

# Reactions of Haloalkanes

- It can be used to study the interaction between the electrophilic carbon and the halide leaving group and the bond forming between the carbon and the nucleophile
- They undergo only two main types of reactions. These are substitution and elimination reactions
- Under substitution reactions there are the Unimolecular Nucleophilic Substitution ( $S_N1$ ) and the Bimolecular Nucleophilic Substitution ( $S_N2$ ) reactions

# Reactions of Haloalkanes

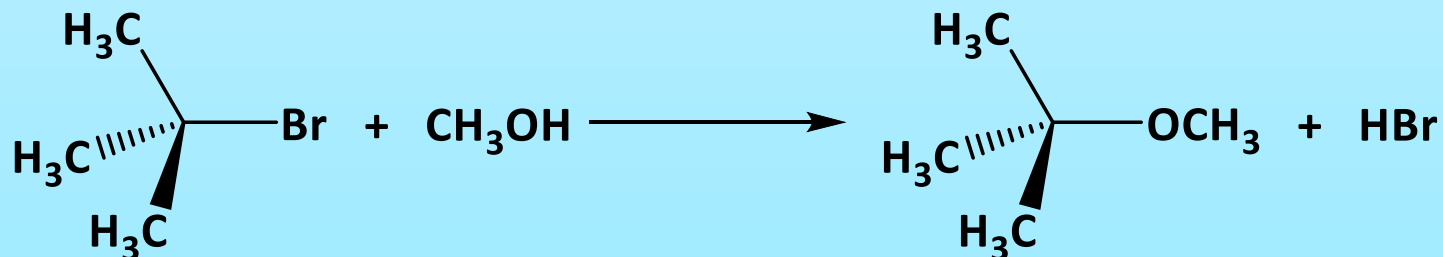
- Under elimination reactions there are the Unimolecular Elimination (**E-1**) and the Bimolecular Elimination (**E-2**) reactions

## Unimolecular Nucleophilic Substitution (**S<sub>N</sub>1**)

- In this type of reaction, bond breaking between the carbon atom and the halide leaving group is entirely completed **BEFORE** bond formation of the carbon and the nucleophile happens

# Reactions of Haloalkanes

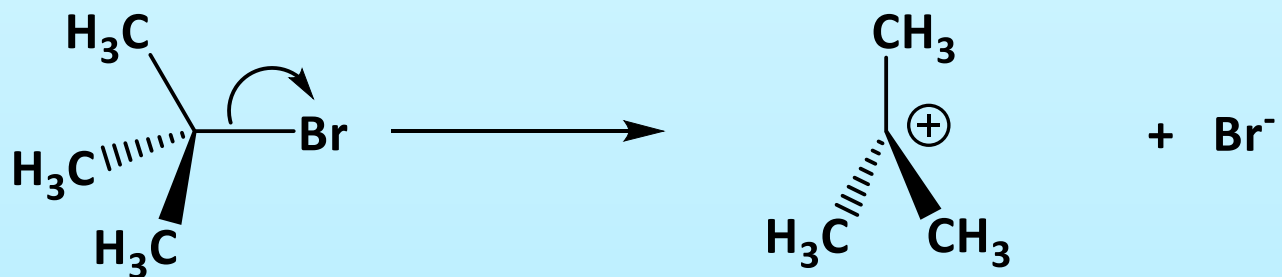
- This means that the bond-breaking step is the rate-determining step because once the bond is broken, the nucleophile then attacks the generated electrophile in a very fast reaction
- The breaking of the carbon-halide bond is a very slow process
- Let's take the conversion of 2-bromo-2-methylpropane to 2-methoxy-2-methylpropane as an example:



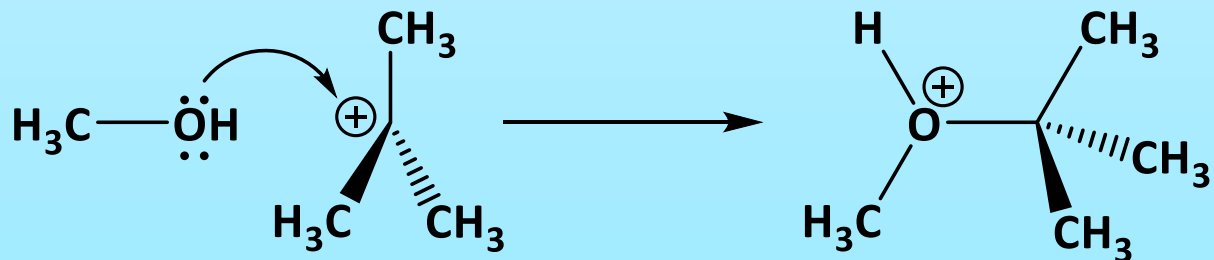
# Reactions of Haloalkanes

## ➤ The mechanism...

**Step 1: This is a very slow rate determining step**

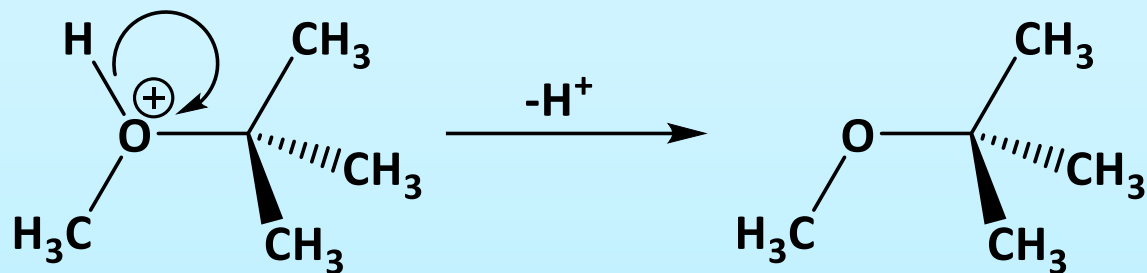


**Step 2: This is a very fast step**



# Reactions of Haloalkanes

Step 3: This is a very fast step

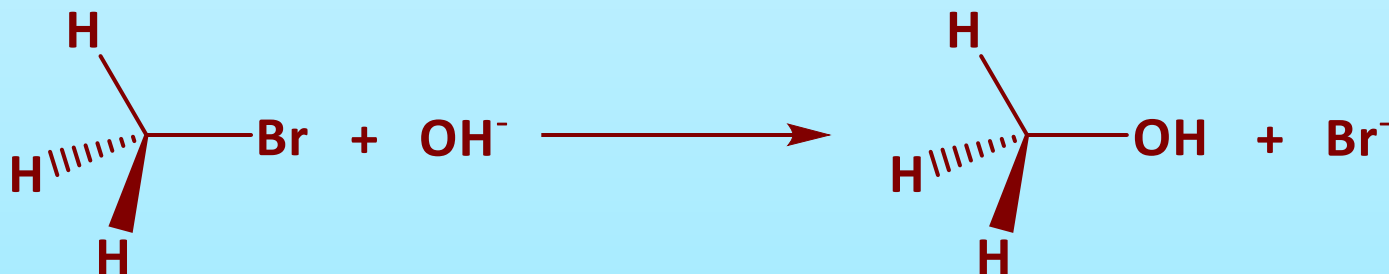


## Bimolecular Nucleophilic Substitution ( $S_N2$ )

- In this type of reaction, the breaking of the carbon-halide bond and the formation of the nucleophile-carbon bond occur in a concerted or simultaneous way

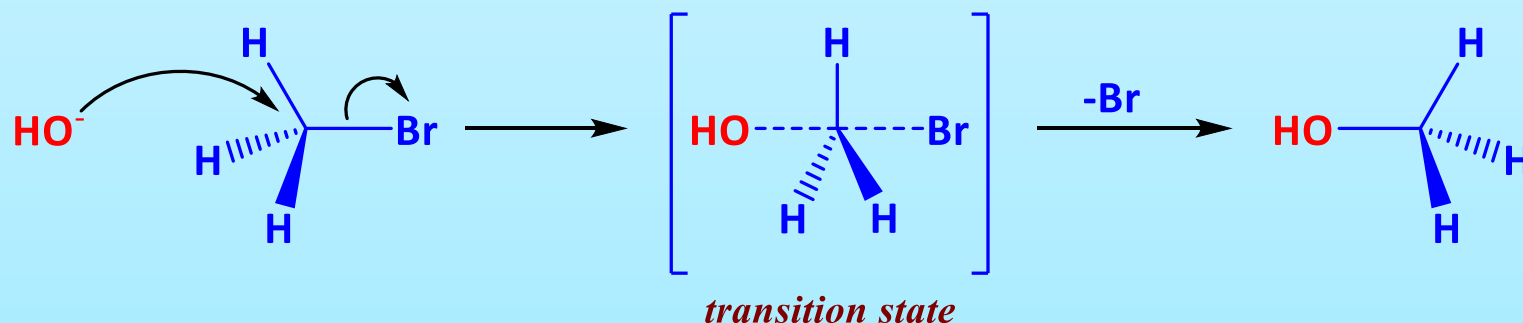
# Reactions of Haloalkanes

- In another sense, we could say that the two reactants are involved in the rate-determining step
- Take the reaction between bromomethane and hydroxide ion to form methanol and the bromide ion



# Reactions of Haloalkanes

- Here the hydroxide ion (nucleophile) attacks the reactive (electrophilic) centre from the side opposite to the leaving group, i.e. the reaction involves a backside attack by the nucleophile



# Reactions of Haloalkanes

- The important thing to note here is that the new O-C bond is forming as the old C-Br bond is breaking – **this happens simultaneously!**

SO HOW CAN WE PREDICT WHETHER A REACTION IS GOING TO PROCEED VIA A  $S_N1$  OR  $S_N2$  MECHANISM?

