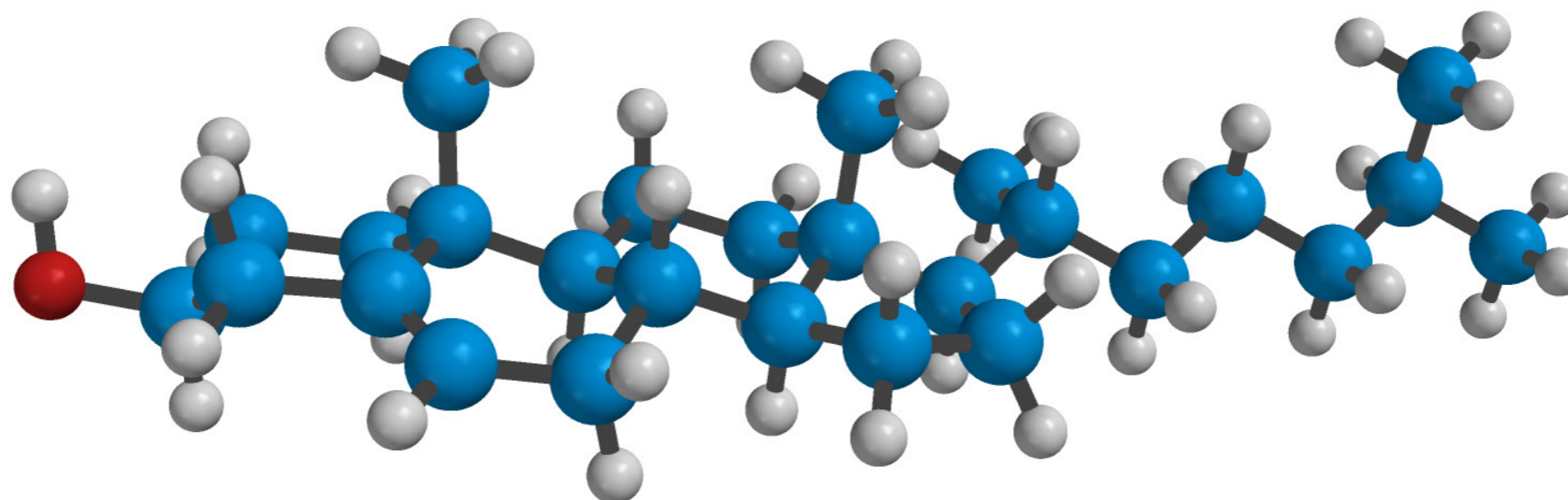


# 9

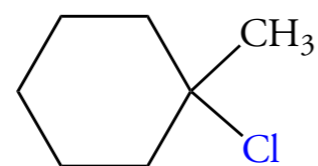
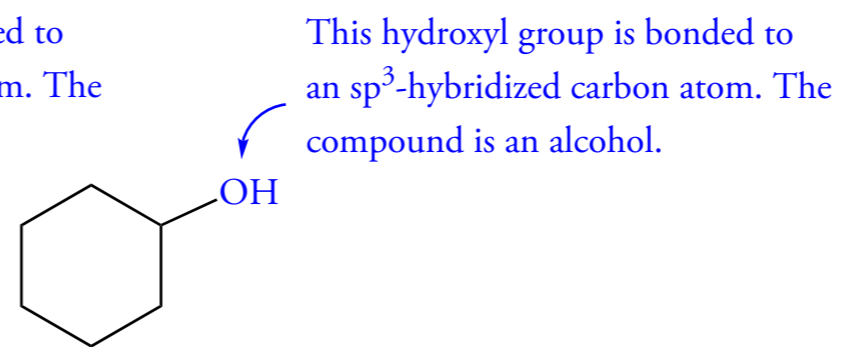
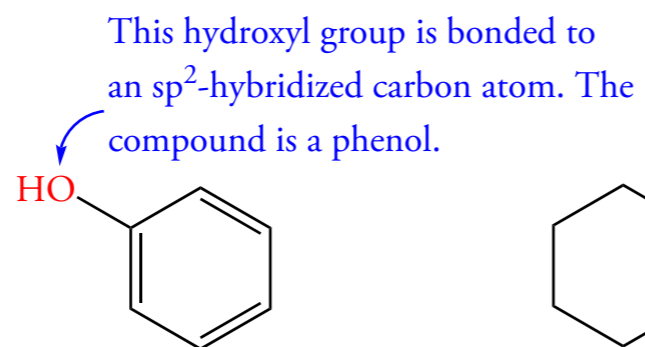
## HALOALKANES AND ALCOHOLS

