Elimination Reactions
2 – Introduction to Elimination Reactions

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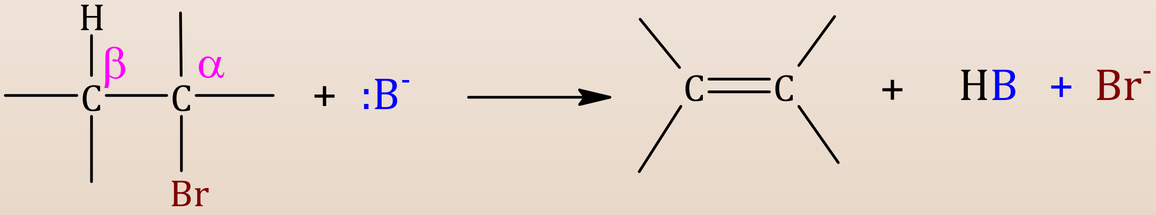
Elimination Reaction Introduction

Elimination reactions are when there is elimination of a hydrogen and leaving group, usually a halide (Br^- or Cl^-). Product of this reaction is an alkene.



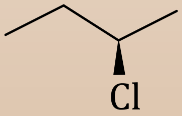
- There are two mechanisms for elimination. E1 and E2.
- Eliminations are called α β-elimination (α carbon is the one that has the leaving group and β is the one next to it with a hydrogen. There can be more than one β hydrogens.) or 1,2-elimination where 1 is the carbon with the LG.

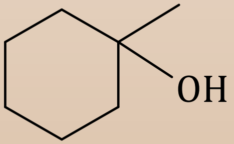
Identifying Hs to Eliminate

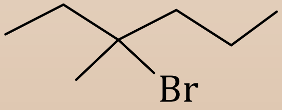
- All eliminations are α β or 1, 2, where α carbon or 1 carbon has the LG and β carbon or 2 carbon has the H.
- The first thing to do in elimination reactions is to identify ALL the β H that can be eliminated in to form ALL the products.
- Some of the products may be the same or major, some minor, but still, one has to know all the β hydrogens.

<u>Solved Problem: Identifying β hydrogens</u>.

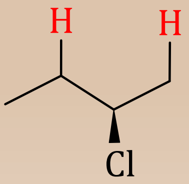
Identify all the beta hydrogens in the compounds given below.

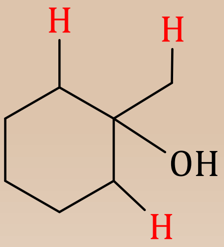


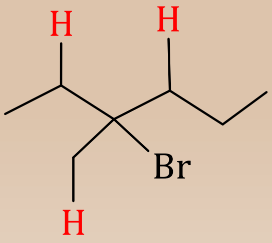




ANSWER





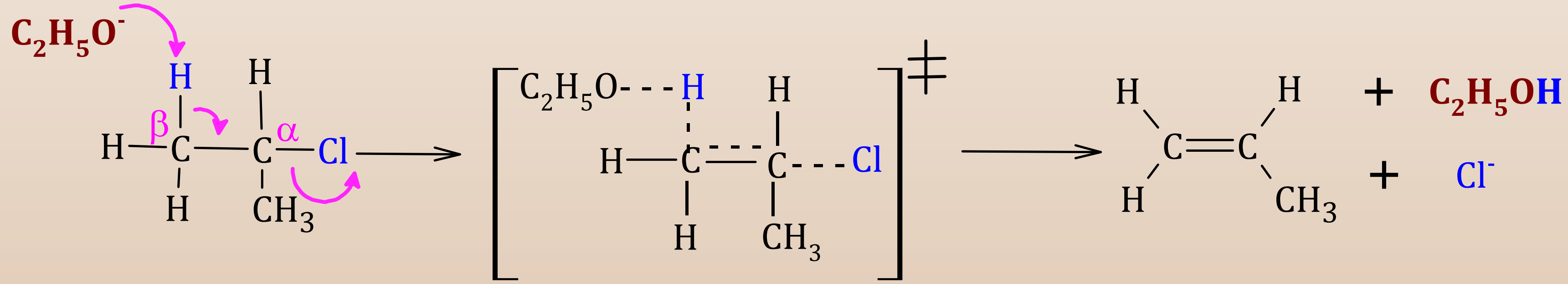


E2 Mechanism

E2 mechanisms are bimolecular reactions, 2nd order. Both substrate and base are in the transition state where the halide leaves and proton abstraction happens simultaneously in one step.

$$C_2H_5O^- + CH_3CHBrCH_3 \longrightarrow CH_2{=}CHCH_3 + C_2H_5OH + Br^-$$

- A strong base is required for these eliminations to occur.



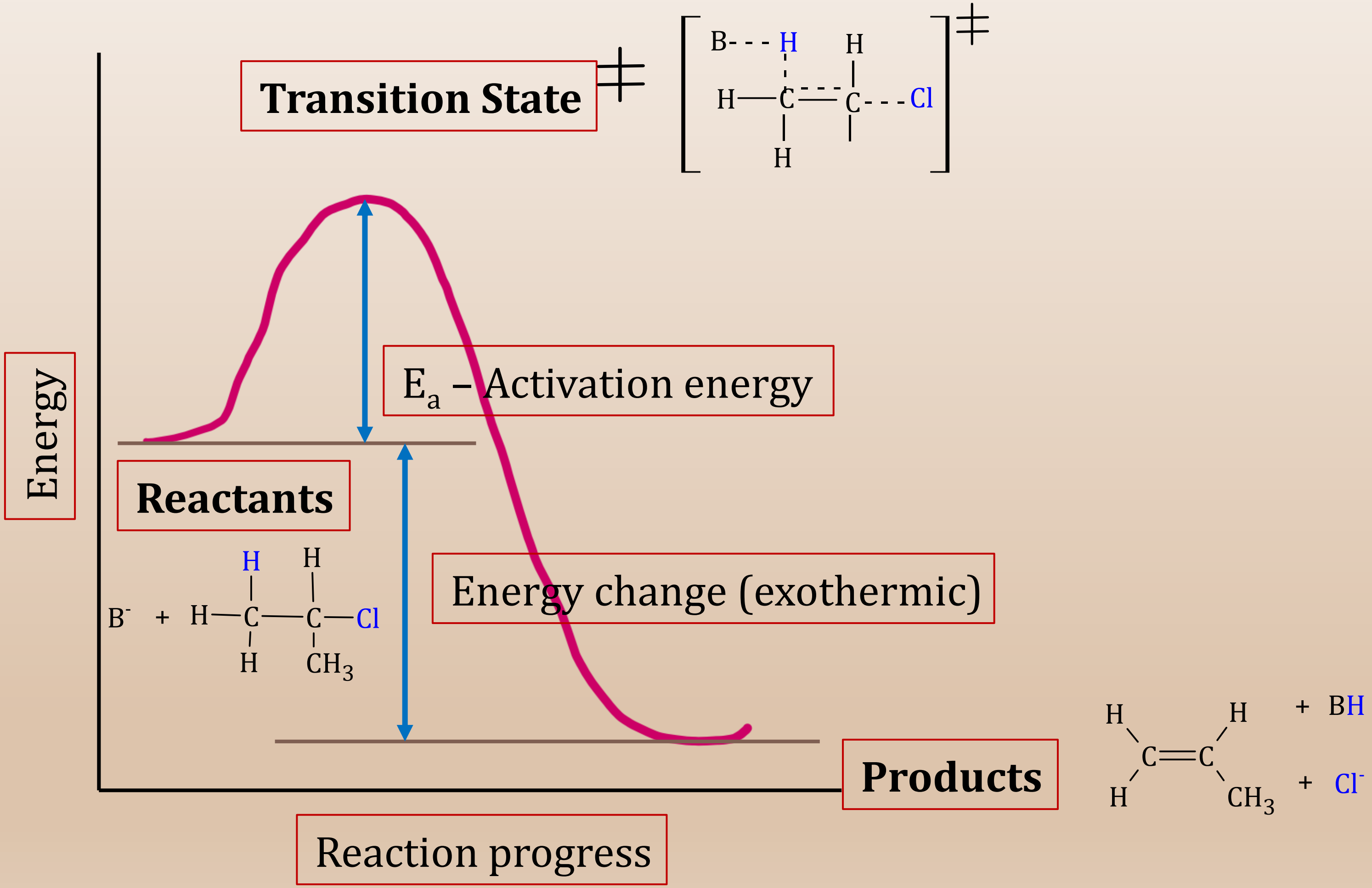
The strong base attacks/ picks up, the β proton, which then leaves its electrons between the β and α electrophilic (E) carbon, where the leaving group (LG) also starts leaving.

