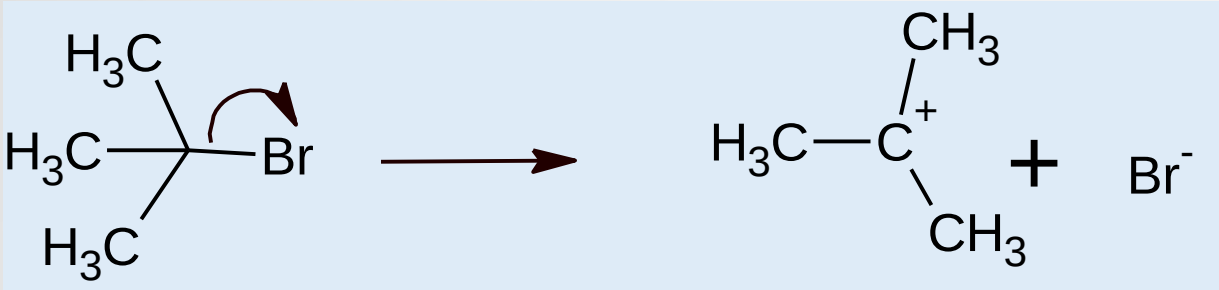


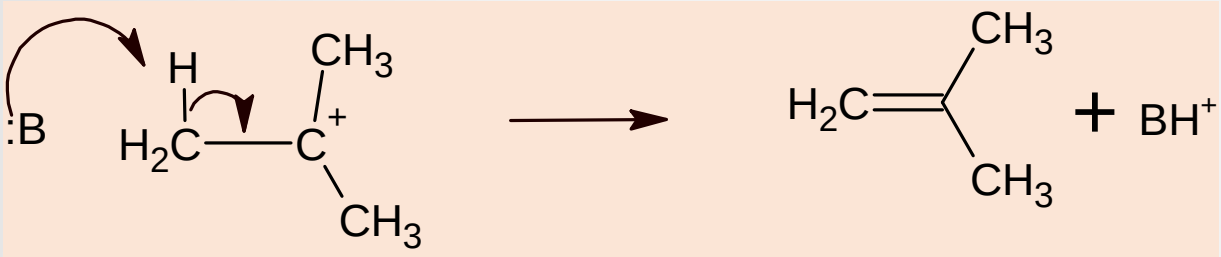


E1 Elimination

- It is unimolecular elimination reaction
- Two-step mechanism
- First step: breaking of Cα-halogen bond and formation of carbocation as an intermediate.
- Second step: breaking of Cβ -hydrogen bond and formation of Cα-Cβ π bond.
- Reactivity of alkyl halide is $3^0 > 2^0 > 1^0$
- Formation of carbocation is take place in slow step(RDS)