### INTRODUCTION TO NUCLEOPHILIC SUBSTITUTION AND ELIMINATION REACTIONS

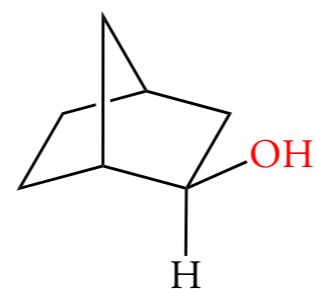


Cholesterol

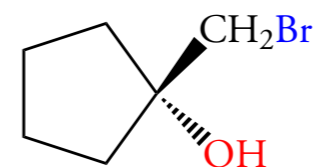
## 9.1 FUNCTIONALIZED HYDROCARBONS



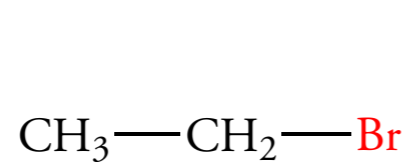
tertiary chloride



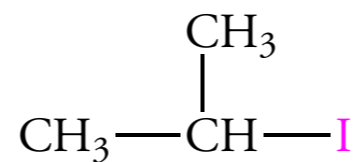
secondary alcohol



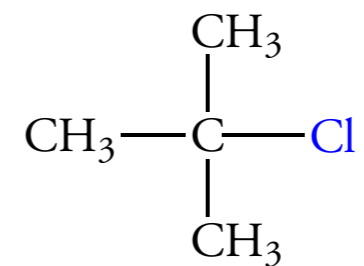
primary bromide,  
tertiary alcohol



ethyl bromide



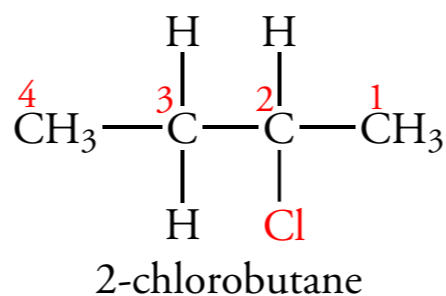
isopropyl iodide



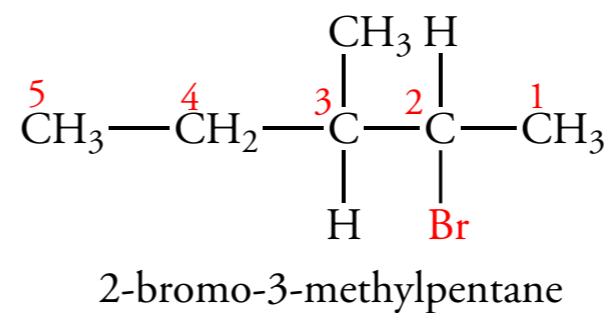
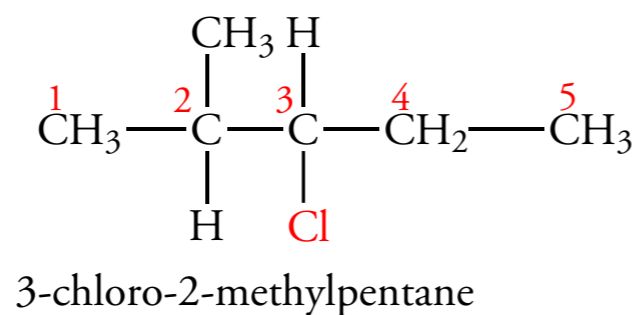
*tert*-butyl chloride

