8.1 Introduction to Addition Reactions

Addition is the opposite of elimination.

C=C $\pi$ bond is converted to two new sigma bonds.

### Table 8.1 Some Common Types of Addition Reactions

<table>
<thead>
<tr>
<th>Type of Addition Reaction</th>
<th>Name</th>
<th>Section</th>
</tr>
</thead>
<tbody>
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<td>8.4</td>
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<td>Addition of H and OH</td>
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<td>Addition of H and H</td>
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<td>Addition of OH and OH</td>
<td>Dihydroxylation</td>
<td>8.10, 8.11</td>
</tr>
</tbody>
</table>
8.1 Introduction to Addition Reactions

- The $\pi$ bond is an electron-pair donor

As a base

As a nucleophile
8.2 Alkenes in Nature and Industry

• Naturally occurring, acyclic alkenes:

- **Allicin**
  Responsible for the odor of garlic

- **Geraniol**
  Isolated from roses and used in perfumes

- **α-Farnesene**
  Found in the natural waxy coating on apple skins
8.2 Alkenes in Nature and Industry

- Cyclic and polycyclic alkenes:

  **Limonene**
  Responsible for the strong smell of oranges

  **Cholesterol**
  Produced by all animals; this compound plays a pivotal role in many biological processes
8.2 Alkenes in Nature and Industry

- C=C double bonds often found in the structures of pheromones

(2Z,6E)-3-Ethyl-7-methyldeca-2,6-dien-1-ol
  A sex pheromone of the codling moth

β-Farnesene
  An aphid alarm pheromone

Muscalure
  Sex pheromone of the common housefly
8.2 Alkenes in Nature and Industry

- Alkenes are critical *precursors* in the chemical industry

- 70 billion pounds of propylene (propene) and 200 billion pounds of ethylene (ethene) are both made from cracking petroleum each year
8.3 Addition vs. Elimination

- Addition and elimination are equilibrating reactions:
  - Which side is favored depends on temperature

- The higher the temperature, the more important entropy becomes:

\[
\Delta G = \Delta H - T\Delta S
\]

- Higher temp means a bigger entropy term
8.3 Addition vs. Elimination

- Addition reactions are **favored by enthalpy**.
- Sigma bonds are stronger (more stable) than \( \pi \) bonds

\[
\Delta H = \text{Bonds broken} - \text{bonds formed}
\]

\[
\Delta H = 166 \text{ kcal/mol} - 185 \text{ kcal/mol}
\]

\[
\Delta H = -19 \text{ kcal/mol}
\]
8.3 Addition vs. Elimination

- Addition reactions are **NOT favored by entropy**.
- Two molecules combine to form one product; entropy decreases.

\[
\text{H} = \text{H} + \text{H} \quad \text{+} \quad \text{H} - \text{Cl} \quad \rightarrow \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H}
\]

\[
\begin{align*}
\text{63 kcal/mol} \quad \text{+} \quad \text{103 kcal/mol} && \quad \text{166 kcal/mol} \\
\text{101 kcal/mol} \quad \text{+} \quad \text{84 kcal/mol} && \quad \text{185 kcal/mol}
\end{align*}
\]

**TWO reactants**  \quad **ONE product**
8.3 Addition vs. Elimination

- At lower temps, enthalpy dominates, and addition reactions are favored.
- At higher temps, entropy dominates, and elimination reactions are favored.

So, we use lower temperatures when doing an addition reaction.
8.4 Hydrohalogenation

- **Hydrohalogenation**: addition of H-X to an alkene
- can use HCl, HBr, or HI

\[
\text{alkene} + \text{H-Br} \quad \text{at } -30^\circ \text{C} \quad \text{product} \quad \text{(76%)}
\]

- If the alkene is not symmetrical, then two **regioisomers are possible**, depending on which carbon gets the “H” and the “X”
8.4 Hydrohalogenation - Regioselectivity

- Hydrohalogenation is **regioselective** for **Markovnikov addition**

- In 1869, Markovnikov observed the H atoms tend to add to the carbon already bearing more H atoms

- The halogen is generally installed at the more substituted carbon
When peroxides are used with HBr, the opposite regioselectivity is observed.