Mechanism of E2 Elimination





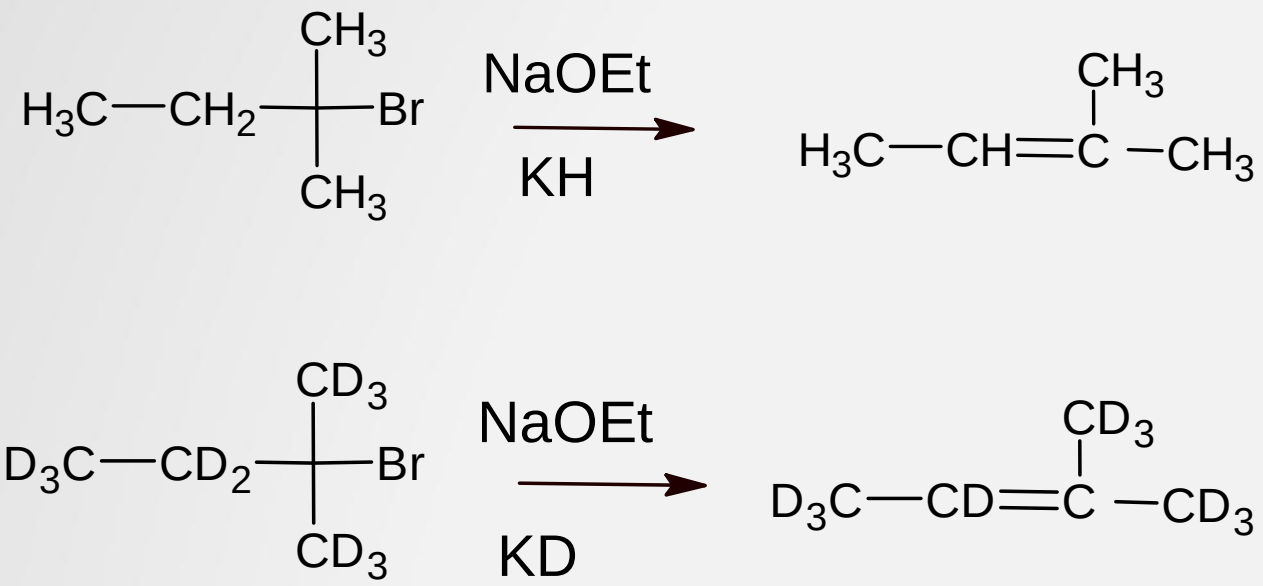
Kinetic

Rate ∝ $[CH_3\text{-}CH_2\text{-}C(CH_3)_2\text{-}Br]$

Rate = K $[CH_3\text{-}CH_2\text{-}C(CH_3)_2\text{-}Br]$

Evidences of E1 Mechanism

1) Kinetic isotopic effect:



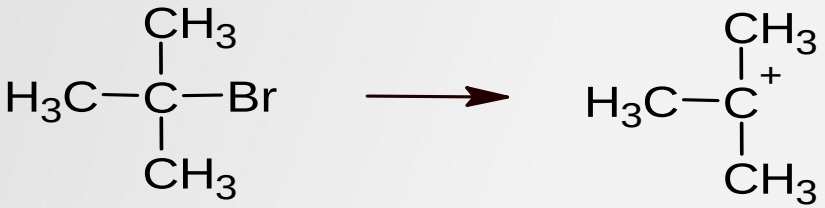
KH = KD

Breaking of C-H or C-D bond take place in fast step. Hence no kinetic isotopic effect is observed in E1 elimination

Evidences of E1 Mechanism

2) Structural effect:

In E1 elimination carbocation is formed as key intermediate. Stability of carbocation is $3^0 > 2^0 > 1^0$