## 9.2 IUPAC NOMENCLATURE OF HALOALKANES

1. Identify the longest continuous chain of carbon atoms that includes the hydroxyl group; this is the parent chain.

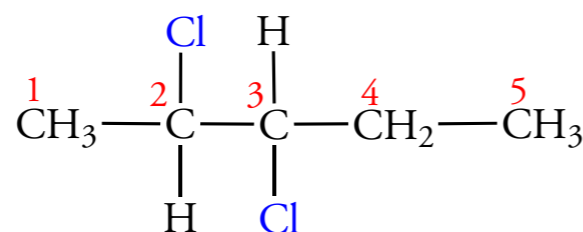


2. If the parent chain has branching alkyl groups, number the chain from the end nearer the first substituent whether it is an alkyl group or a halogen atom.

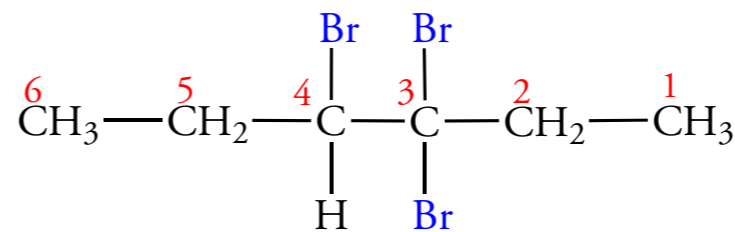


## 9.2 IUPAC NOMENCLATURE OF HALOALKANES, II

3. If the compound contains two or more halogen atoms of the same type, indicate them with the prefixes di-, tri-, etc. Give each halogen atom a number that corresponds to its position in the parent chain.

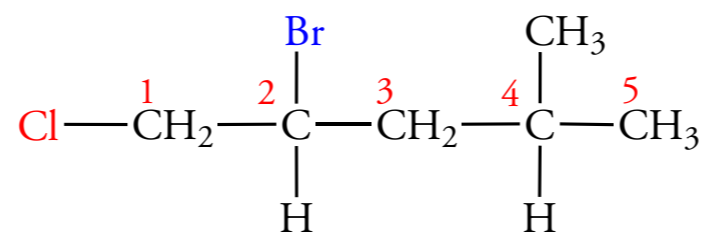


2,3-dichloropentane



3,3,4-tribromohexane

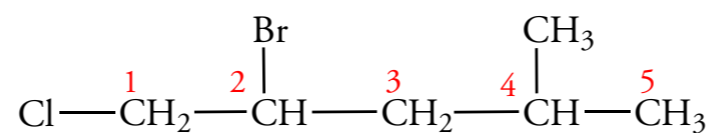
4. If a compound contains different halogen atoms, number them according to their positions on the chain, and list them in alphabetical order.



2-bromo-1-chloro-4-methylpentane

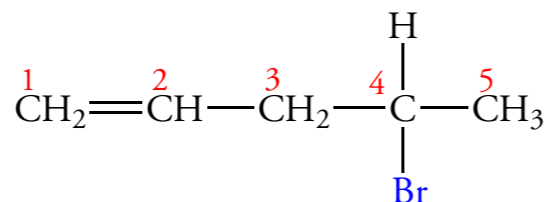
## 9.2 IUPAC NOMENCLATURE OF HALOALKANES, III

5. If the chain can be numbered from either end based on the location of the substituents, begin at the end nearer the substituent that has alphabetical precedence, whether it is an alkyl group or a halogen atom.