The reaction mechanism must be different, when peroxides are present.
8.4 Hydrohalogenation - Regioselectivity

- The important lesson here is that the **regioselectivity of HBr addition can be controlled**: 

```
\begin{center}
\begin{tikzpicture}
\node at (0,0) {\text{\textbf{\textcolor{black}{Markovnikov addition}}}};
\node at (0,-1) {\text{\textbf{\textcolor{black}{Anti-Markovnikov addition}}}};
\node at (-1.5,-1) {\text{\textbf{\textcolor{black}{HBr}}}};
\node at (-1.5,0) {\text{\textbf{\textcolor{black}{HBr}}}};
\draw (0,0) -- (1,0);
\draw (0,-1) -- (1,-1);
\end{tikzpicture}
\end{center}
```
8.4 Hydrohalogenation - Regioselectivity

- **Conceptual Checkpoint 8.1** – Draw the expected *major* product for the following reactions.

![Chemical structures](image1)

![Chemical structures](image2)
8.4 Hydrohalogenation - Regioselectivity

- Conceptual Checkpoint 8.1 – Draw the expected *major* product for the following reactions

- There are more practice problems in Checkpoint 8.1
8.4 Hydrohalogenation - Mechanism

- The mechanism is a two step process

**Proton transfer**

The alkene is protonated, forming a carbocation intermediate and a bromide ion

**Nucleophilic attack**

The bromide ion functions as a nucleophile and attacks the carbocation intermediate
8.4 Hydrohalogenation - Mechanism

- The step with the highest $E_a$ is the rate determining step, which is the formation of the carbocation intermediate (the first step)
8.4 Hydrohalogenation - Mechanism

- Recall that there are two possible products, Markovnikov and anti-Markovnikov

Markovnikov pathway

anti Markovnikov pathway

- Markovnikov product is formed because of carbocation stability
8.4 Hydrohalogenation - Mechanism

- The Markovnikov product is formed through a lower energy (i.e. faster) transition state.

Practice with Skillbuilder 8.1
8.4 Hydrohalogenation - Stereochemistry

- Hydrohalogenation may result in the formation of a chirality center

- There are actually TWO Markovnikov products formed in this rxn

Two enantiomers are formed in equal amounts.
8.4 Hydrohalogenation - Stereochemistry

- The carbocation intermediate can be attacked from either side of the empty $p$ orbital, with equal probability.

Practice with conceptual checkpoint 8.5
8.4 Hydrohalogenation - Rearrangements

- Recall carbocations can rearrange (hydride or methide shift) if they can become more stable.

- When this alkene undergoes hydrohalogenation, the 2° carbocation could rearrange to a more stable, 3° carbocation.

\[ 	ext{Secondary} ightarrow 	ext{Tertiary} \]
8.4 Hydrohalogenation - Rearrangements

• Recall carbocations can rearrange (hydride or methide shift) if they can become more stable.

• When carbocation rearrangements can occur, the DO occur

```
C=C\rightarrow\text{H\rightarrowCl}\\
\text{Cl} \quad \text{40}\% \quad + \quad \text{60}\%
```

• Practice with Skillbuilder 8.2
8.5 Acid-catalyzed Hydration

- The components of **water** (H and OH) are added across the π bond
- **Acid-catalyzed hydration** follows **Markovnikov regioselectivity**

![Chemical reaction diagram]

- Sulfuric acid is typically the acid catalyst used

![Chemical reaction diagram]
8.5 Acid-catalyzed Hydration

- The **OH** is added to the more substituted carbon of the alkene
- The more substituted the carbon atom is, the faster the reaction