3^0 carbocation

2^0 carbocation

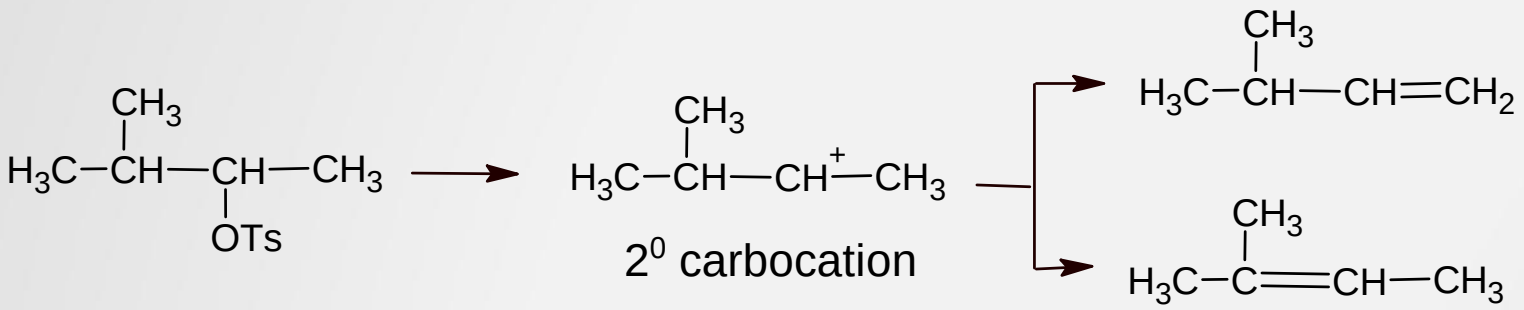
1^0 carbocation

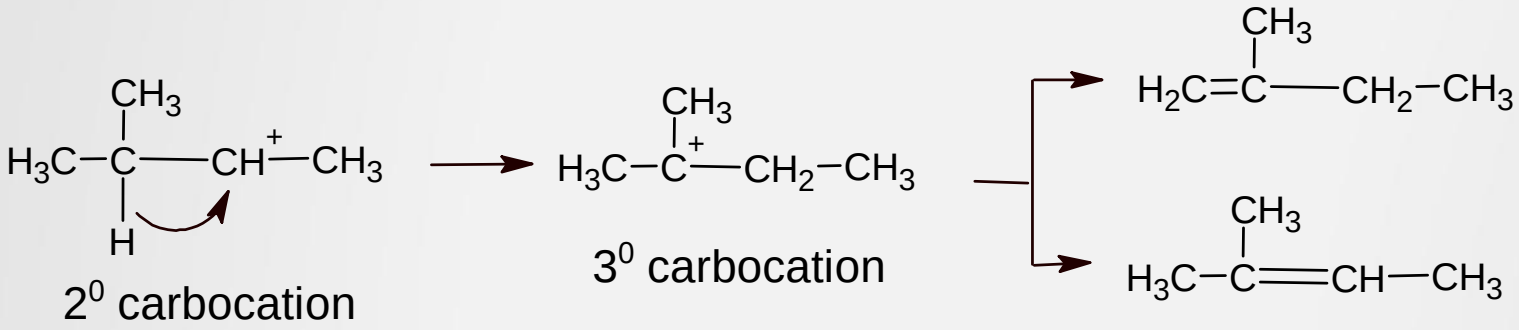
Rate of E1 reaction is in following order $3^0 > 2^0 > 1^0$

Evidences of E1 Mechanism

3) Rearrangements

Stability of carbocation is $3^0 > 2^0 > 1^0$. Thus primary and secondary carbocations rearranges to more stable carbocation.

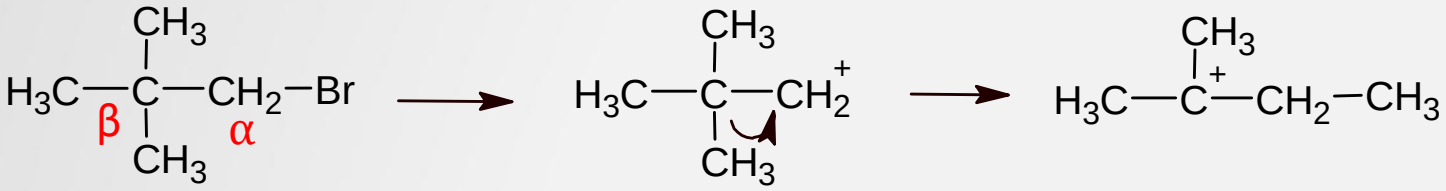




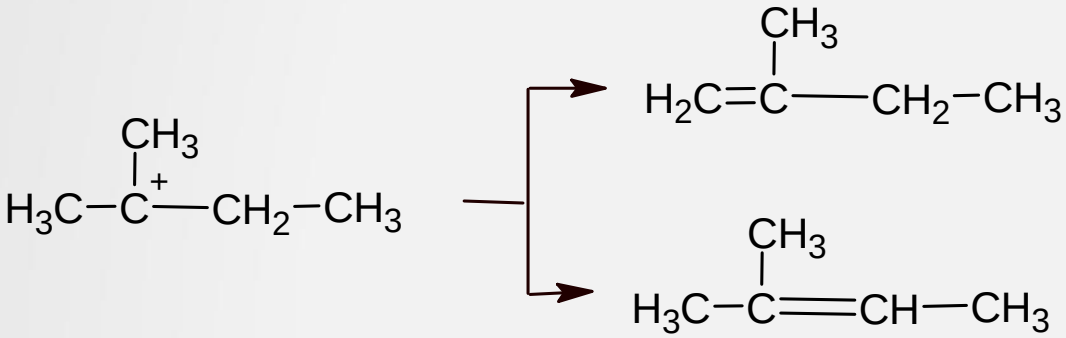
Evidences of E1 Mechanism

4) Absence of β Hydrogen

In absence of β hydrogen E2 mechanism is not possible but E1 elimination can take place by formation of carbocation.