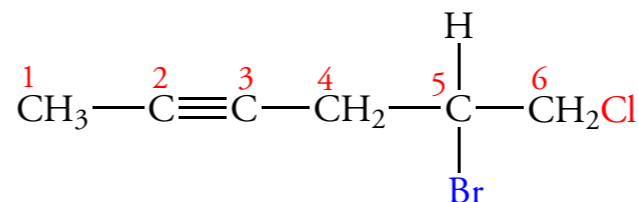


2-bromo-1-chloro-4-methylpentane

6. In a halogen-containing compound with a double or triple bond, the unsaturated unit takes precedence in numbering the carbon chain. Place the number indicating the position of the multiple bond in front of the name of the alkene (or alkyne). Use the number that indicates the position of the halogen group as a prefix to the name of the alkene (or alkyne).

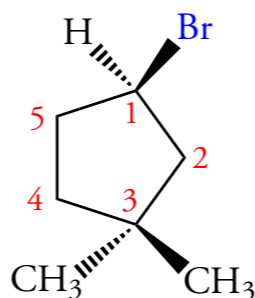


4-bromo-1-pentene

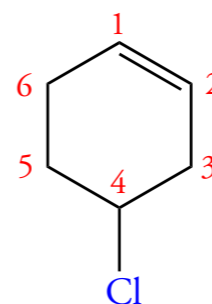


5-bromo-6-chloro-2-hexyne

7. Number halocycloalkanes from the carbon atom bearing the halogen atom unless another functional group, such as a double bond, takes precedence. Number carbon atoms in the ring to give the lower number to the substituent.



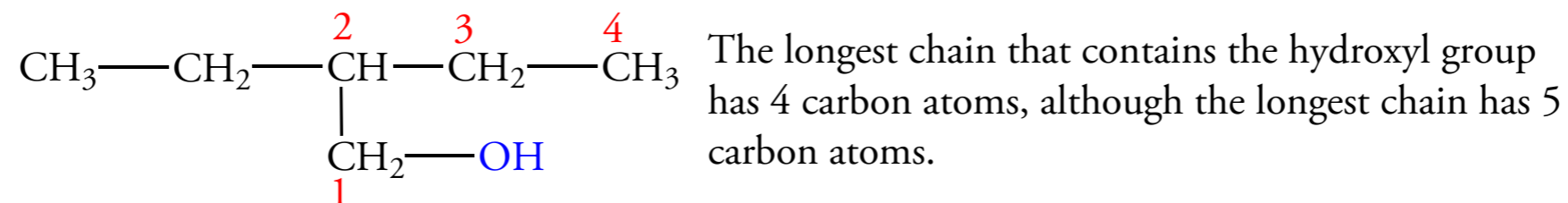
1-bromo-3,3-dimethylcyclopentane



4-chlorocyclohexene

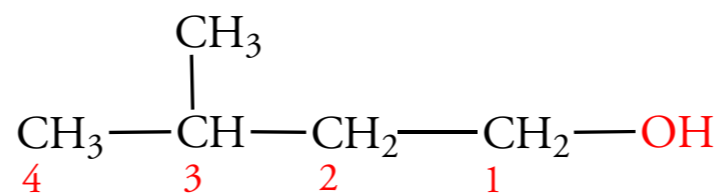
## 9.3 IUPAC NOMENCLATURE OF ALCOHOLS, I

1. Identify the longest continuous chain of carbon atoms that includes the hydroxyl group as the parent chain.



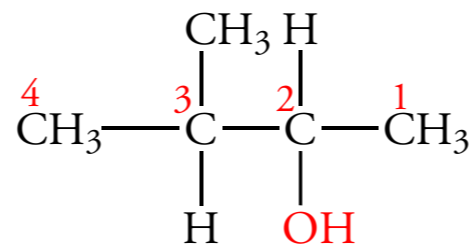
2-ethyl-1-butanol

2. Name the parent by substituting the suffix *-ol* for the final *-e* of the corresponding alkane.



3-methyl-1-butanol

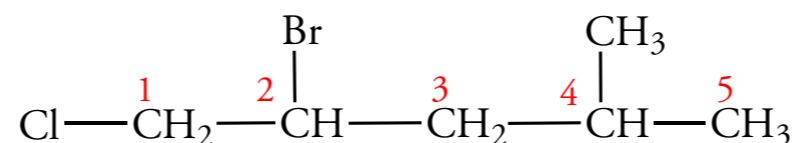
3. Indicate the position of the hydroxyl group using the number of the carbon atom to which it is attached. Number the chain so that the carbon atom bearing the hydroxyl group has the lower number.