This data is consistent with a mechanism that proceeds through a carbocation intermediate.
8.5 Hydration - Mechanism

The mechanism for acid-catalyzed hydration is essentially the same as hydrohalogenation:

- The alkene is protonated, forming a carbocation intermediate.
- Carbocation
- Water functions as a nucleophile and attacks the carbocation intermediate.
8.5 Hydration - Mechanism

- The mechanism for acid-catalyzed hydration is essentially the same as hydrohalogenation:

- But with hydration, **nucleophilic attack produces an oxonium ion, which is deprotonated** to afford the alcohol product:

![Oxonium ion diagram](image)

Proton transfer

Water functions as a base and deprotonates the oxonium ion, yielding the product.
8.5 Hydration - Thermodynamics

- The reactants and products of hydration are in equilibrium
- We exploit La Chatelier’s principle to control the equilibrium

\[
\text{Dilute } \text{H}_2\text{SO}_4 \quad \text{(more } \text{H}_2\text{O)} \\
\text{Conc. } \text{H}_2\text{SO}_4 \quad \text{(less } \text{H}_2\text{O)}
\]

- If we are synthesizing an alcohol from an alkene, we would use excess water
- If we are synthesizing an alkene from an alcohol, we would only use acid, and not add water to the reaction
8.5 Hydration - Stereochemistry

- The stereochemistry of hydration is analogous to hydration, for the same reason(s).
- If a new chirality center is formed, a mixture of R and S is obtained.

\[ \text{XXX} + \text{H}_3\text{O}^+ \rightarrow \frac{50}{50} \]

- As always, if enantiomers are formed in a reaction, then a racemic mixture is obtained.

- Practice with SkillBuilder 8.3
8.6 Oxymercuration-Demercuration

- Markovnikov hydration (H₂O, H₂SO₄) has limited application... rearrangements often occur, giving mixture of products
- **Oxymercuration-demercuration** is an alternative
  - Markovnikov addition of H and OH
  - No rearrangements occur
8.6 Oxymercuration-Demercuration

- The mercuric cation is the (Lewis) acid in this reaction, instead of $H^+$

$$\text{AcO}^-\text{Hg} \rightleftharpoons \text{AcO}^-\text{Hg}^+$$

Mercuric acetate  Mercuric cation

$$\text{AcO}^-\text{Hg}^+ + \text{OAc}^- \rightarrow \text{AcO}^-\text{Hg} \rightleftharpoons \text{AcO}^-\text{Hg}^+$$

Acetylacetone
8.6 Oxymercuration-Demercuration

- When the \( \pi \) bond attacks the mercuric cation, a stabilized cation is formed, and so it will not rearrange like carbocations do.

 carbocations will rearrange if they can

Mercurinium ions will not rearrange
8.6 Oxymercuration-Demercuration

- The mercurinium ion reacts with nucleophiles, and it can easily be attacked by a nucleophile.

- $\text{NaBH}_4$ is generally used to replace the $-\text{HgOAc}$ group with a $-\text{H}$ group via a free radical mechanism.
The two reaction sequence provides same product as acid-catalyzed hydration, but without rearrangement.

A 1,2-methide shift would occur if $\text{H}_2\text{O},\text{H}_2\text{SO}_4$ was used.
8.7 Hydroboration-Oxidation

- Hydroboration-Oxidation adds H and OH with *anti* Markovnikov regioselectivity

\[
\begin{align*}
\text{1) BH}_3 \cdot \text{THF} & \rightarrow \text{Less substituted vinylic position} \\
\text{2) H}_2\text{O}_2, \text{NaOH} & \rightarrow \text{Anti-Markovnikov addition (90%)}
\end{align*}
\]

- Note that this is a two-reaction sequence
8.7 Hydroboration-Oxidation

- Hydroboration-Oxidation is also **stereoselective**
  - H and OH are added in a *syn* fashion

\[
\text{1) BH}_3 \cdot \text{THF} \quad \text{2) H}_2\text{O}_2, \text{NaOH} \]

\[
\begin{align*}
\text{Enantiomers} & \quad +
\end{align*}
\]