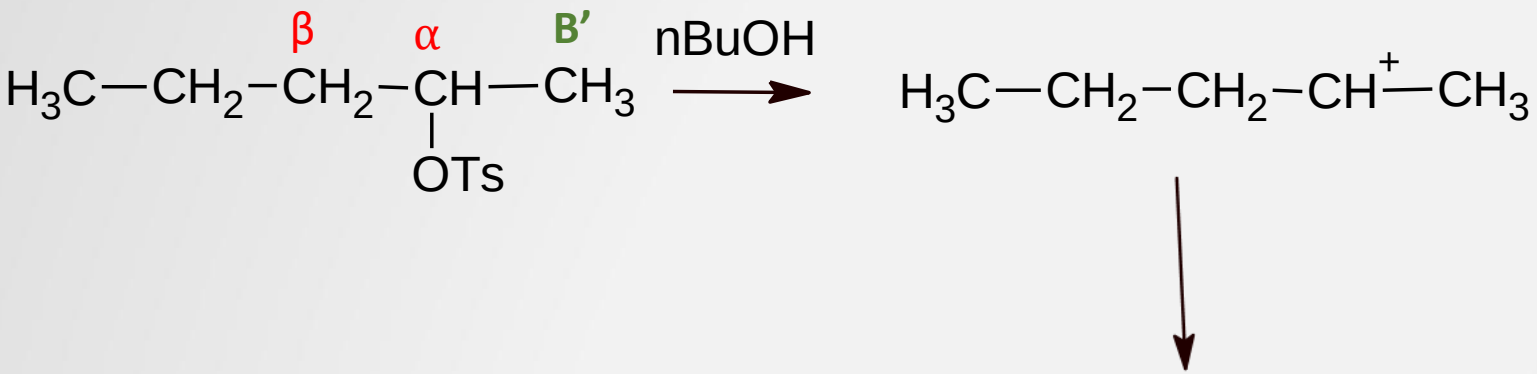


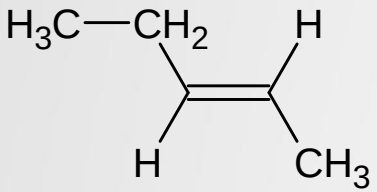
1^0 carbocation 3^0 carbocation



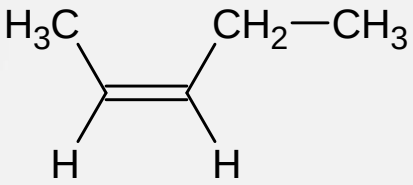
Orientation of E1 Mechanism

E1 elimination shows strong Saytzeff orientation





trans 2-pentene 70%



Cis 2-pentene 19%

1-pentene 11%

Factors affecting E1 Mechanism

A) Effect of Substrate

- Reactivity order of alkyl halide is

$(CH_3)_3C-X > (CH_3)_2CH-X > CH_3CH_2-X > CH_3-X$

- In first step (RDS) of E1 reaction carbocation is formed.
- Stability of carbocation is $3^0 > 2^0 > 1^0$
- The rate of an E1 elimination increases as the number of R groups attached to α carbon increases

Factors affecting E1 Mechanism

B) Leaving group

- In E1 elimination breaking of C-L.G bond take place in slow step (RDS)
- Rate of E1 elimination is greatly affected by the nature of leaving group
- Better the leaving group, the faster the E1 elimination

Factors affecting E1 Mechanism

C) Base

- As involvement of base in E1 elimination is in fast step, thus rate is not affected by the nature of the base
- Generally weak base favors E1 elimination.

d) Solvent

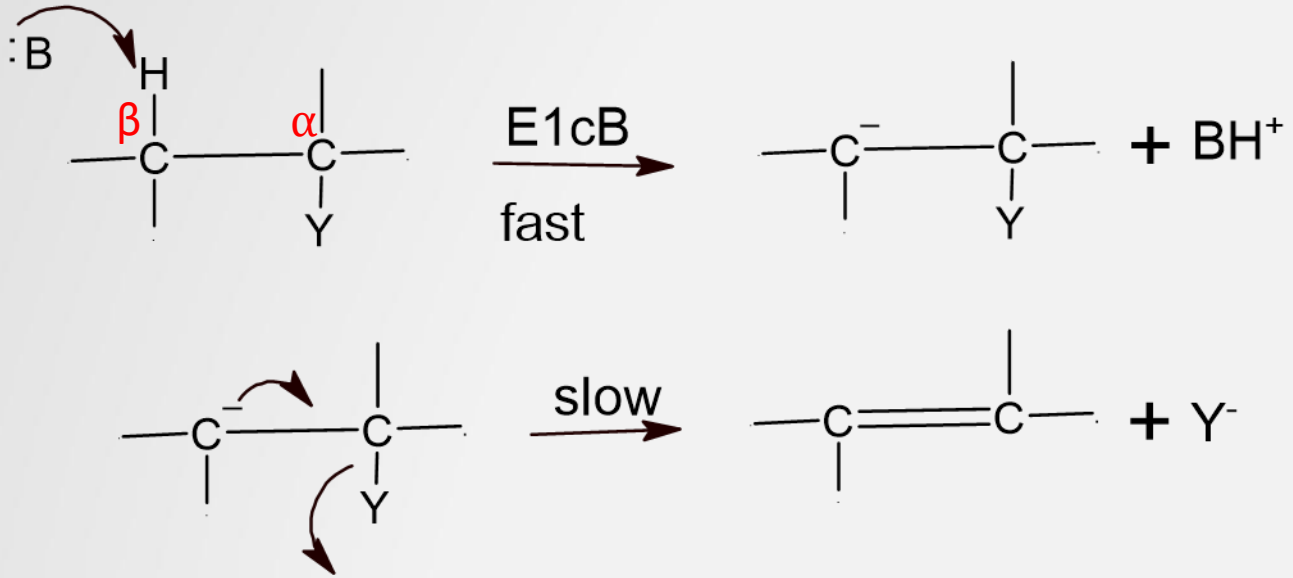
E1 elimination favored by Polar solvents as it stabilizes intermediate carbocation.