Transition state is where base, the proton and LG are in the process of bond formation and bond breaking. Square brackets and crosshair symbol, indicate transition state.

Product forms with new bond between the two carbons to give the alkene. LG bond is now broken. The base has picked up the proton to give the conjugate acid.

E2 Mechanism – Energy Diagram

There is only one transition state that has both the base and the substrate.



Transition State ‡

E_a – Activation energy

Reactants

Energy change (exothermic)

Products

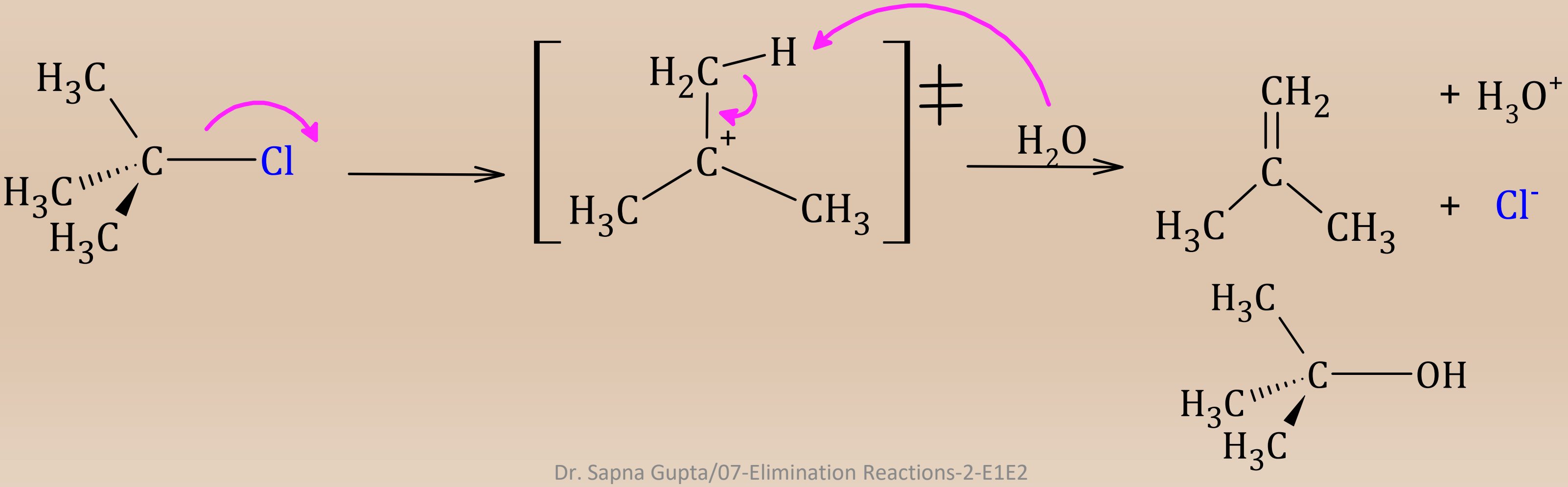
Energy

Reaction progress

E1 Mechanism

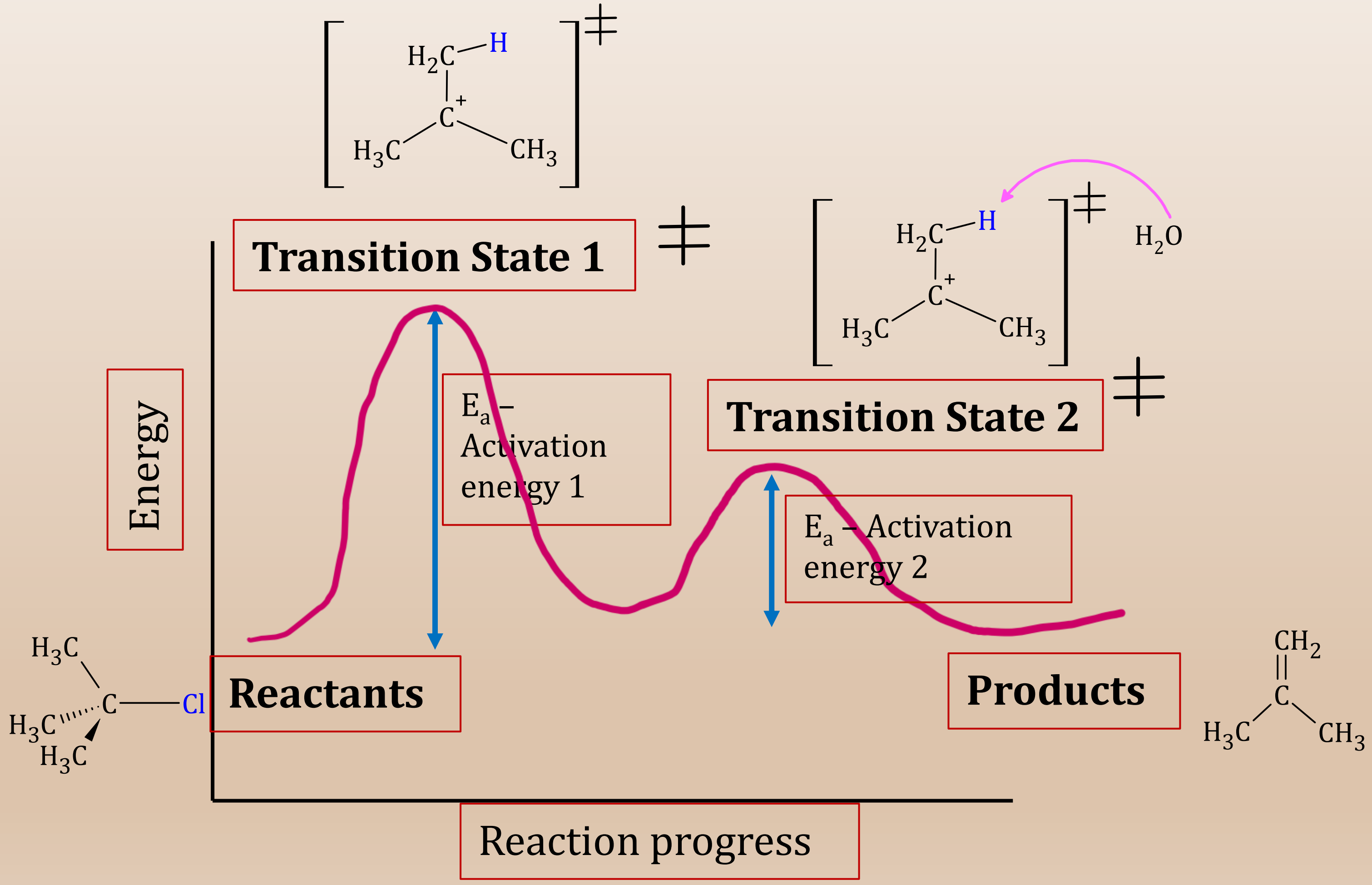
E1 mechanisms are unimolecular reactions, 1st order. The first step of the reaction is loss of the LG creating a carbocation. In the second step a weak base then abstracts a proton forming the alkene product.