3-methyl-2-butanol

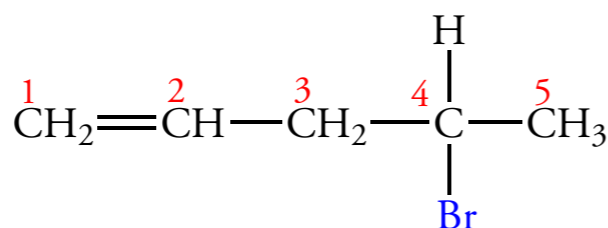
## 9.3 IUPAC NOMENCLATURE OF ALCOHOLS, II

5. If the chain can be numbered from either end based on the location of the substituents, begin at the end nearer the substituent that has alphabetical precedence, whether it is an alkyl group or a halogen atom.

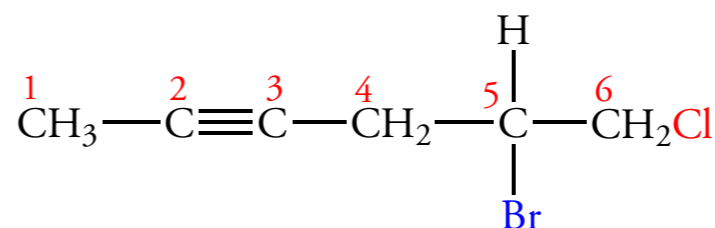


2-bromo-1-chloro-4-methylpentane

6. In a halogen-containing compound with a double or triple bond, the unsaturated unit takes precedence in numbering the carbon chain. Place the number indicating the position of the multiple bond in front of the name of the alkene (or alkyne). Use the number that indicates the position of the halogen group as a prefix to the name of the alkene (or alkyne).

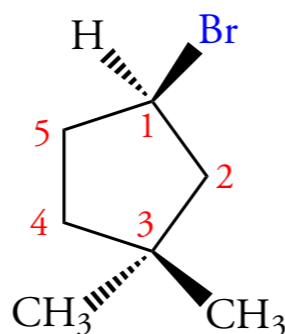


4-bromo-1-pentene

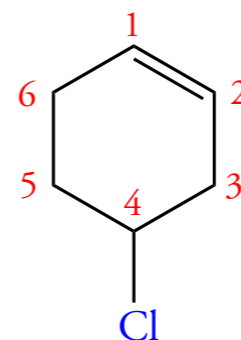


5-bromo-6-chloro-2-hexyne

7. Number halocycloalkanes from the carbon atom bearing the halogen atom unless another functional group, such as a double bond, takes precedence. Number carbon atoms in the ring to give the lower number to the substituent.

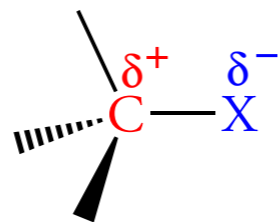


1-bromo-3,3-dimethylcyclopentane



4-chlorocyclohexene

## 9.4 STRUCTURE AND PROPERTIES OF HALOALKANES



where X = F, Cl, Br, I

	CH <sub>3</sub> —F	CH <sub>3</sub> —Cl	CH <sub>3</sub> —Br	CH <sub>3</sub> —I
bond length (pm)	139	178	193	214
	CH <sub>3</sub> —CH <sub>2</sub> —F	CH <sub>3</sub> —CH <sub>2</sub> —Cl	CH <sub>3</sub> —CH <sub>2</sub> —Br	CH <sub>3</sub> —CH <sub>2</sub> —I
boiling point (C°)	-37.7	12.7	38.4	72