- Several factors can be used to predict  $S_N1$  or  $S_N2$  is favoured – these can be grouped into four main categories:



# Reactions of Haloalkanes

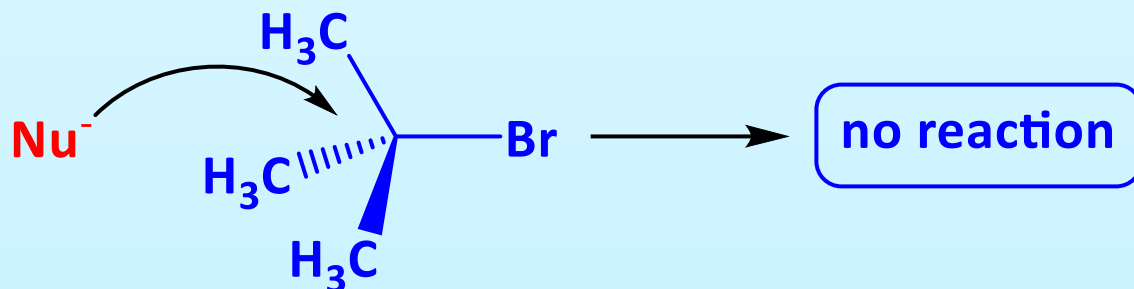
## 1. The Structure of the Substrate

- For  $S_N2$  reactions, the main factor here is that the nucleophile **MUST ACCESS** the electrophilic carbon (C-X) atom
- For this reason simple alkyl halides show the following general trend of reactivity:  
**methyl>primary>secondary>tertiary**
- In terms of how fast they react, methyl halides undergo  $S_N2$  reaction most rapidly followed by primary alkyl halides then come secondary alkyl halides

# Reactions of Haloalkanes

- For tertiary alkyl halides, the reactions are so slow that they are considered *unreactive* in the  $S_N2$  sense
- The biggest factor, which makes tertiary alkyl halides unreactive is that the nucleophile does not have access to the electrophilic carbon atom
- This is because the carbon to which the halide is attached to has got bulky groups attached, stopping the nucleophile's approach

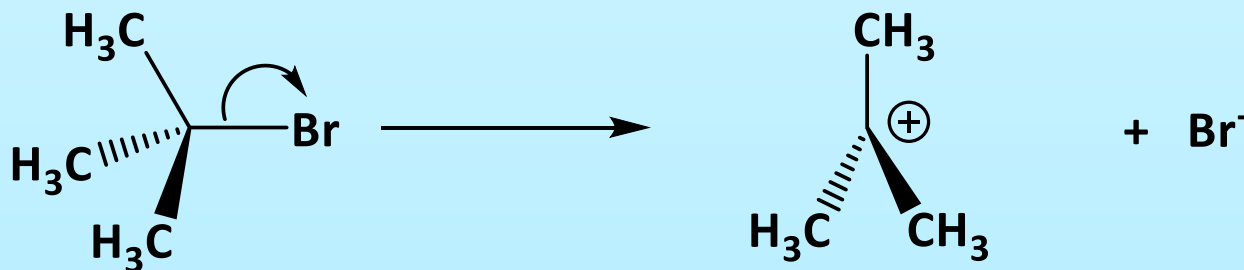
# Reactions of Haloalkanes



- This type of restricted access is known as **steric hindrance**
- In methyl, primary and secondary alkyl halides, the steric hindrance is not as great as it is in tertiary alkyl halides

# Reactions of Haloalkanes

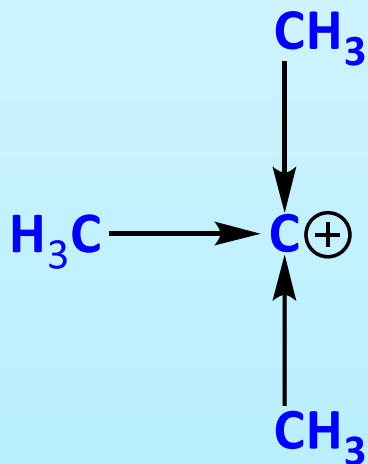
- In  $S_N1$ , the primary factor that determines the reactivity of organic substrates is the relative stability of the carbocation that is formed



- This carbocation is an electron-deficient species so it needs electrons to stabilize it
- Alkyl groups are electron donors or pushers

# Reactions of Haloalkanes

- This means they push electrons towards the electron-deficient site (carbocation) and in doing so, it stabilizes the positive charge