- As usual two atoms are lost (usually X^- and H^+)
- Nucleophile will also be the base, but here a weak base can also work.
- The two drawbacks of this reaction are:
  - There can be formation of S_N1 products (mixture).
  - If there are two β protons then two products will form, may or may not be in equal proportion depending on the substrate.



E1- Mechanism Energy Diagram

There are two transition states that has both the base and the substrate.



Transition State 1

Transition State 2

E_a – Activation energy 1

E_a – Activation energy 2

Energy

Reactants

Products

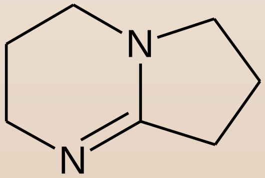
Reaction progress

Bases

- Both E1 and E2 require good bases but E2 more than E1.
- Bases are used here as they have the ability to abstract protons.
- Good bases can also be good nucleophiles, so it can be challenging to decide whether to do E2 or S_N2 can be challenging.
- Some good bases are:

  H^-, DBN (1,5-Diazabiyclo[4.3.0]non-5-ene;

  structure shown on the side)



- Below are some oxides that are good Nu and bases:

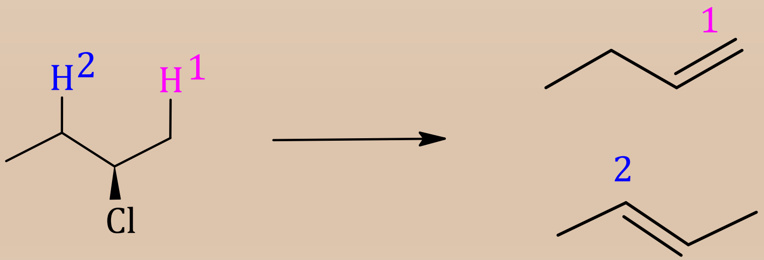
  OH^-, MeO^-, EtO^-, $tBuO^-$

E1/E2 Mechanism – Regioselectivity

When there are more than one β proton in the substrate then both protons can be abstracted. Depending on the location of the protons, two or more products will form. These products may not be in equal quantities due to different stabilities.

- **Zaitsev's product** where the alkene is more stable. When H-2 is eliminated then double bond 2 is formed which is less stable.
- **Hoffman product** where the alkene is less stable. When H-1 is eliminated then double bond 1 is formed which is more stable as it is more substituted.

Generally, a terminal H elimination leads to Hoffman product and internal H elimination leads to Zaitsev's product.

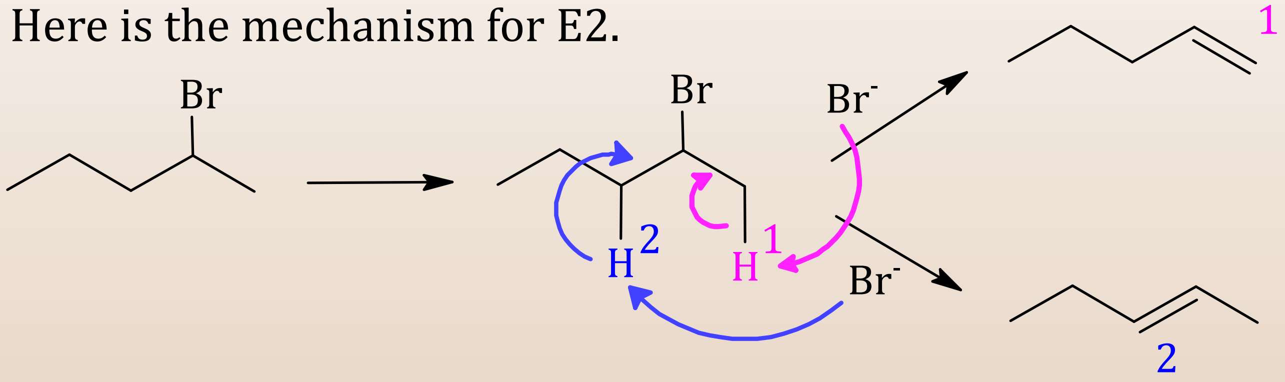


Hoffman product

Zaitsev's product

E2 Mechanism – Regioselectivity

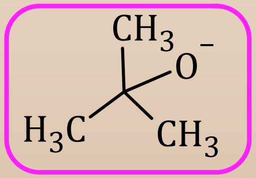
Here is the mechanism for E2.



