

4.7
Preparation of Alkyl Halides from Alcohols and Hydrogen Halides

$$\text{ROH} + \text{HX} \rightarrow \text{RX} + \text{H}_2\text{O}$$

Reaction of Alcohols with Hydrogen Halides

$$\text{ROH} + \text{HX} \rightarrow \text{RX} + \text{HOH}$$

Hydrogen halide reactivity

HF HCl HBr HI

least reactive most reactive

Reaction of Alcohols with Hydrogen Halides

$$\text{ROH} + \text{HX} \rightarrow \text{RX} + \text{HOH}$$

Alcohol reactivity

CH_3OH	RCH_2OH	R_2CHOH	R_3COH
Methanol	Primary	Secondary	Tertiary

least reactive most reactive

Preparation of Alkyl Halides

$$(\text{CH}_3)_3\text{COH} + \text{HCl} \xrightarrow{25^\circ\text{C}} (\text{CH}_3)_3\text{CCl} + \text{H}_2\text{O}$$

78-88%

73%

$$\text{CH}_3(\text{CH}_2)_5\text{CH}_2\text{OH} + \text{HBr} \xrightarrow{120^\circ\text{C}} \text{CH}_3(\text{CH}_2)_5\text{CH}_2\text{Br} + \text{H}_2\text{O}$$

87-90%

Preparation of Alkyl Halides

A mixture of sodium bromide and sulfuric acid may be used in place of HBr.

$$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \xrightarrow[\text{heat}]{\text{NaBr, H}_2\text{SO}_4} \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$$

70-83%

Question 5

What is the product of the reaction of 2-methylcyclohexanol with HBr?

A)

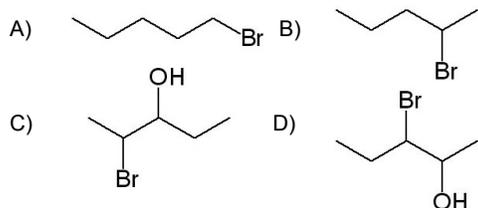
B)

C)

D)

Question 6

What product will be isolated from the reaction of 2-pentanol with HBr?



4.8
Mechanism of the Reaction of Alcohols with Hydrogen Halides

About mechanisms

A mechanism describes how reactants are converted to products.

Mechanisms are often written as a series of chemical equations showing the *elementary steps*.

An elementary step is a reaction that proceeds by way of a single transition state.

Mechanisms can be shown *likely* to be correct, but cannot be *proven* correct.

About mechanisms

For the reaction:



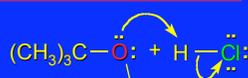
tert-Butyl alcohol

tert-Butyl chloride

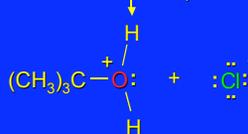
the generally accepted mechanism involves three elementary steps.

Step 1 is a Brønsted acid-base reaction.

Step 1: Proton Transfer



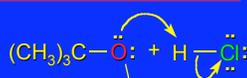
fast, bimolecular



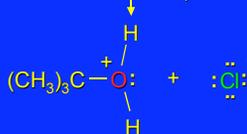
tert-Butyloxonium ion

Like proton transfer from a strong acid to water, proton transfer from a strong acid to an alcohol is normally very *fast*.

Step 1: Proton Transfer



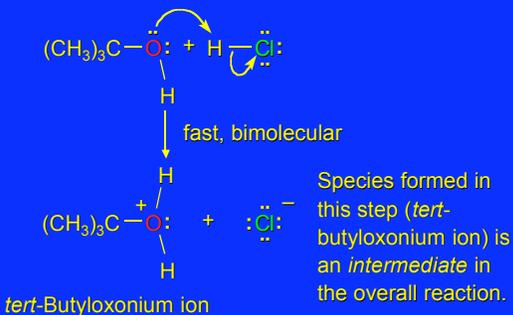
fast, bimolecular



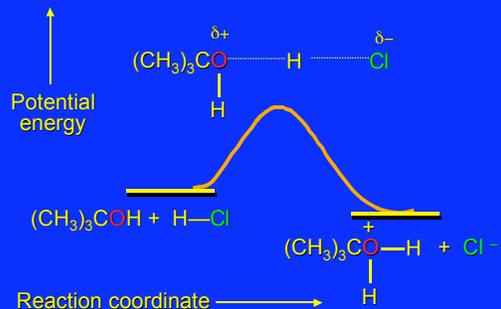
tert-Butyloxonium ion

Two molecules react in this elementary step; therefore it is *bimolecular*.