- **Anti** addition is NOT observed
8.7 Hydroboration-Oxidation

- $\text{B}_2\text{H}_6$ has to be stabilized in an ether solvent so that an appreciable amount of $\text{BH}_3$ is present.
- **The active reagent is** $\text{BH}_3\cdot\text{THF}$.
8.7 Hydroboration-Oxidation Mechanism

- **Hydroboration** follows *anti* Markovnikov regioselectivity
- The less substituted carbon attacks the boron, and the more substituted carbon develops a $\delta^+$ which triggers a hydride shift

![Reaction Mechanism]

- One BH$_3$ reacts with three equivalents of alkene

![Reaction Mechanism with BH$_3$]

The first step is repeated for each B–H bond to form a trialkylborane.
8.7 Hydroboration-Oxidation Mechanism

- Hydroboration follows *anti* Markovnikov regioselectivity
- Sterics also influence the regioselectivity

![Transition state diagrams](image.png)
8.7 Hydroboration-Oxidation Mechanism

Oxidation

Proton transfer

A hydroxide ion functions as a base and deprotonates hydrogen peroxide, forming a hydroperoxide

\[ pK_a = 11.8 \]

Nucleophilic attack

The hydroperoxide functions as a nucleophile and attacks the trialkylborane

\[ pK_a = 15.7 \]

Rearrangement

An alkyl group migrates, causing the expulsion of a hydroxide ion

Loss of a leaving group

An alkoxide ion is expelled, removing the negative charge from boron

Proton transfer

The alkoxide ion is protonated

A trialkoxyborane

The first three steps of oxidation are repeated, converting the trialkyborane into a trialkoxyborane

A trialkoxyborane

The hydroxide ion functions as a nucleophile and attacks the trialkoxyborane

A trialkoxyborane
8.7 Hydroboration-Oxidation selectivity

- Hydroboration is **stereospecific**: only *syn addition* occurs.

\[
\begin{align*}
\text{1) BH}_3 \cdot \text{THF} \\
\text{2) H}_2\text{O}_2, \text{NaOH} \\
\end{align*}
\]

If only one chirality center is formed, a pair of enantiomers is formed by addition to either side of the alkene.

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Hydroboration is stereospecific: only *syn* addition occurs.

If *two chirality centers* are formed, again a pair of enantiomers is obtained.
8.7 Hydroboration-Oxidation

• Predict the product(s) of the following reaction:

\[
\text{1) } \text{BH}_3 \cdot \text{THF} \quad \xrightarrow{} \quad \text{2) } \text{H}_2\text{O}_2, \text{NaOH}
\]
8.7 Hydroboration-Oxidation

- Predict the product(s) of the following reaction:

\[
\text{1) BH}_3 \cdot \text{THF} \\
\text{2) H}_2\text{O}_2, \text{NaOH}
\]

In this case, a mixture of diastereomers is obtained.

- Two chirality centers are formed. Why do we not obtain a mixture of enantiomers?

- Practice with SkillBuilder 8.4
8.8 Catalytic Hydrogenation

- **Hydrogenation** - the addition of H\(_2\) across a C=C double bond
- Requires a metal catalyst
- Alkene is converted to the corresponding alkane

\[
\text{\begin{tikzpicture}
\node (a) at (0,0) {\text{\begin{tikzpicture}[scale=0.5]
\draw (0,0) -- (1,0) -- (1.5,0.866) -- cycle;
\draw (0,0) -- (0.5,0) -- (0.5,0.866) -- cycle;
\end{tikzpicture}\}};
\node (b) at (3,0) {\text{\begin{tikzpicture}[scale=0.5]
\draw (0,0) -- (1,0) -- (1.5,0.866) -- cycle;
\end{tikzpicture}\}};
\node (c) at (5,0) {\text{\begin{tikzpicture}[scale=0.5]
\draw (0,0) -- (1,0) -- (1.5,0.866) -- cycle;
\end{tikzpicture}\}};
\node (d) at (3,0) {$\text{H}_2$};
\node (e) at (3,0) {$\text{Pt}$};
\node (f) at (5,0) {$(100\%)$};
\end{tikzpicture}}
\]
8.8 Catalytic Hydrogenation selectivity