## 9.4 STRUCTURE AND PROPERTIES OF HALOALKANES, II

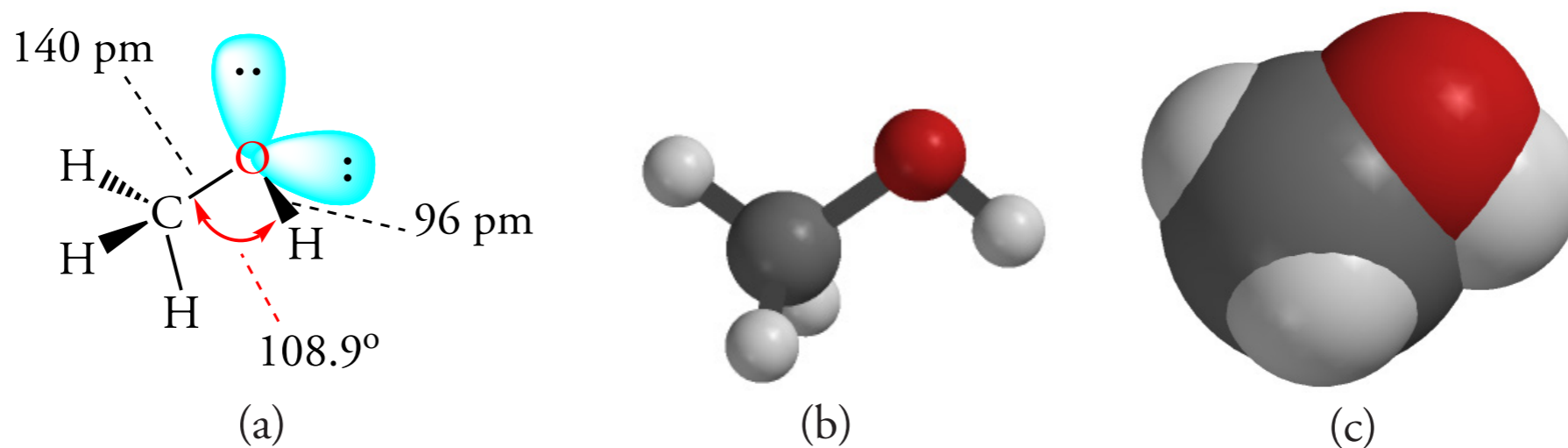
**Table 9.1**  
**Boiling Points and Densities of Haloalkanes**

Compound	Boiling Point (°C)	Density g/mL
CH <sub>3</sub> F	-78	1.44
CH <sub>3</sub> Cl	27	2.22
CH <sub>3</sub> Br	40.2	1.47
CH <sub>3</sub> I	42	2.28
CH <sub>2</sub> Cl <sub>2</sub>	40	1.34
CHCl <sub>3</sub>	61	1.50
CCl <sub>4</sub>	77	1.60
CH <sub>3</sub> CH <sub>2</sub> F	-38	1.70
CH <sub>3</sub> CH <sub>2</sub> Cl	12	0.92
CH <sub>3</sub> CH <sub>2</sub> Br	38	0.716
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> F	3	0.782
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> Cl	47	0.89
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> Br	71	1.35
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> I	102	1.75