Step 1: Proton Transfer

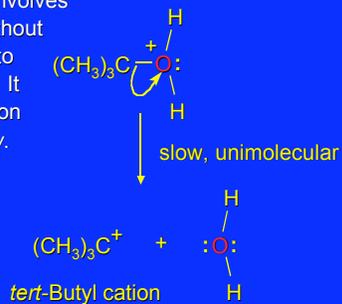


Potential Energy Diagram for Step 1



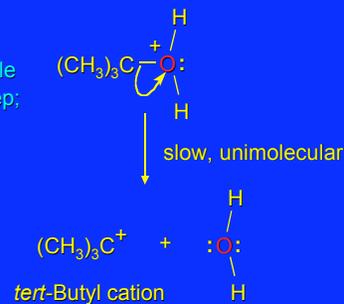
Step 2: Carbocation Formation

Dissociation of the alkyloxonium ion involves bond-breaking, without any bond-making to compensate for it. It has a high activation energy and is *slow*.



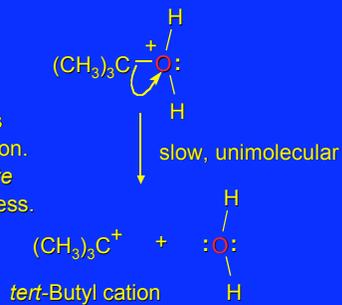
Step 2: Carbocation Formation

A single molecule reacts in this step; therefore, it is *unimolecular*.

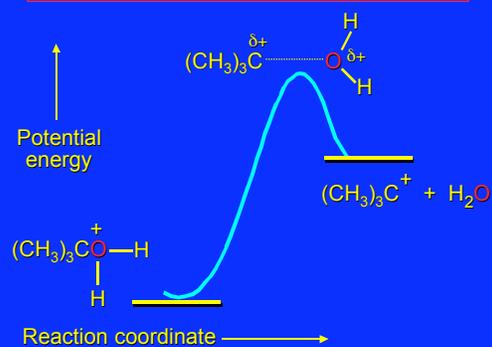


Step 2: Carbocation Formation

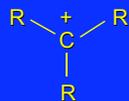
The product of this step is a carbocation. It is an *intermediate* in the overall process.



Potential Energy Diagram for Step 2



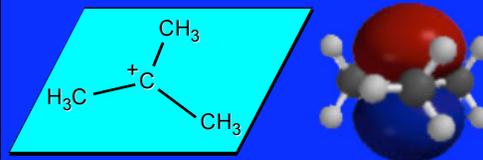
Carbocation



The key intermediate in reaction of secondary and tertiary alcohols with hydrogen halides is a carbocation.

A carbocation is a cation in which carbon has 6 valence electrons and a positive charge.

Figure 4.8 Structure of tert-Butyl Cation

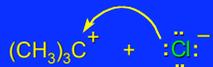


Positively charged carbon is sp^2 hybridized.

All four carbons lie in same plane.

Unhybridized p orbital is perpendicular to plane of four carbons.

Step 3: Carbocation Capture



fast, bimolecular

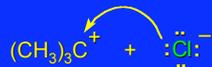


tert-Butyl chloride

Bond formation between the positively charged carbocation and the negatively charged chloride ion is fast.

Two species are involved in this step. Therefore, this step is *bimolecular*.

Step 3: Carbocation Capture



fast, bimolecular

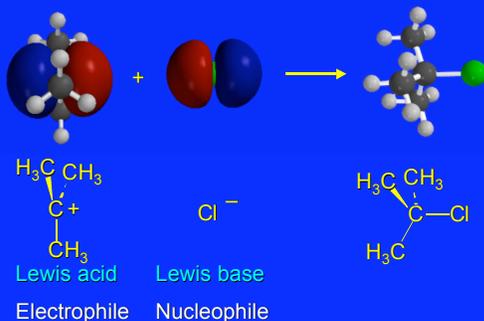


tert-Butyl chloride

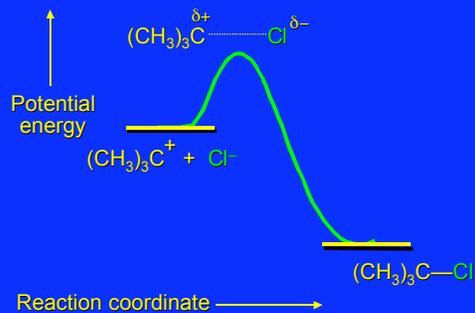
This is a Lewis acid-Lewis base reaction. The carbocation is the Lewis acid; chloride ion is the Lewis base.

The carbocation is an *electrophile*. Chloride ion is a *nucleophile*.

Step 3: Carbocation Capture



Potential Energy Diagram for Step 3



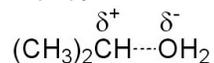
Question 7

What is the rate-determining step in the reaction of cyclobutanol with HCl?

- A) protonation of the OH group
- B) attack of the bromide on the carbocation
- C) simultaneous formation of the C-Br bond and the breaking of the C-OH bond
- D) carbocation formation

Question 8

The species shown below represents _____ of the reaction between isopropyl alcohol and hydrogen bromide.