The E1cB Mechanism

E1 Elimination	E2 Elimination
1) Rate of reaction does not depend on concentration and nature of base.	1) Rate of reaction depends upon concentration and nature of base.
2) Reactivity of substrate by E1 increases because of the greater stability of carbocation formed in R.D.S.	2) Reactivity of substrate by E2 increases because of the greater stability of highly branched alkene formed.
3)E1 mechanism takes place with secondary and tertiary substrate	3) E2 mechanism take place with primary substrate

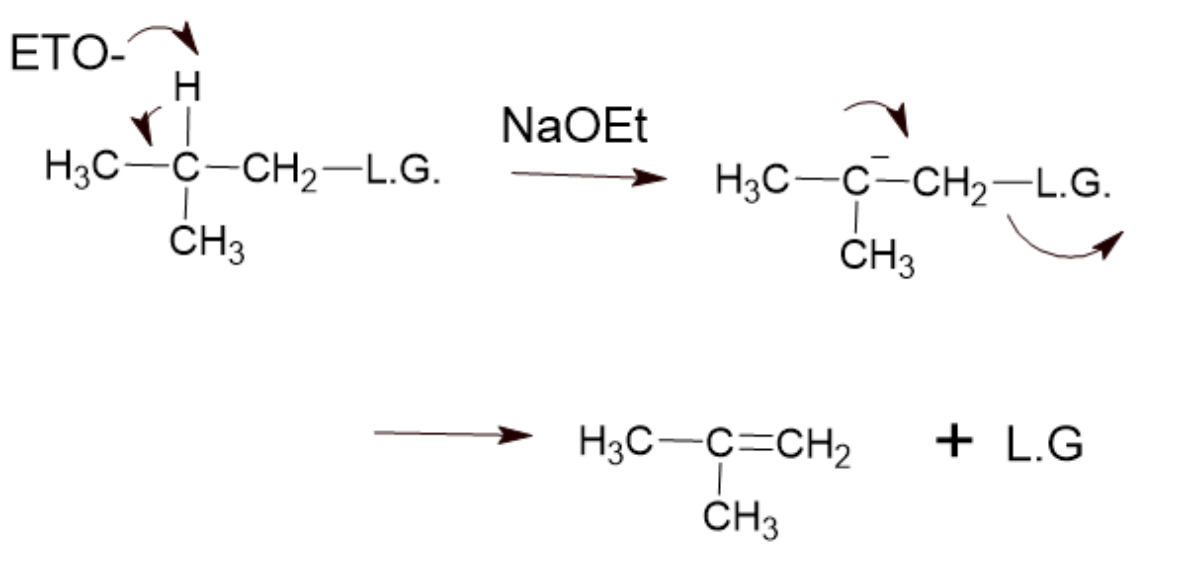
The E1cB Mechanism

E1cB (Elimination through conjugate base)



- It is unimolecular elimination
- Intermediate carbanion form in fast step
- It is two step process.
- This mechanism is less common as compare to E1 and E2 mechanism