## 9.5 STRUCTURE AND PROPERTIES OF ALCOHOLS, I

### Figure 9.1 Structure of Methanol

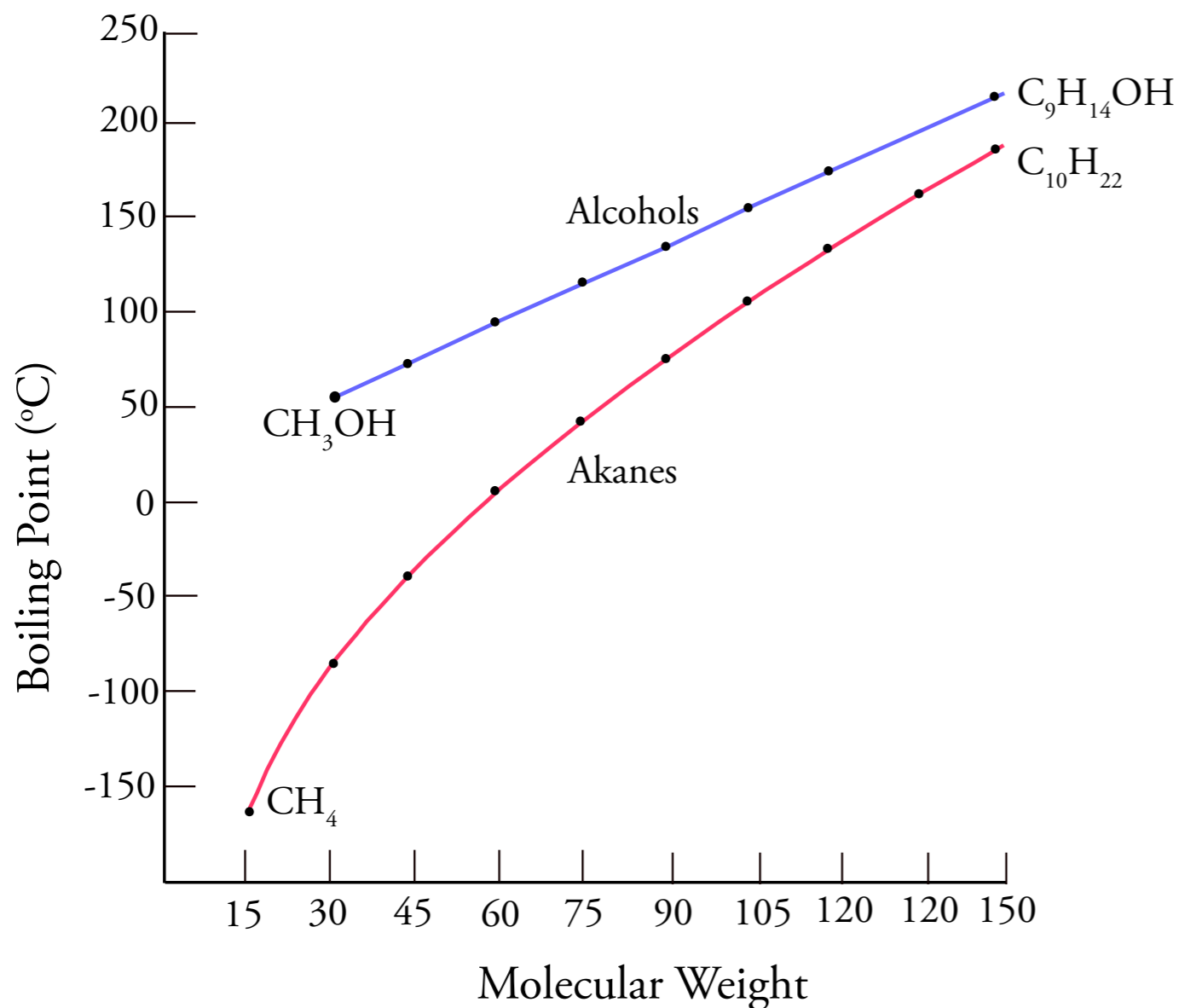
(a) The oxygen atom of methanol is  $sp^3$ -hybridized. The C—O—H bond angle is close to the tetrahedral bond angle. The two sets of lone pair electrons are in  $sp^3$  hybrid orbitals that are directed to two of the corners of a tetrahedron. (b) Ball-and-stick model of methanol. (c) Space-filling model of methanol.



## 9.5 STRUCTURE AND PROPERTIES OF ALCOHOLS, II

**Figure 9.2 Comparison of the Boiling Points of Alcohols and Alkanes**

The boiling points of alkanes and alcohols increase with increasing chain length. Alcohols have higher boiling points than alkanes of comparable molecular weight. This difference decreases as the length of the carbon chain increases.