- The tertiary carbocation is a relatively very stable ion because three alkyl groups are pushing electrons to the electron-deficient site thus stabilizing it

# Reactions of Haloalkanes

## 2. The Concentration and Reactivity of the Nucleophile

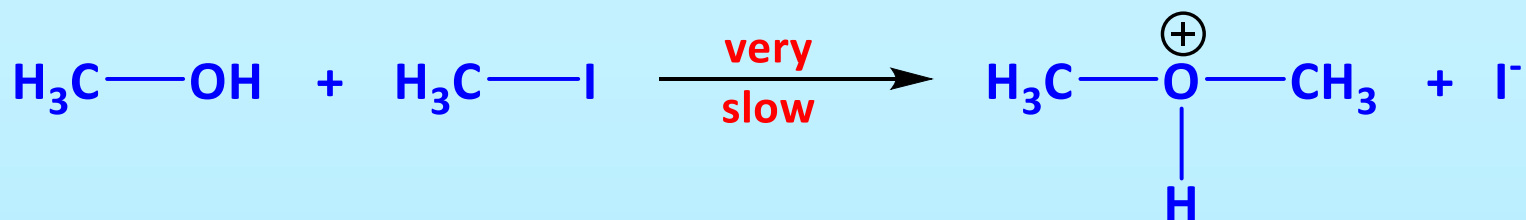
- In  $S_N1$ , this is not an issue because the nucleophile is not involved in the rate-determining step
- In  $S_N2$  reactions, this is a major factor simply because the nucleophile is involved in the formation of the transition state
- Both the concentration and identity of the attacking nucleophile must be known

# Reactions of Haloalkanes

- The general rule is that the higher the concentration of the nucleophile, the faster the  $S_N2$  reaction proceeds
- The identity of the nucleophile is also very important in the rate-determining step
- Nucleophiles can be classified as good or poor
- A good nucleophile reacts rapidly with the given substrate to give a product
- A poor nucleophile reacts very slowly with the same substrate

# Reactions of Haloalkanes

➤ Take a look at the following examples:



➤ In general, the methoxide ion is a good nucleophile while methanol is a poor one



# Reactions of Haloalkanes

➤ Two general rules are:

1. A negatively charged nucleophile is always a more reactive nucleophile than its conjugate acid
2. In a group of nucleophiles in which the nucleophilic atom is the same, nucleophilicity parallels basicity

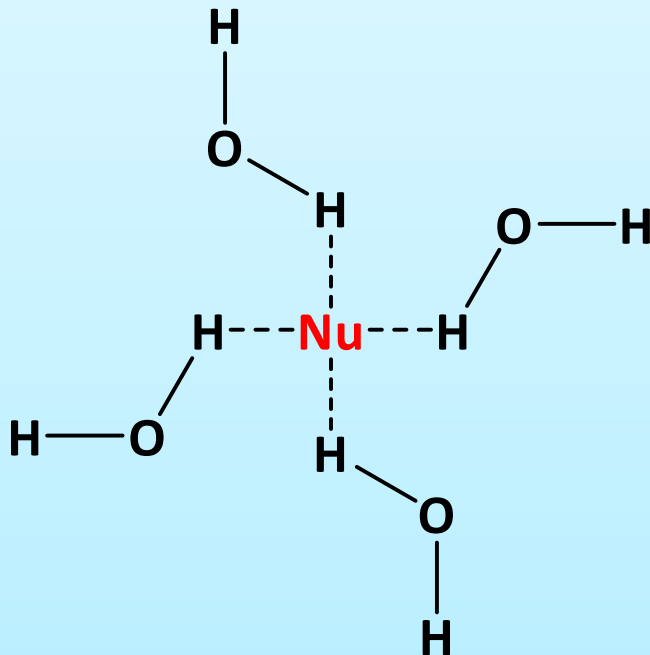


# Reactions of Haloalkanes

## 3. The Effect of the Solvent

- The relative strength of the nucleophile can be diminished by being in a solvent, which will coordinate with it
- A molecule such as water or alcohol – called a **protic solvent** – has a hydrogen atom attached to an atom of a strongly electronegative element (oxygen)
- Such solvents can ‘bind’ to the nucleophile in the following manner

# Reactions of Haloalkanes



- The protic solvent forms hydrogen bonds to the nucleophile thus diminishing the ability to act as a nucleophile

# Reactions of Haloalkanes

## 4. The Nature of the Leaving group

- The best-leaving groups are those that give the most stable ion after they depart
- This means when they cleave off from the carbon atom, the negative charge on them is stabilized and it exists in that form very favourably
- In the halides, the order of leaving is as follows:



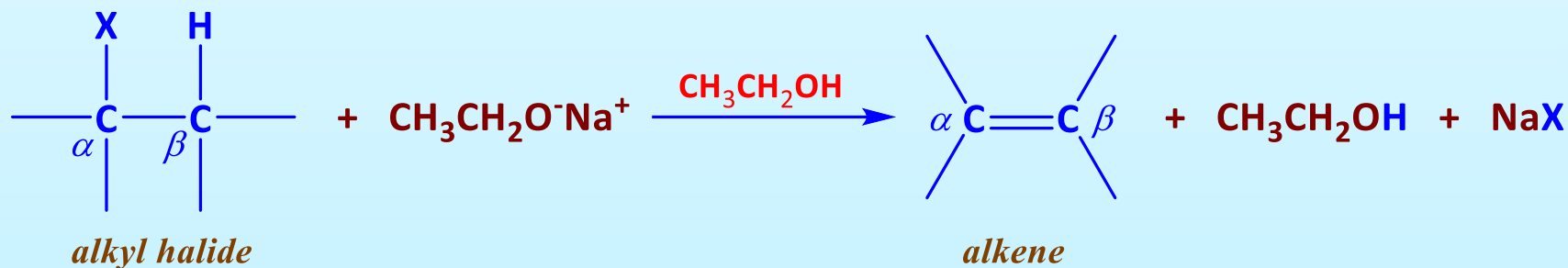
# Reactions of Haloalkanes

## Elimination Reaction:

### 1. $\beta$ -Elimination

- In the presence of a strong base, such as a hydroxide or an ethoxide ion, haloalkanes can undergo an elimination reaction, which is known as dehydrohalogenation
- This means a halogen atom can be removed from one carbon (the  $\alpha$ -carbon) and a hydrogen atom for an adjacent carbon atom (the  $\beta$ -carbon)

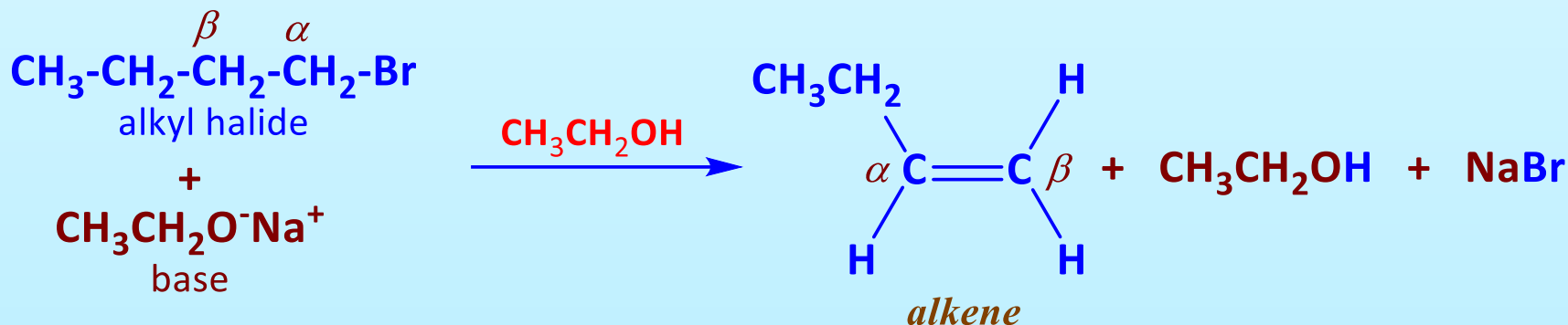
# Reactions of Haloalkanes



- This is an elimination reaction because a small molecule such as HCl, HBr, or HI is removed from this larger haloalkane
- And because they are removed from adjacent carbon atoms, this type of elimination reaction is referred to as a *β-elimination* reaction