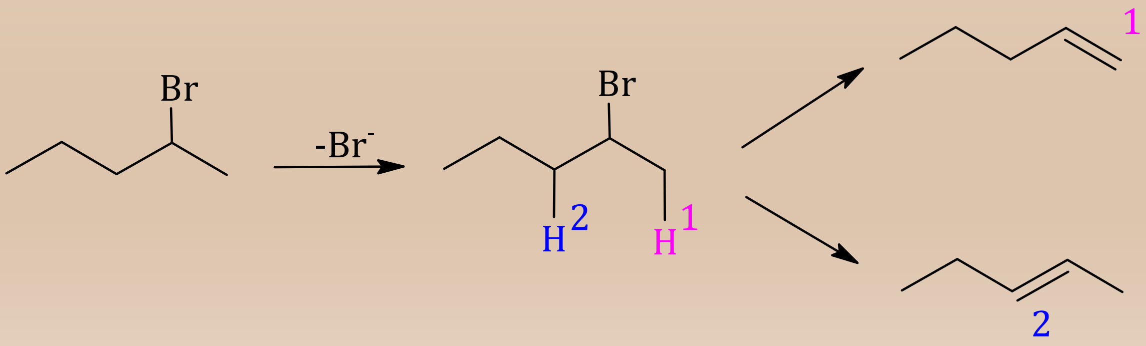
Minor:
Hoffman product

Major:
Zaitsev's product

In E2 mechanism, the products can depend on the nature of the substrate and the size of the base. A small base will promote Zaitsev's product while a bulky base will promote Hoffman product. Below is the reaction when a 2° substrate is used two different size bases.



CH_3O^-



Major:
Hoffman product

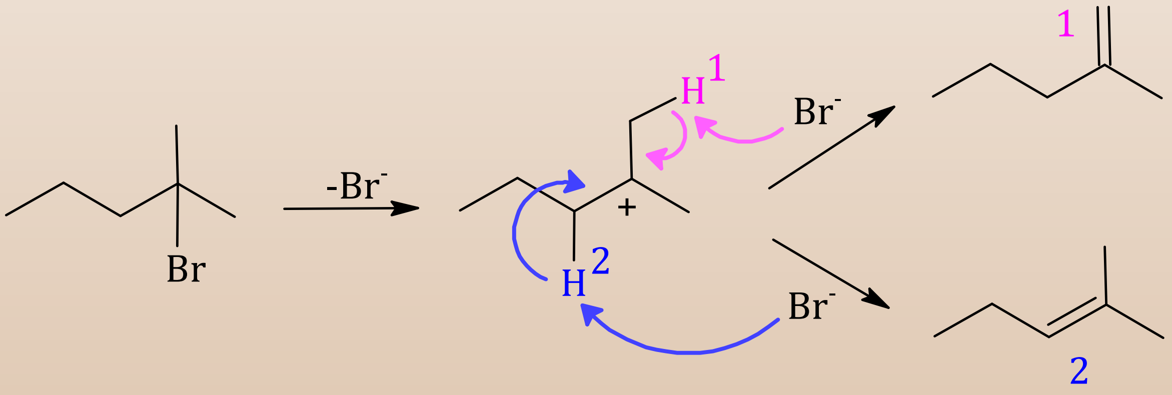
Very Minor
Zaitsev's product

Very Minor
Zaitsev's product

Major:
Hoffman product

E1 Mechanism – Regioselectivity

Here is the mechanism for E1. Once the carbocation is formed the β hydrogens are abstracted by a weak base to give the two products. In case of E1, the major product is always Zaitsev's product. The base size does not play a role in regioselectivity because the carbocation is trigonal planar and there are no steric hinderance issues.



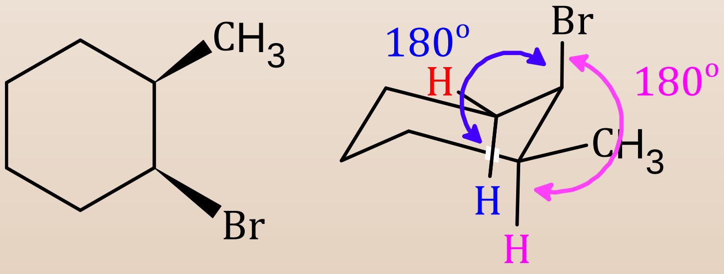
Minor: Hoffman product

Major: Zaitsev's product

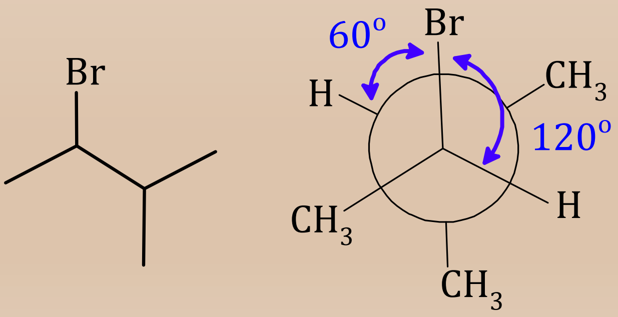
E2 Mechanism - Stereoselectivity

E2 is most favorable (lowest activation energy) when H and LG are oriented antiperiplanar, i.e., 180^{o} to each other. H and LG are periplanar when the angle is less than 180^{o}.

- In cyclohexane structures with the stereochemistry given and the mechanism is E2, the chair conformation should be drawn to see the direction of the hydrogen with respect to the LG. <u>Always write the LG on the top right carbon</u>. The H **anti** to the LG is the one to be eliminated (*blue and pink*). The red H is equatorial and is periplanar and is not eliminated.

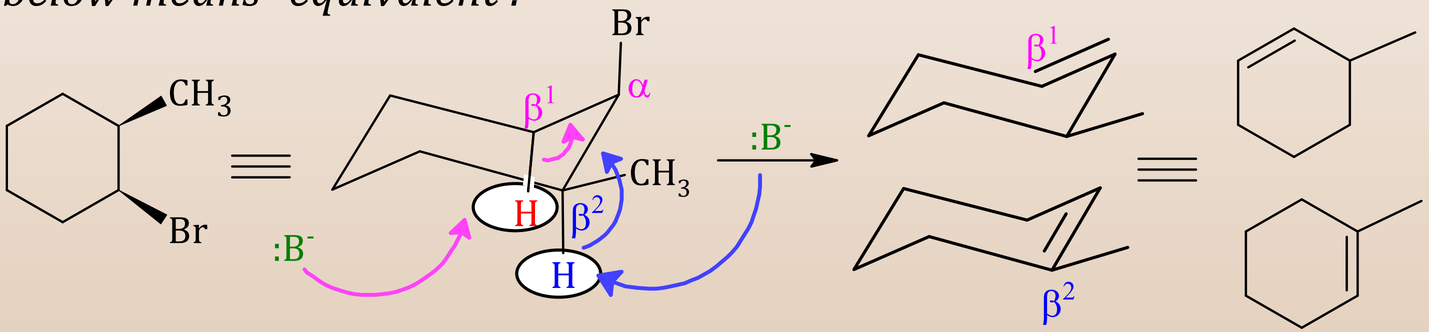


- In case of aliphatic alkanes, the Newman projection should be drawn with the lowest conformation energy, to see if there is an antiperiplanar H. If there is none, as shown on the right, E2 reaction will not occur. *Note: E1 can still proceed.*