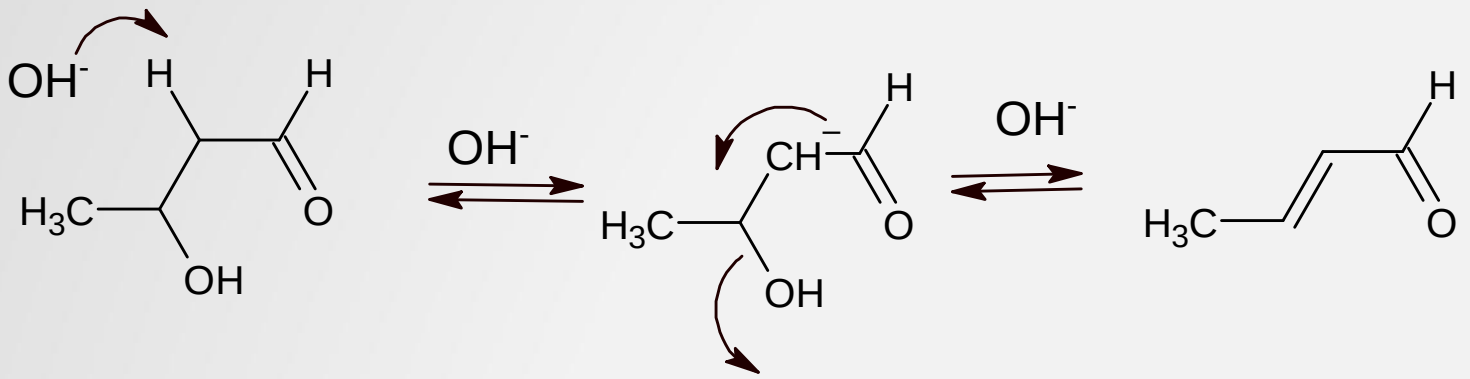
The E1cB Mechanism



First step of E1cB is formation of carbanion.
Second step involve departure of leaving group and formation of double bond / triple bond

Rate= K [Substrate]

The E1cB Mechanism



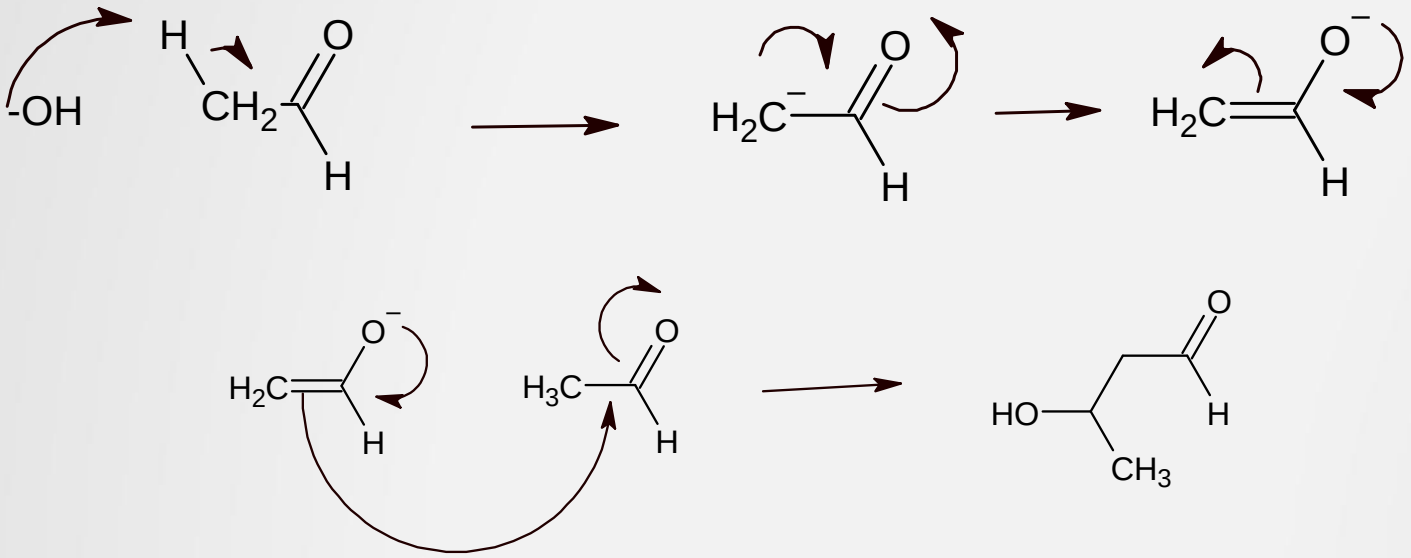
- Most common reaction of E1cB mechanism is dehydration of aldol

- Aldol on deprotonation produce carbanion/enolate and finally produce α-β unsaturated carbonyl compound by E1cB mechanism