# Reactions of Haloalkanes

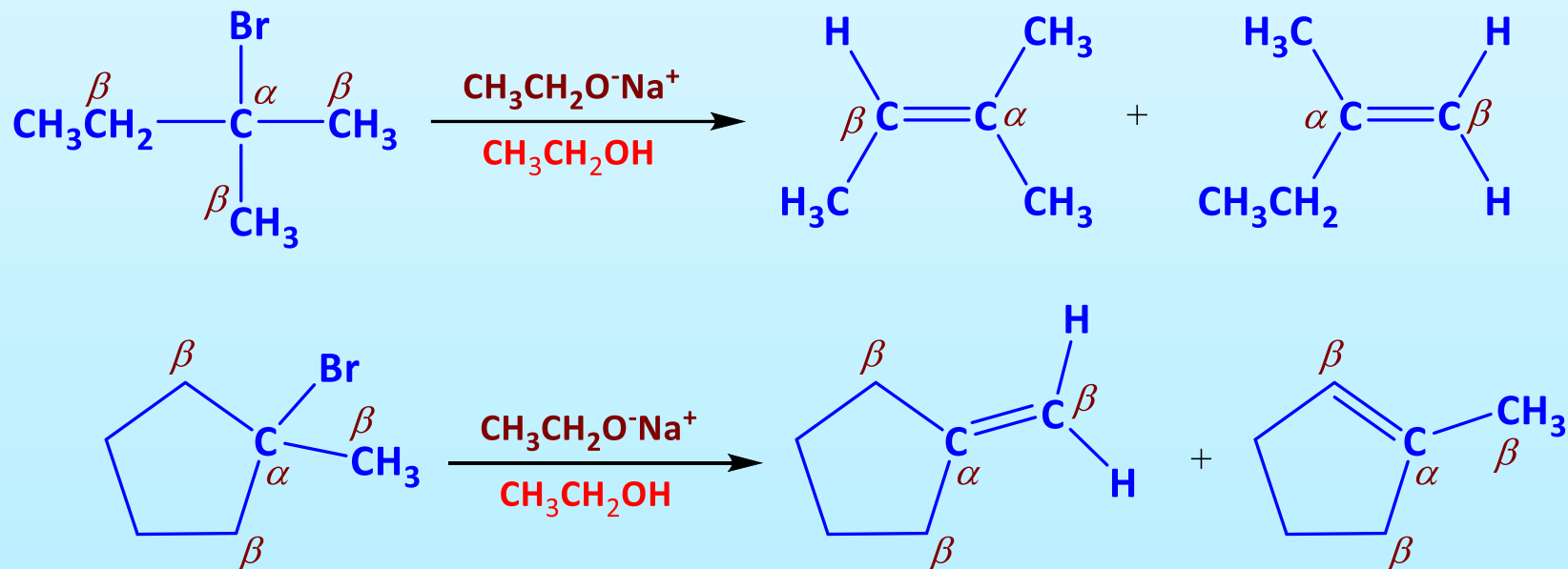
➤ Take a look at the three examples below



➤ In this case, there is only one possible type of  $\beta$ -hydrogen atom so this reaction will lead to only one product as in 1-butene

➤ Now let us look at the next two examples:

# Reactions of Haloalkanes



- In these two cases, there are three sets of  $\beta$ -hydrogen atoms which could lead to three possible products