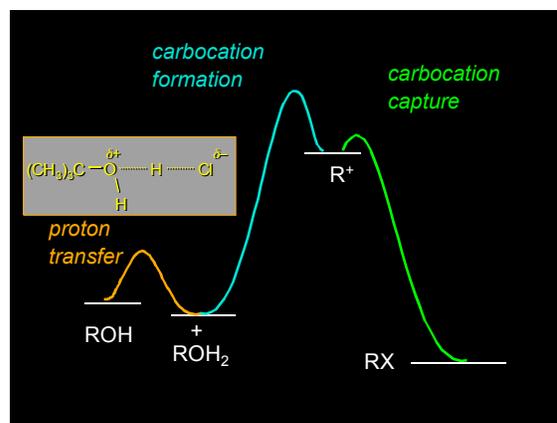
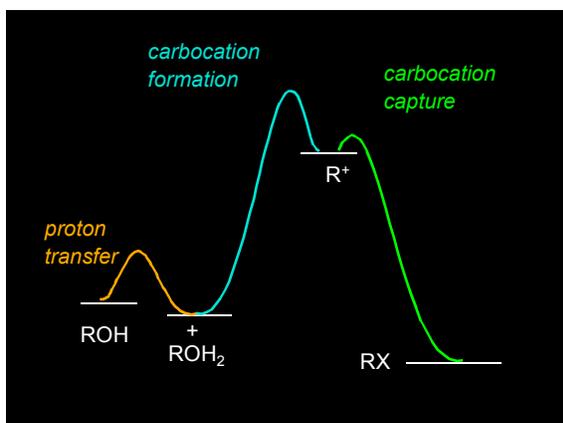
- A) the alkyloxonium ion intermediate
- B) the transition step of the bimolecular proton transfer
- C) the transition state of the attack of the nucleophile on the carbocation
- D) the transition state of the unimolecular dissociation

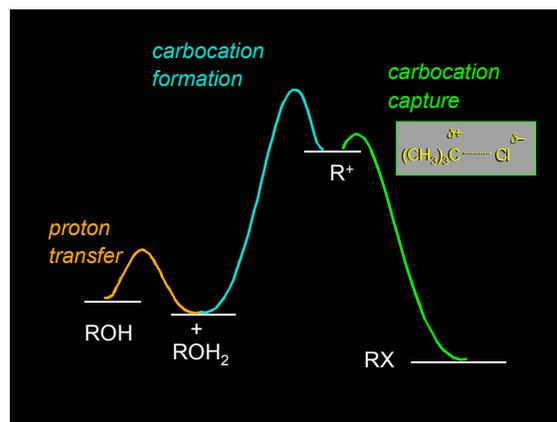
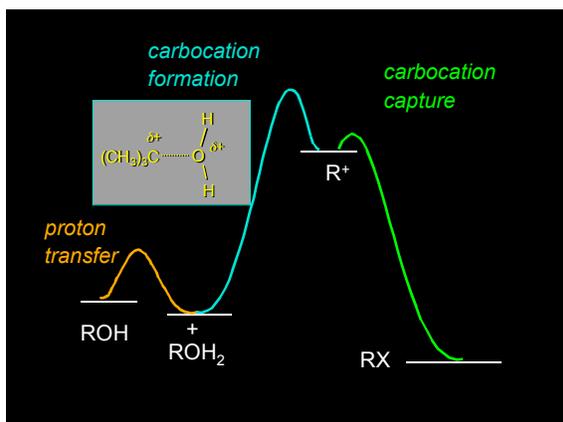
4.9
Potential Energy Diagrams for
Multistep Reactions:
The S_N1 Mechanism

Potential Energy Diagram - Overall

The potential energy diagram for a multistep mechanism is simply a collection of the potential energy diagrams for the individual steps.

Consider the three-step mechanism for the reaction of *tert*-butyl alcohol with HCl.





Mechanistic Notation

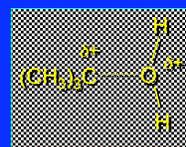
The mechanism just described is an example of an S_N1 process.

S_N1 stands for substitution-nucleophilic-unimolecular.

The molecularity of the rate-determining step defines the molecularity of the overall reaction.

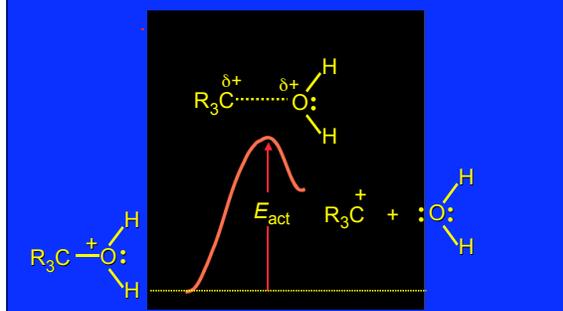
Mechanistic Notation

The molecularity of the rate-determining step defines the molecularity of the overall reaction.