- **Hydrogenation** - the addition of $\text{H}_2$ across a $\text{C}=$C double bond
- **Stereospecific** – only *syn* addition is observed with hydrogenation

Two chirality centers are formed only the stereoisomers resulting from *syn* addition are obtained.
8.8 Catalytic Hydrogenation

- Without the metal catalyst, the addition of $H_2$ is too slow due to a very high activation energy ($E_a$)
8.8 Catalytic Hydrogenation

- The metal surface binds the $\text{H}_2$, and the alkene, which explains why $\text{H}$ atoms are added syn across the $\pi$ bond
8.8 Catalytic Hydrogenation

- Syn addition of H2 to a symmetrical alkene will not produce a pair of enantiomers.
- A meso compound will be produced instead

Practice with SkillBuilder 8.5
8.8 Catalytic Hydrogenation

- **Heterogenous catalyst** – does not dissolve in reaction medium, like Pt or Pd metal
- **Homogenous catalyst** – does dissolve in the reaction medium, accomplished by using a *ligand* with the metal

![Chemical Reaction](image)

Wilkinson’s catalyst
8.8 Asymmetric Hydrogenation

- Recall that the creation of one or two chiral centers results in a mixture of enantiomers (unless a meso compound is produced)
8.9 Halogenation

- **Halogenation** – addition of two halogen atoms across a C=C double bond

\[
\text{\text{Cl}}_2 \rightarrow \text{Cl} \quad \text{Cl} \\
(97\%)
\]

- Halogenation is a key step in the production of PVC
8.9 Halogenation

- Halogenation only **practical with Cl\(_2\) and Br\(_2\)**
- halogenation with I\(_2\) is poor; halogenation with F\(_2\) is too violent

**Regioselectivity** – halogenation occurs with **anti addition**
8.9 Halogenation

- Br₂ is nonpolar, but polarizable. Approach of a nucleophile will induce a dipole
- Think of Br₂ as a bromine atom bonded to a good leaving group

The alkene acts as the nucleophile
8.9 Halogenation - stereoselectivity

- Only \textit{anti addition} is observed, so the mechanism is not consistent with a true carbocation intermediate.
- \textit{Syn} addition doesn’t occur.
8.9 Halogenation - mechanism

- The formation of a **bromonium ion intermediate** is consistent with *anti* addition
- This intermediate is similar to the mercurinium ion

![Diagram of halogenation mechanism showing nucleophilic attack and formation of bromonium ion]

The alkene functions as a nucleophile and attacks molecular bromine, expelling bromide as a leaving group and forming a bridged intermediate, called a bromonium ion.
8.9 Halogenation - mechanism

- The formation of a bromonium ion intermediate is consistent with *anti* addition.
- Br- attacks backside (*anti*) to the bromonium ion.
8.9 Halogenation - stereoselectivity

- Halogenation is **stereospecific**, the stereochemistry of the starting alkene determines the stereochemistry of the product(s).