E2 Mechanism – Stereoselectivity - Examples

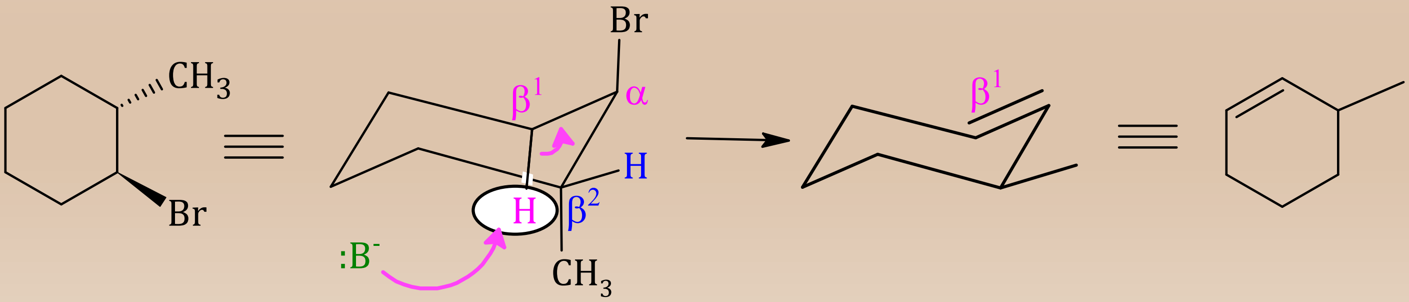
The example below is E2 of *cis*-2-methylbromocyclohexane. Draw the chair conformation to see the spatial locations of hydrogens Br (LG). In this case there are two H in the anti-periplanar orientation. *The sign "≡" in the equations below means "equivalent".*



Minor: Hoffman product

Major: Zaitsev's product

The example below is E2 of *trans*-2-methylbromocyclohexane. Again, draw the chair conformation to see the spatial arrangement of H and Br. In this case there is only one anti-periplanar H (pink), the blue one is periplanar. Even though Hoffman product is not stable, that is the only one formed here.

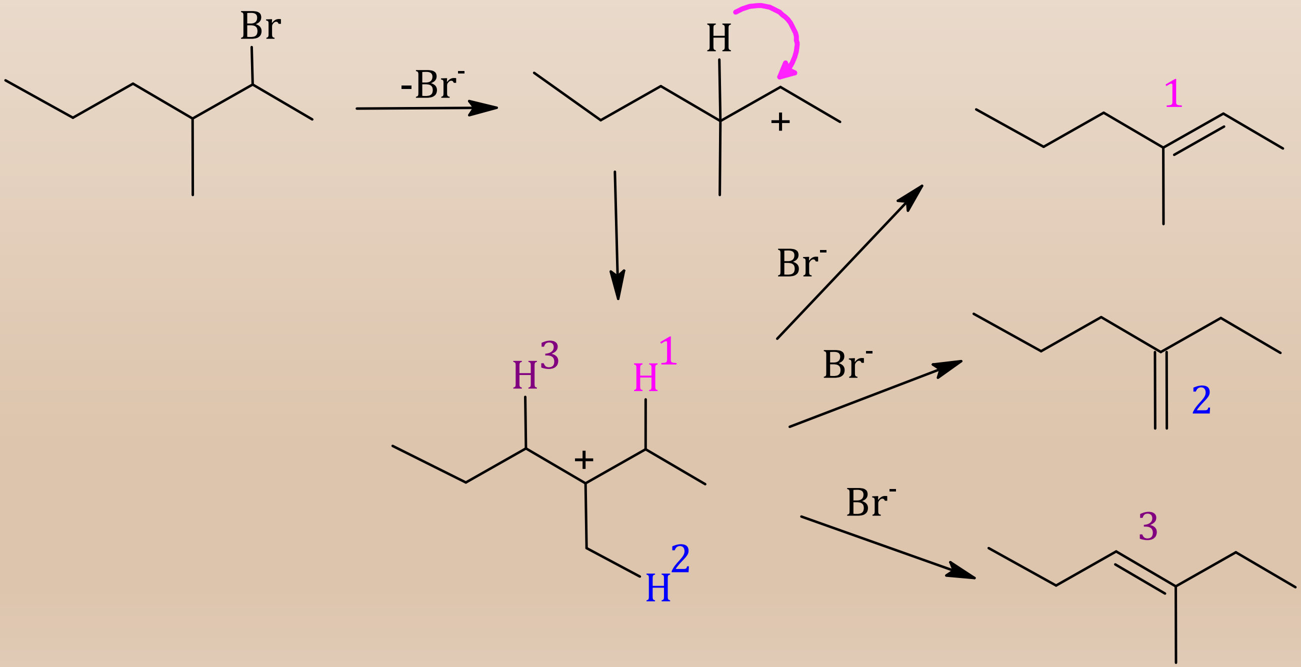


Only product: Hoffman product

E1 Mechanism – Rearrangement

Just like in S_N1 mechanism, the carbocation intermediate in E1 can result in rearrangement if it can form a more stable carbocation.

After rearrangement, if there are more than one β hydrogen then more than one product will form. The major product is Zaitsev and minor is Hoffman. Remember that if rearrangement can occur, products will form only after rearrangement.