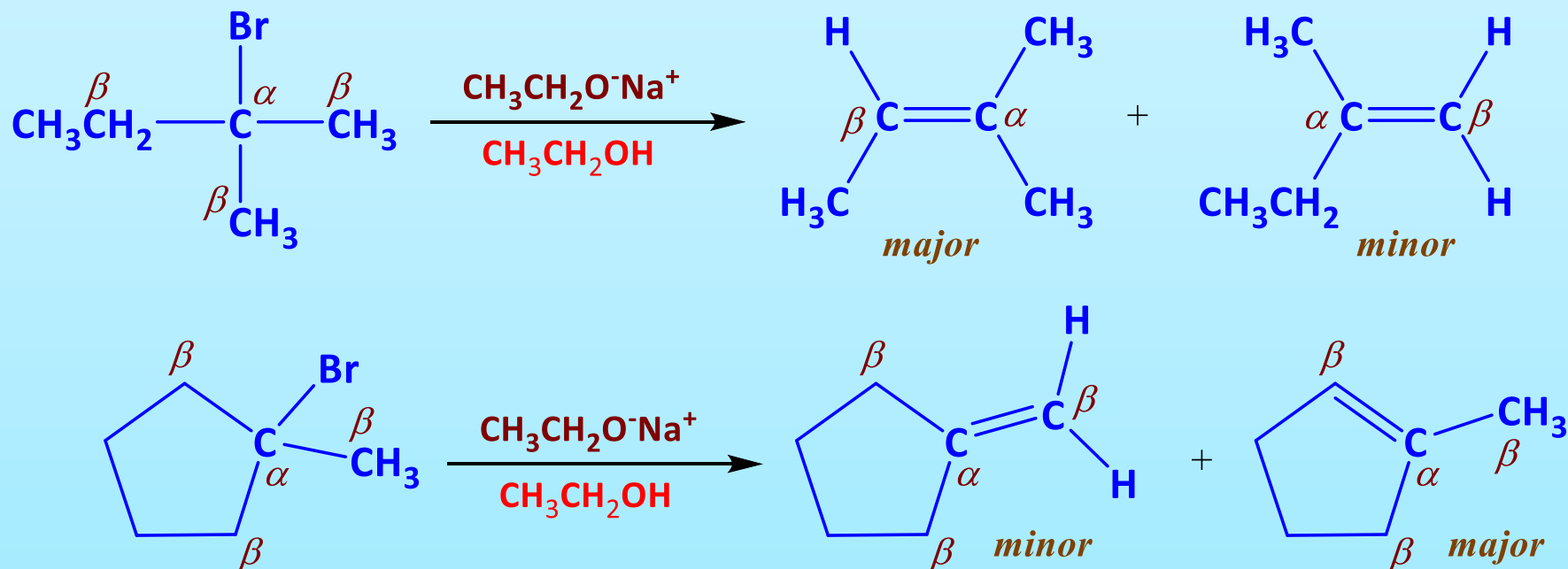


# Reactions of Haloalkanes

- However, in these cases, two of the  $\beta$ -hydrogen atoms are identical and as such would lead to two identical products
- Therefore, for these two cases, there will be only two possible (isomeric) products as shown above
- When such a possibility arises, the major product will come from the **dehydrohalogenation** which leads to *the most substituted alkene*

# Reactions of Haloalkanes

- This generalization is Zaitsev's rule
- In the reactions given, the major products will be 2-methylbut-2-ene and methylcyclopentene



# Mechanism of the $\beta$ -elimination

- $\beta$ -elimination reactions proceed by two limiting mechanisms: **E1** and **E2**
- The fundamental difference between them is the timing of the bond-breaking and the bond-forming steps

## E1 mechanism

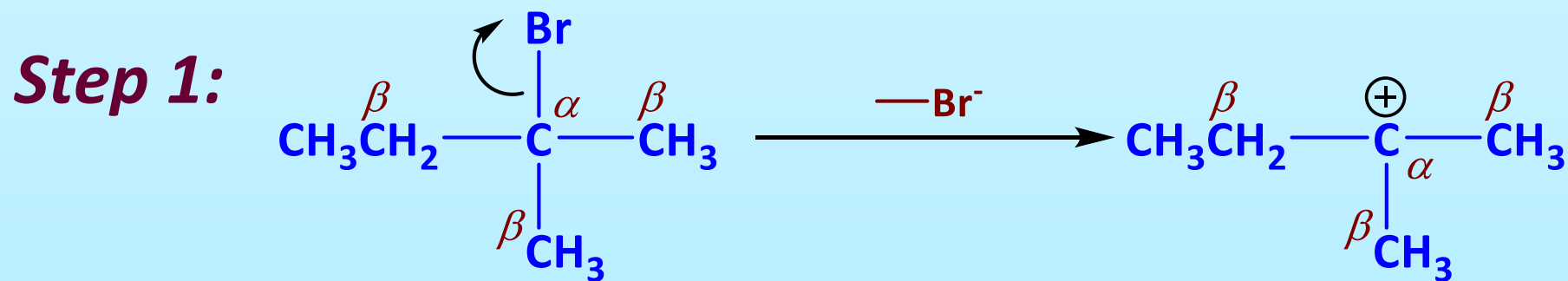
- At one extreme, breaking of the C-X bond is complete before any other reaction occurs

# Mechanism of the $\beta$ -elimination

- Once the C-X bond is broken, a carbocation is formed and this allows for the base now to abstract (remove) the hydrogen atom from the  $\beta$ -carbon which then leads to the formation of the double bond between the  $\alpha$ - and the  $\beta$ -carbon atoms
- This is the **E1** reaction where **E** stands for *elimination* and the **1** stands for the fact that only *one* reactant is involved in the rate-determining step – *Unimolecular Elimination*

# Mechanism of the $\beta$ -elimination

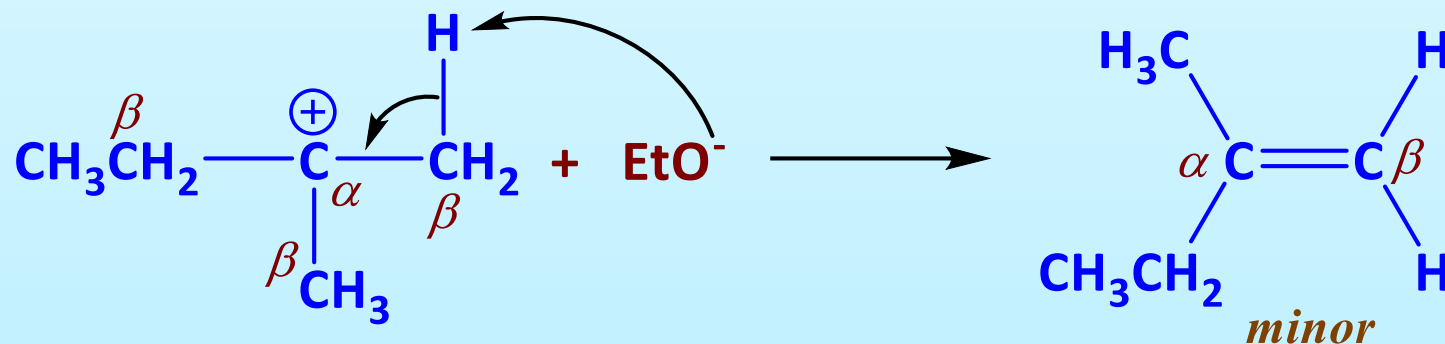
- The reactions of 2-bromo-2-methylbutane and 1-bromo-1-methylcyclopentane shown above proceed via this mechanism