![Chemical Structures]

- Practice with Conceptual Checkpoint 8.20

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8.9 Halohydrin Formation

- **Halohydrins** – formed when halogenation is conducted in water
- Water acts as the nucleophile that attacks the bromonium ion

There are many more $\text{H}_2\text{O}$ molecules compared to $\text{Br}^{1-}$ ions, so $\text{H}_2\text{O}$ outcompetes $\text{Br}^{1-}$ for the bromonium ion.
8.9 Halohydrin Formation

- After water attacks, it is deprotonated to yield the neutral *bromohydrin* product.
8.9 Halohydrin Formation—Regioselectivity

- Halohydrin Formation is **regioselective**
  - The **halide** adds to the **less substituted carbon**
  - The **OH** adds to the **more substituted carbon**
8.9 Halohydrin Formation-Regioselectivity

- Regioselectivity results from $\text{H}_2\text{O}$ attacking the more substituted carbon (faster than it attacks the less substituted one)
8.9 Halohydrin Formation-Regioselectivity

- Regioselectivity results from $\text{H}_2\text{O}$ attacking the more substituted carbon (faster than it attacks the less substituted one).

- The more substituted carbon has more cationic character.

- Practice with SkillBuilder 8.6
8.10 *Anti*-Dihydroxylation

- **Dihydroxylation** – addition of \( \text{OH and OH} \) across the \( \pi \) bond

- **Anti** dihydroxylation of an alkene is a two-reaction process
8.10 Anti-Dihydroxylation

1. Conversion of alkene to an epoxide:

   - A peroxycacid is used as the reagent

   ![Reaction Diagram]

   - Transition state

   - An epoxide

   ![Chemical Structures]

   - Peroxyacetic acid
   - meta-Chloroperoxybenzoic acid (MCPBA)
8.10 Anti-Dihydroxylation - mechanism

1. Conversion of alkene to an epoxide:

2. The epoxide is reacted with H₂O and acid catalyst to form the anti diol.
8.10 *Anti*-Dihydroxylation

- Note the similarities between these three key intermediates

\[
\begin{align*}
&\text{A protonated epoxide} \\
&\text{A bromonium ion} \\
&\text{A mercurinium ion}
\end{align*}
\]

- Ring strain and a +1 formal charge makes these structures good electrophiles
- They also each yield *anti* products, because the nucleophile must attack from the side opposite the leaving group
- **Practice with SkillBuilder 8.7**
8.11 Syn Dihydroxylation

- syn dihydroxylation – adds OH and OH across the $p$ bond, in a concerted, syn fashion.

A cyclic osmate ester

\[
\text{Os} \quad \text{Na}_2\text{SO}_3/\text{H}_2\text{O} \quad \text{or} \quad \text{NaHSO}_3/\text{H}_2\text{O}
\]

\[
\text{OH} \quad \text{OH}
\]
8.11 Syn Dihydroxylation

- OsO₄ is expensive, and toxic.
- NMO or an alkyl peroxide is used as an *co-oxidant*, so only a catalytic amount of OsO₄ is necessary.
8.11 Syn Dihydroxylation

- Syn dihydroxylation can also be achieved with KMnO₄ but only under mild conditions (cold temperatures)

- The synthetic utility of MnO₄⁻ is limited: it reacts with many other functional groups as well

- Practice with Conceptual Checkpoint 8.27
8.12 Oxidative Cleavage

- C=C double bonds are also reactive toward oxidative cleavage
- Ozonolysis is one such process

Ozone exists as a resonance hybrid of two contributors

\[
\text{[Ozone structure]} \quad \longleftrightarrow \quad \text{[Another ozone structure]}
\]
8.12 Oxidative Cleavage

Common reducing agents include dimethyl sulfide and Zn/H₂O. 

Practice with SkillBuilder 8.8
8.12 Oxidative Cleavage

- Predict a bicyclic reactant used to form the product below.
8.12 Oxidative Cleavage

- Predict a bicyclic reactant used to form the product below.
8.13 Predicting Products of Addition Rxns

1. Analyze the reagents used to determine what groups will be added across the C=C double bond
2. Determine the regioselectivity (Markovnikov or anti-Markovnikov)
3. Determine the stereospecificity (syn or anti addition)

- Each step can be achieved with minor reagent memorization and a firm grasp of the mechanistic rational
- The more familiar you are with the mechanisms, the easier predicting products will be

- Practice with SkillBuilder 8.9
To set up a synthesis, assess the reactants and products to see what changes need to be made.