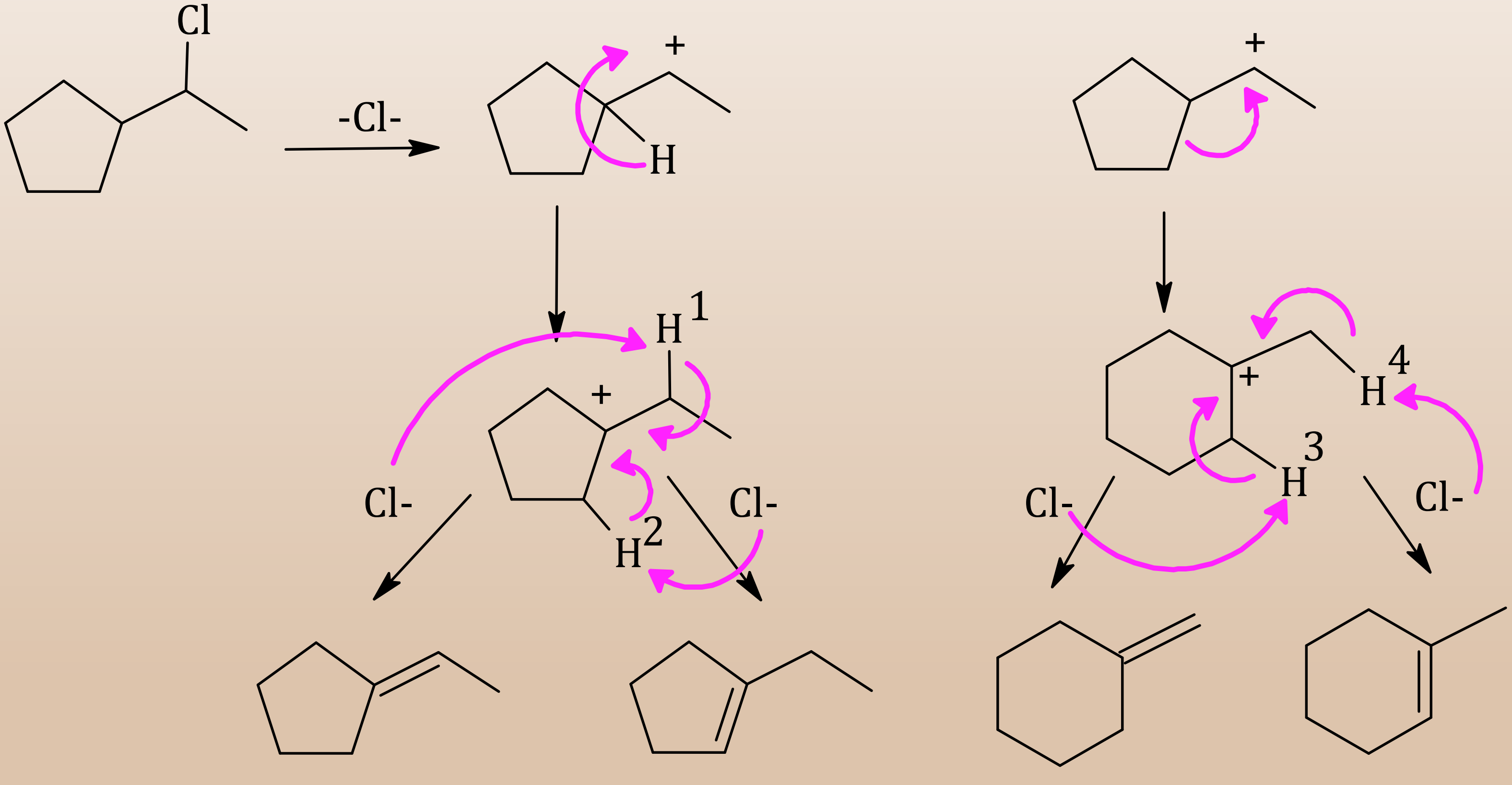
Major: ***Zaitsev's product***

Minor: ***Hoffman product***

Major: ***Zaitsev's product***

Rearrangement with Ring Size Change

In some cases, carbocation rearrangement can lead to ring expansion or shrinking. There still can be major and minor products. To avoid multiple products from forming, it is best to use a substrate that does not rearrange.



1

Major: Zaitsev's product

2

Major: Zaitsev's product

3

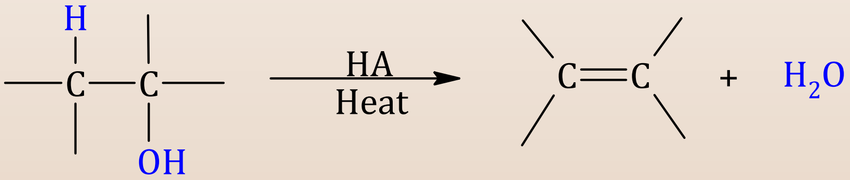
Minor: Hoffman product

4

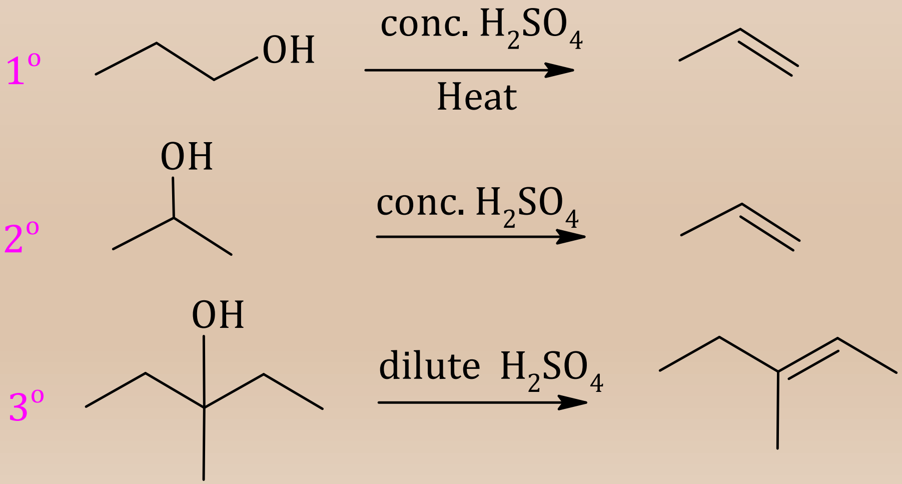
Major: Zaitsev's product

E1 - Dehydration of Alcohols

Alcohols can be dehydrated using acids, usually sulfuric acid or phosphoric acid. The mechanism is always E1, because OH groups are not good leaving groups.

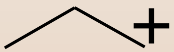


- The temperature and concentration of acid required to dehydrate depends on the structure of the alcohol.
  - Primary alcohols are most difficult to dehydrate, tertiary are the easiest.

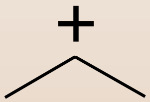


Dehydration of Secondary and Tertiary Alcohols – E1

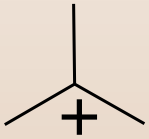
The easy dehydration of a tertiary alcohol indicates that the mechanism prefers a carbocation formation since tertiary carbocation is more stable than secondary and least stable is the primary.



1^{o}



2^{o}

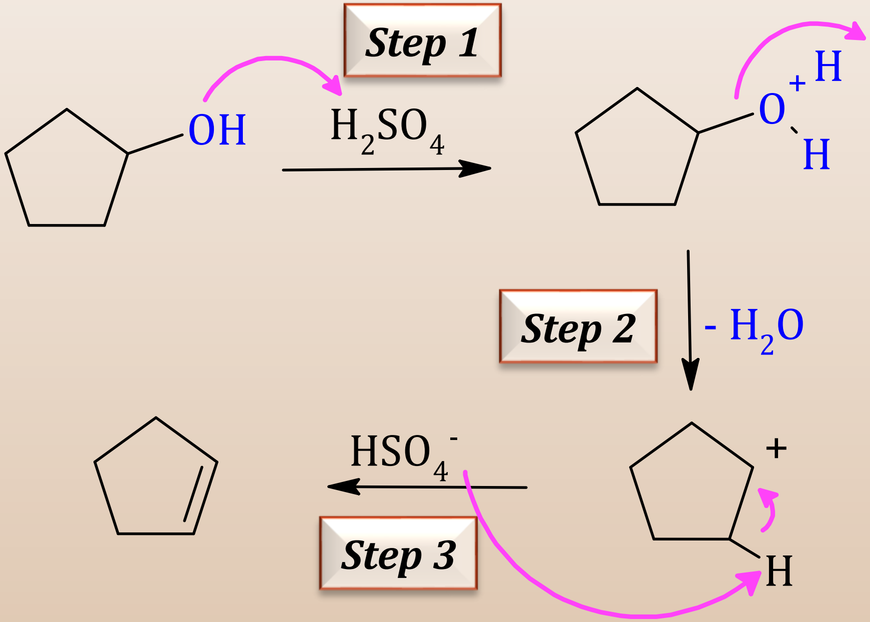


3^{o}

- Dehydration of alcohols can be viewed as making OH a good leaving group by protonating it with an acid to make it into H_2O, which is a weak base and a good LG.
- The second step of the E1 mechanism in which the carbocation forms is rate determining step.
- Rearrangements of the carbon skeleton can occur in cases where carbocation forms which is for 2^{o} and 3^{o} alcohols.