- This step involves the breaking of the C-Br bond in the rate-determining step to form the carbocation intermediate

# Mechanism of the $\beta$ -elimination

**Step 2:**



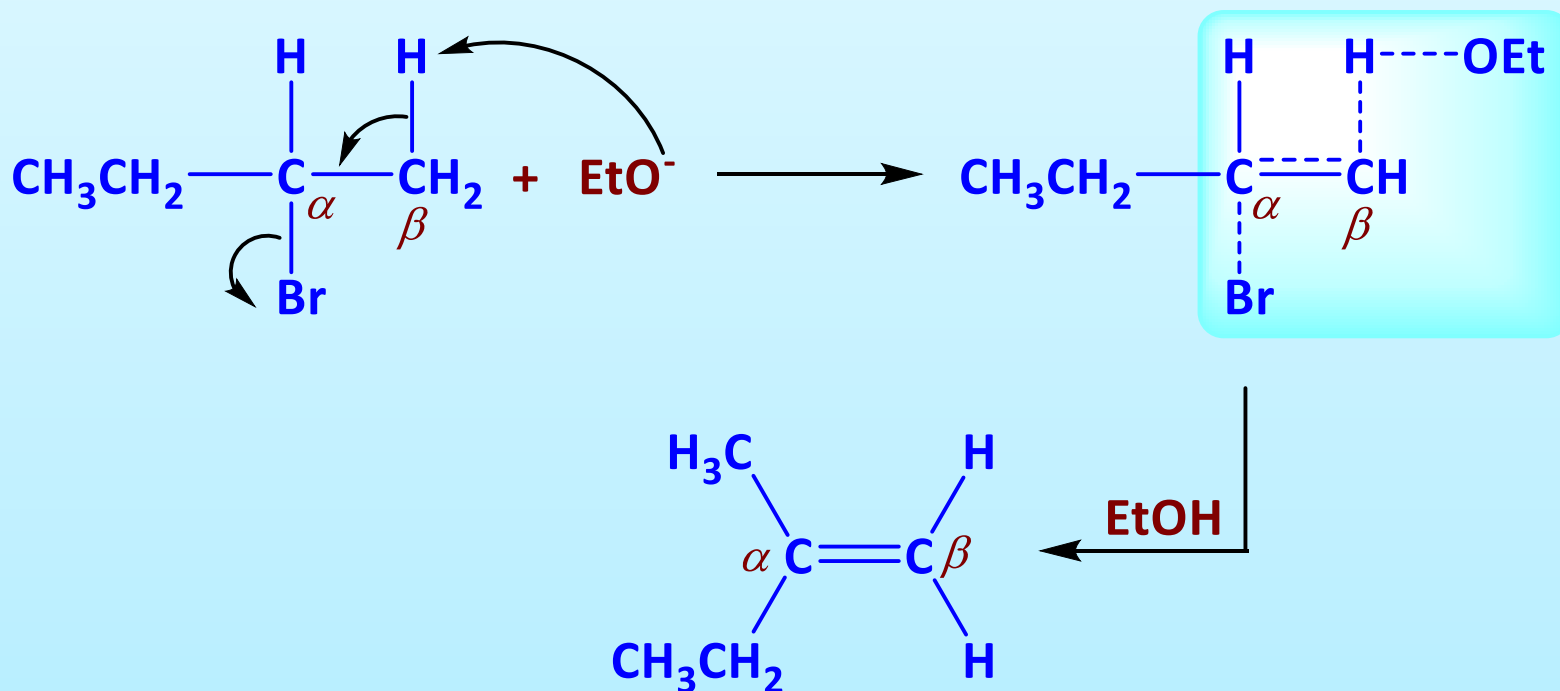
- Here the proton on one of the  $\beta$ -carbon atoms from the carbocation intermediate is abstracted by the ethoxide ion (base) to give the alkene product

# Mechanism of the $\beta$ -elimination

## E2 mechanism

- At the other extreme is a concerted (one-step) process, designated as **E2**
- **E** because it is an *elimination* reaction and **2** because *two* reactants, in this case, the haloalkane and the base are involved in the transition state of the rate-determining step
- In the E2 mechanism, there is only *one* step

# Mechanism of the $\beta$ -elimination



- The key step here is that, as the C-H bond is breaking, the new C-C  $\pi$  bond is forming and at the same time, the C-Br bond is also breaking