- **Addition rxn**
  
  - $\text{Reactant}$
  
  - $\text{Product}$

- **Substitution rxn**
  
  - $\text{Reactant}$
  
  - $\text{Product}$

- **Elimination rxn**
  
  - $\text{Reactant}$
  
  - $\text{Product}$
8.14 One-Step Syntheses

- To set up a synthesis, assess the reactants and products to see what changes need to be made.

- Give reagents and conditions for the following.

Here, we need to do an addition rxn, and add H and OH, Markovnikov.
8.14 One-Step Syntheses

- To set up a synthesis, assess the reactants and products to see what changes need to be made
- Give reagents and conditions for the following

\[
\text{H}_2\text{O}, \text{H}_2\text{SO}_4
\]

- Practice with the other examples in SkillBuilder 8.10
8.14 Multi-step Syntheses

• Changing the position of a Leaving Group:
  The following transformation cannot be done with a single rxn:

\[
\begin{align*}
\text{Br} & \quad \rightarrow \\
\end{align*}
\]

It can be accomplished in a two-rxn sequence:

\[
\begin{align*}
\text{Br} & \quad \xrightarrow{\text{Elimination}} \\
\rightarrow & \quad \xrightarrow{\text{Addition}} \\
\end{align*}
\]
8.14 Multi-step Syntheses

- Changing the position of a Leaving Group:

To do the elimination reaction, the base needs to be carefully chosen:

This is the alkene we need, so we use non-bulky base.
8.14 Multi-step Syntheses

- **Changing the position of a Leaving Group:**

Then we need to decide the reagents needed to add H and Br:

So, overall:

Markovnikov addition of H and Br
8.14 Multi-step Syntheses

- Consider the following transformation:

- This is not a simple substitution, addition or elimination, so two processes must be combined.
8.14 Multi-step Syntheses

- The elimination must be done to give the Hofmann alkene, via an E2 elimination.

\[ \text{OH} \quad \xrightarrow{\text{Elimination}} \quad \text{alkene} \quad \xrightarrow{\text{Addition of H and OH}} \quad \text{alkene} \]

- The alcohol must be changed to a good leaving group so we can use a bulky base to afford the Hofmann product:

\[ \text{Conversion of OH into a good leaving group} \quad \xrightarrow{\text{TsCl, pyridine}} \quad \text{OTs} \quad \xrightarrow{t-\text{BuOK}} \quad \text{alkene} \]
8.14 Multi-step Syntheses

- The addition reaction must give *anti* Markovnikov addition of H and OH
- So, overall:

![Conversion of OH into a good leaving group](image)

Practice with SkillBuilder 8.11
8.14 Multi-step Syntheses

- Changing the position of a $\pi$ bond:

- Again, two processes must be combined

  - anti Markovnikov addition of H and Br
  - elimination to give the Hofmann product
8.14 Multi-step Syntheses

- Changing the position of a $\pi$ bond:
- Now recall the reagents needed for each reaction:

$$\text{Addition} \quad \text{Elimination}$$

\[ \text{anti Markovnikov} \quad \text{elimination to give} \]
\[ \text{addition of H and Br} \quad \text{the Hofmann product} \]

- Practice with Skillbuilder 8.12
8.14 Review of Addition Reactions

- Ten reactions of alkenes covered in this chapter:

1. Hydrohalogenation (Markovnikov)
2. Hydrohalogenation (anti-Markovnikov)
3. Acid-catalyzed hydration and oxymercuration-demercuration
4. Hydroboration-oxidation
5. Hydrogenation
6. Bromination
7. Halohydrin formation
8. Anti dihydroxylation
9. Syn dihydroxylation
10. Ozonolysis
8.14 Review of Addition Reactions