The E1cB Mechanism

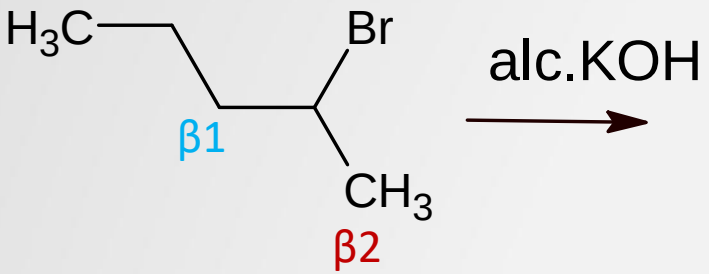
- Most common reaction of E1cB mechanism is aldol condensation reaction.
- It involve formation of stable carbanion /enolate.

Followed by reaction with anther aldehyde to produce aldol.



Elimination Reactions

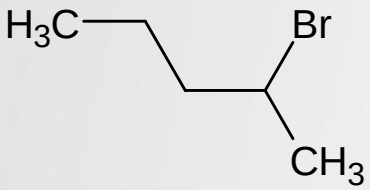
Predict the products



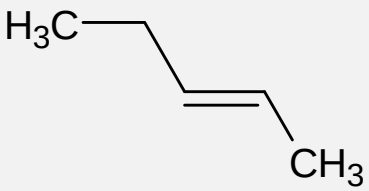
alc.KOH →

? + ?