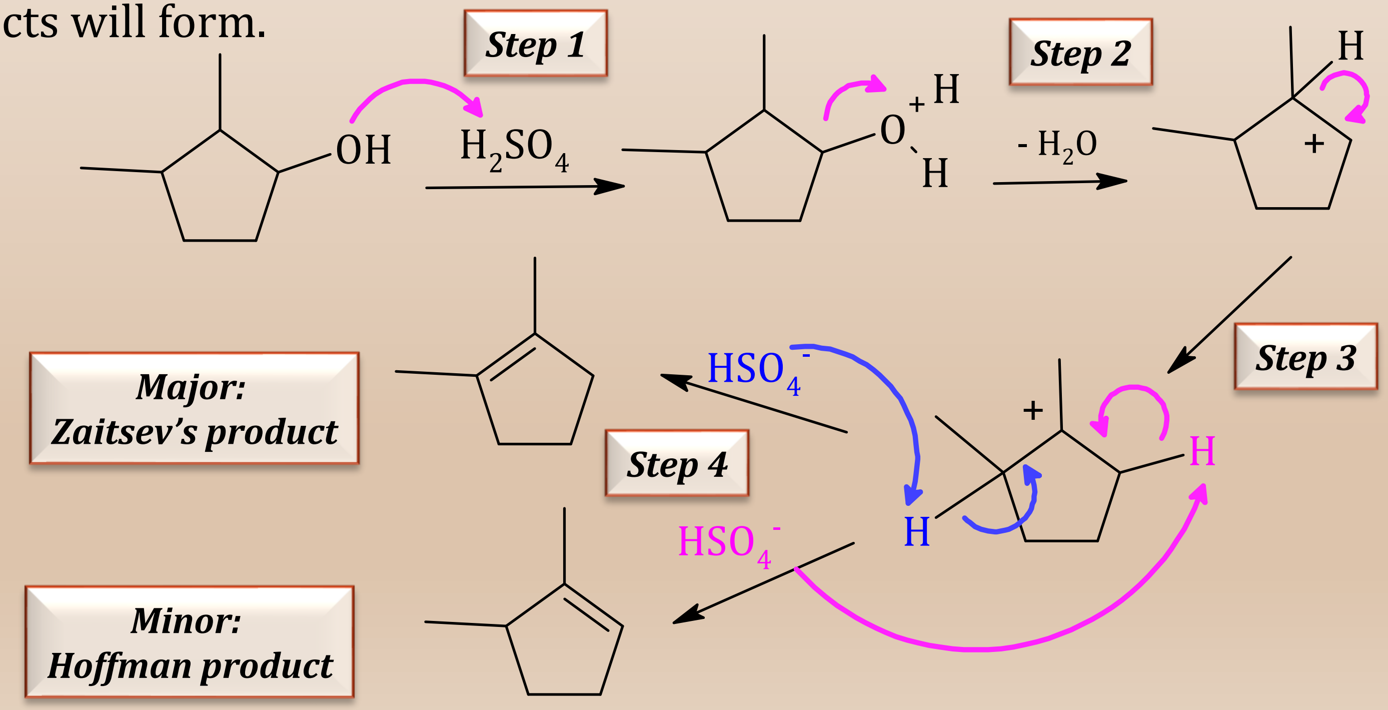
Carbocation, E1 mechanism

- Step 1: The first step in E1 mechanism is the loss the leaving group. In case of alcohol dehydration, the first step is protonation of the alcohol group (Lewis base) by reacting with the acidic proton in the medium.
- Step 2: This OH is now H_2O^+ which is a good leaving group (a strong base converts to a weak base), and it leaves as H_2O forming a carbocation.
- Step 3: The conjugate base of the acid now abstracts the β proton creating the double bond between the α and β carbons.



E1 mechanism with Rearrangement

- Step 1: As usual, in the first step in E1 mechanism alcohol dehydration, the first step protonation of the alcohol group.
- Step 2: This OH is now H_2O^+, which leaves as H_2O forming a carbocation.
- Step 3: Rearrangement occurs to form a more stable carbocation.
- Step 4: The conjugate base of the acid now abstracts the β proton creating the double bond between the α and β carbons. NOTE: Because there are two β protons, two products will form.