Rate-determining step is unimolecular dissociation of alkyloxonium ion.

Activation energy for formation of *tertiary* carbocation is less than that for formation of *secondary* carbocation.



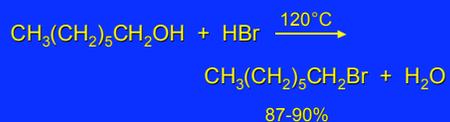
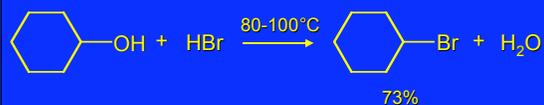
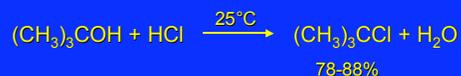
Question 9

Select the most stable carbocation.

- A)  B) 
- C)  D) CH_3CH_2^+

4.12
Reaction of Primary Alcohols with
Hydrogen Halides.
The S_N2 Mechanism

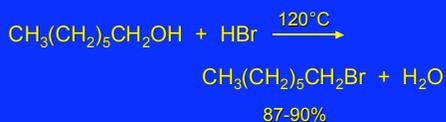
Preparation of Alkyl Halides



Preparation of Alkyl Halides

Primary carbocations are too high in energy to allow S_N1 mechanism. Yet, primary alcohols are converted to alkyl halides.

Primary alcohols react by a mechanism called S_N2 (substitution-nucleophilic-bimolecular).



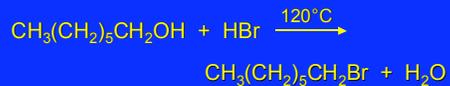
The S_N2 Mechanism

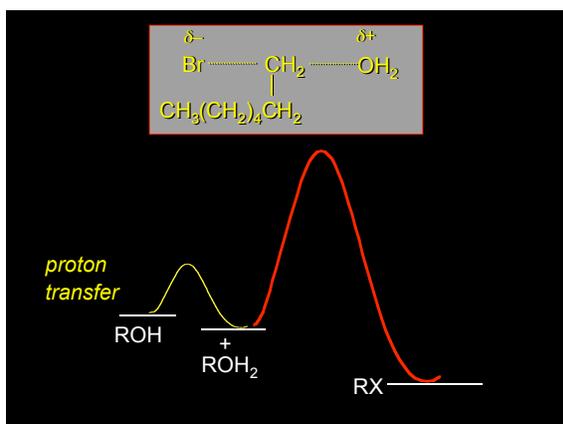
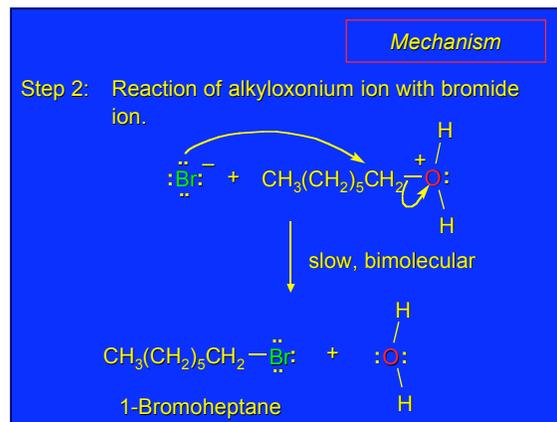
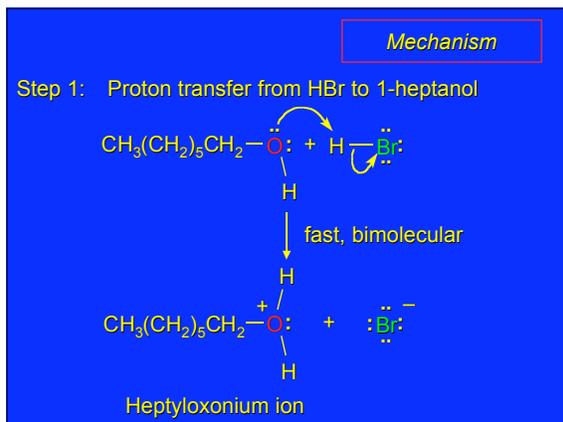
Two-step mechanism for conversion of alcohols to alkyl halides:

- (1) proton transfer to alcohol to form alkyloxonium ion
- (2) bimolecular displacement of water (water is the "leaving group") by the halide which is the "nucleophile"

Bimolecular Reaction

Example





Question 11

Which of the following is the least able to serve as a nucleophile in a chemical reaction?

A) Br⁻
 B) OH⁻
 C) NH₃
 D) CH₃⁺