major minor

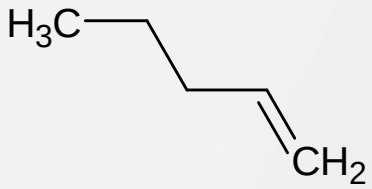


alc.KOH →



major

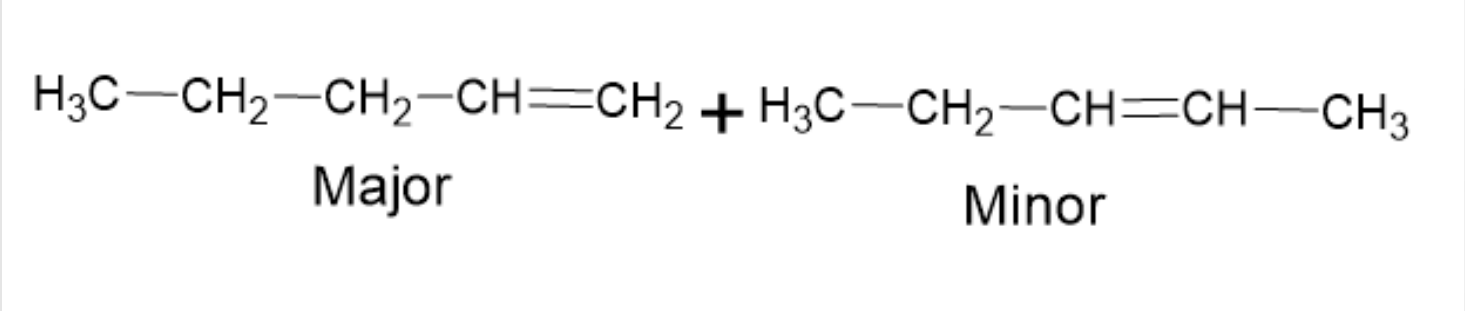
+



minor

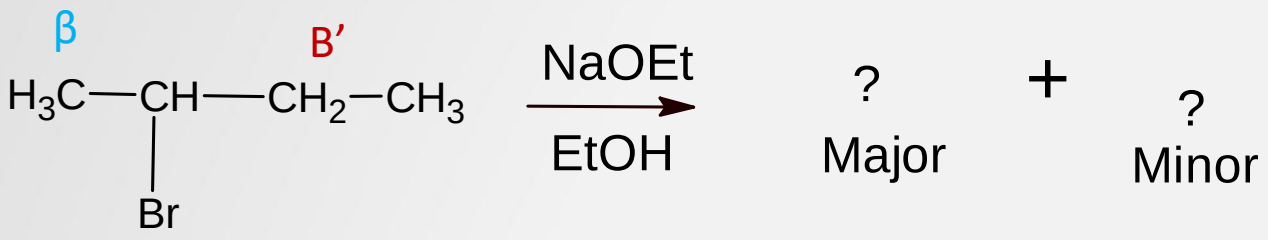
Elimination Reactions

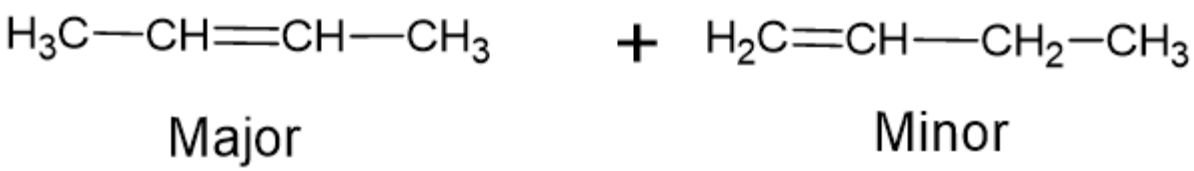
Predict the products



Elimination Reactions

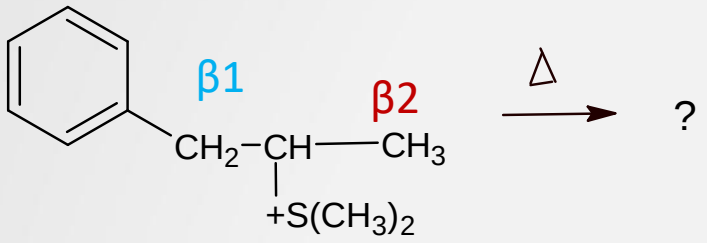
Predict the products

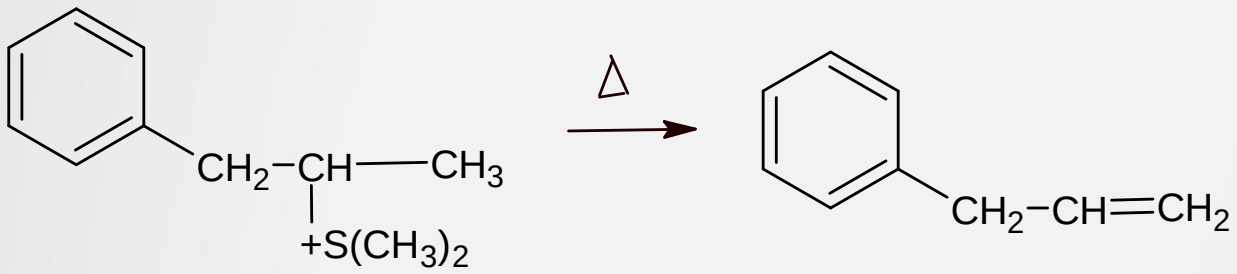




Elimination Reactions

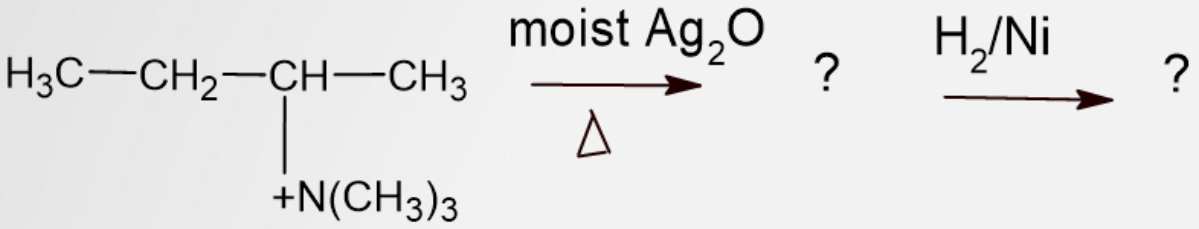
Predict the products

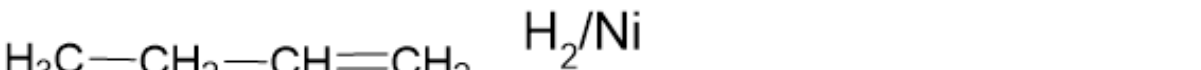




Elimination Reactions

Predict the products





Student Assignment

1. What is E1 elimination? Discuss the mechanism of E1 elimination
2. Explain E1cB mechanism with example

SUMMARY

- Mechanism of E1 Elimination
- Evidences in E1 mechanism
- Factors affecting E1 elimination
- Mechanism E1cB Elimination
- Major and minor product aa per Saytzeff and Hofmann rule

References

- R.T. Morrison & R.N. Boyd: Organic Chemistry, 7th edition, Prentice Hall.
- Reference: J. Clayden Organic Chemistry
- Organic Chemistry: Graham Solomons


Thank You so Much