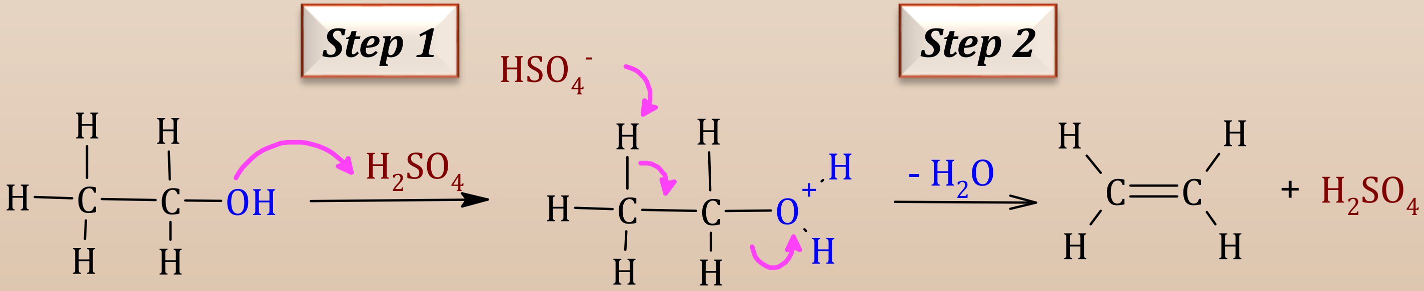
Major: Zaitsev's product

Minor: Hoffman product

Dehydration of Primary Alcohols, E2

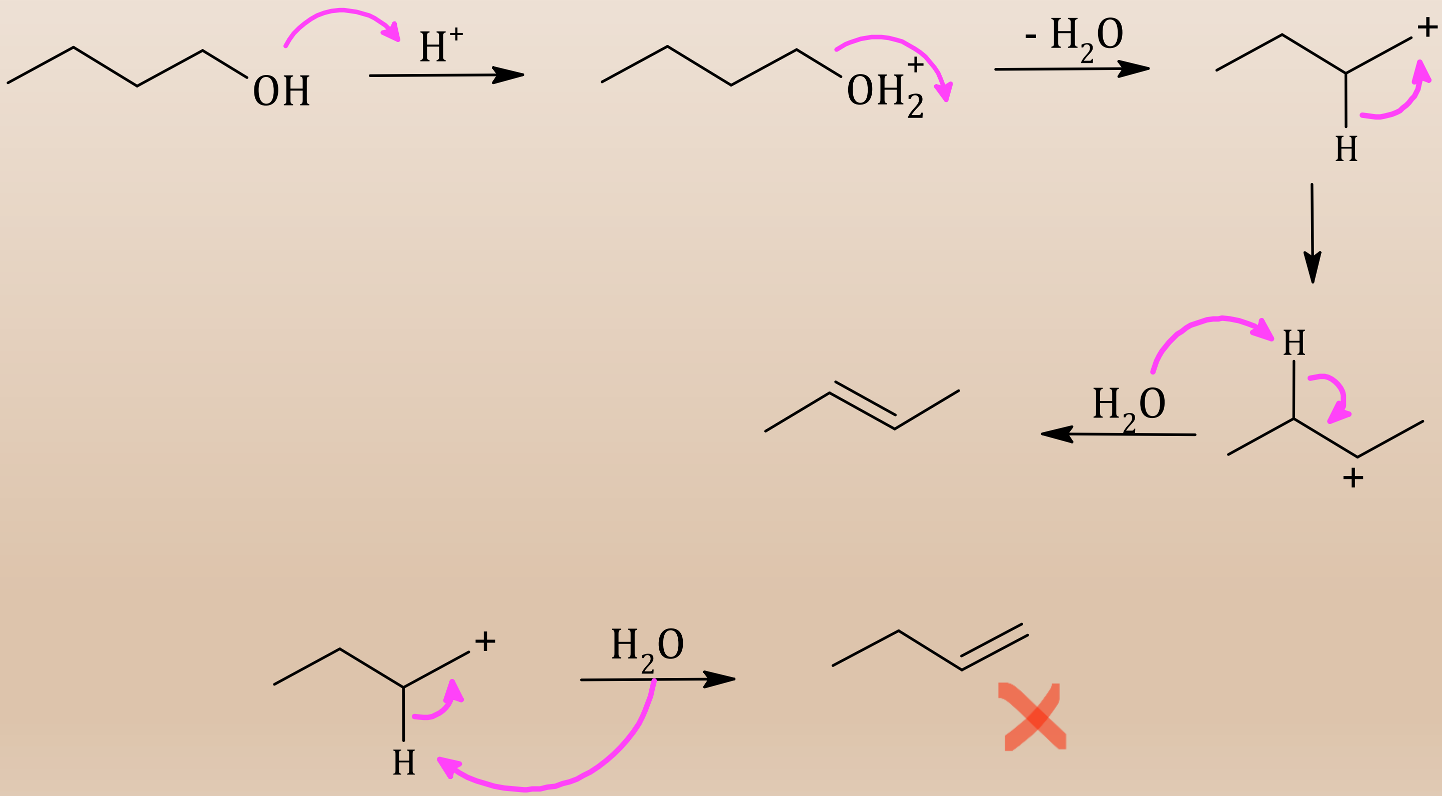
The mechanism for primary alcohols is E2 because primary carbocations are not stable.

- Step 1: The first step is protonation of alcohol from the acid in the medium. This makes the alcohol a good leaving group by converting OH^- to H_2O^+. The H_2O^+ is now the leaving group, H_2O.
- Step 2: The second step is the E2 mechanism of β proton abstraction of the conjugate base of the acid, or water. The leaving group is H_2O.



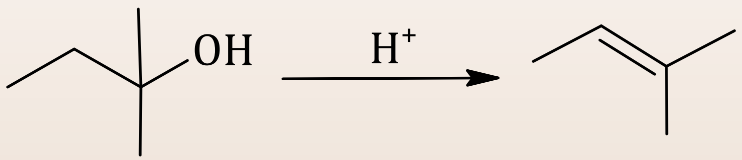
Dehydration of Primary Alcohols, E1

In case of longer chain primary alcohols, even if a carbocation is formed, there will be an immediate hydride shift to a more stable carbocation. But-1-ene will never be formed as a product.

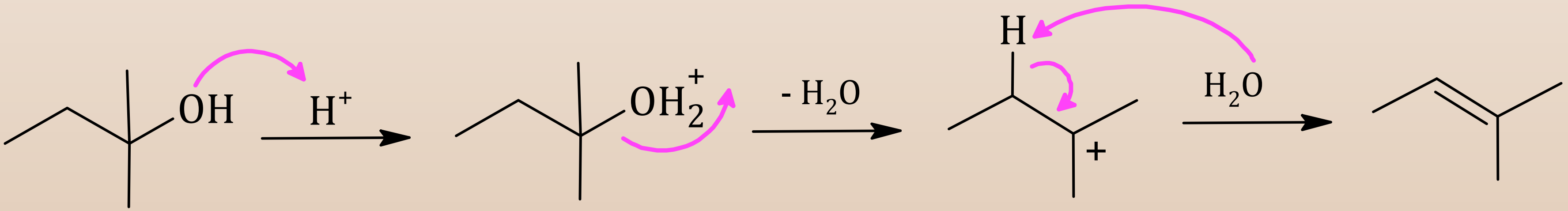


Solved Problem: Dehydration of alcohol

Show the E1 mechanism of the reaction given below.



ANSWER



Review – Synthesis of Alkenes

- Most synthesis of alkenes are elimination reactions.
  - Elimination – dehydrohalogenation (-HX) starting with alkyl halides.
  - Elimination – dehydration (-H_2O) starting with alcohols.
- Elimination gives two kinds of products
  - Zaitsev’s product (more stable alkene).
  - Hoffman product (less stable alkene).
- Anti periplanar elimination occurs in very specific conformations in E2.
- Rearrangements during carbocation transition state formation in E1.

Conditions of Elimination

Condition	E1	E2
Mechanism	1st order	2nd order
Kinetics	[substrate]	[substrate] [base]
Substrate	3° - should form a stable carbocation	1° for better results
Bases	Does not need a strong base	Needs a strong base to cause elimination
Solvent	polar	Nonpolar
Competes	With S_N1	With S_N2
Stereochemistry	Regiospecific (gives Zaitsev's product as major product)	Stereospecific (needs the H and leaving groups to be anti-periplanar)

Key Words/Concepts

- Elimination Reaction
- Base
- Leaving group
- 1st order reaction (unimolecular)
- 2nd order reaction (bimolecular)
- Transition state
- Rate determining step
- Carbocation
- Solvent considerations
- Zaitsev’s product
- Hoffman product
- Regioselectivity
- Stereoselectivity