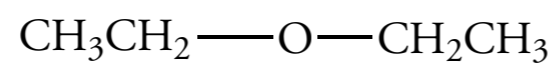
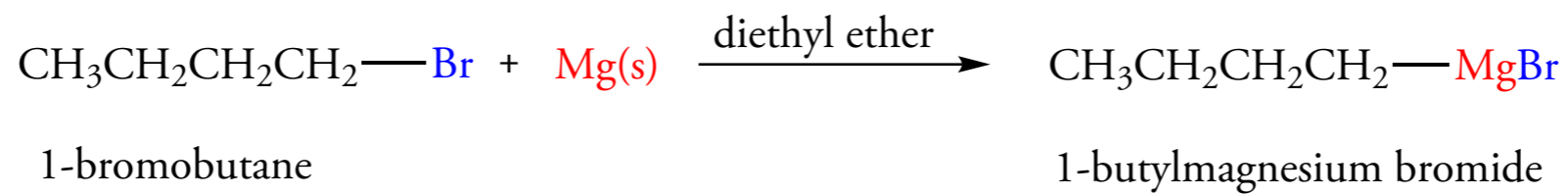
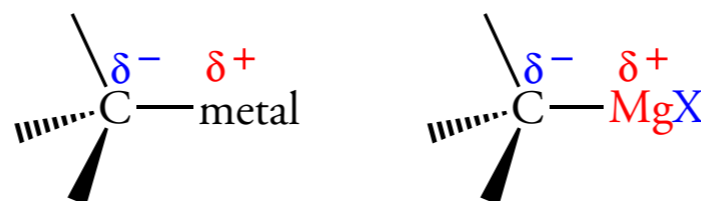


**Table 9.2**  
**Boiling Points and Solubilities of Alcohols**

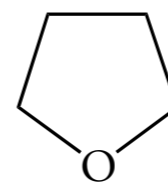
Compound	Boiling Point (°C)	Solubility (g/100 ml mL water)
methanol	65	miscible
ethanol	78	miscible
1-propanol	97	miscible
1-butanol	117	7.9
1-pentanol	137	2.7
1-hexanol	158	0.59
1-heptanol	176	0.09
1-octanol	194	insoluble
1-nonanol	213	insoluble
1-decanol	229	insoluble

## 9.6 ORGANOMETALLIC COMPOUNDS, I

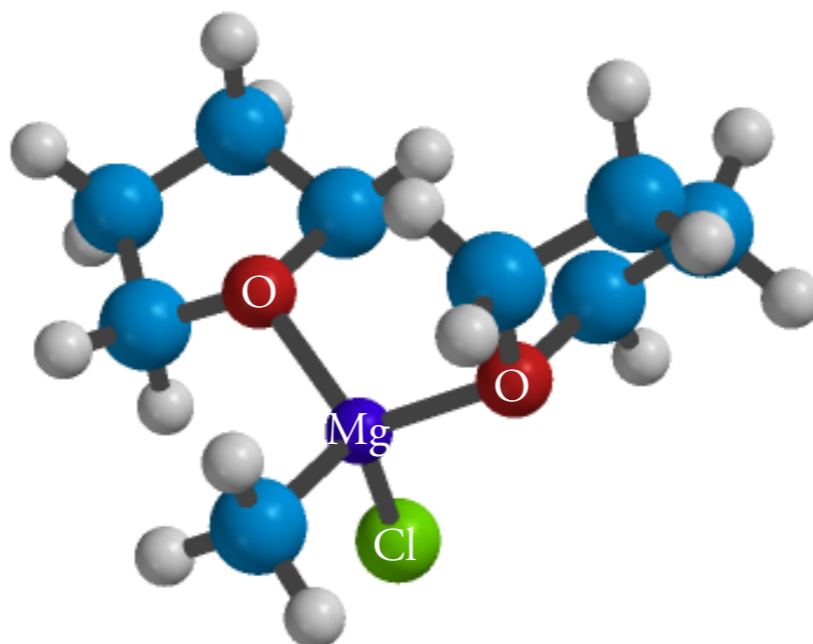
### Grignard Reagents



diethyl ether  
bp 35 °C

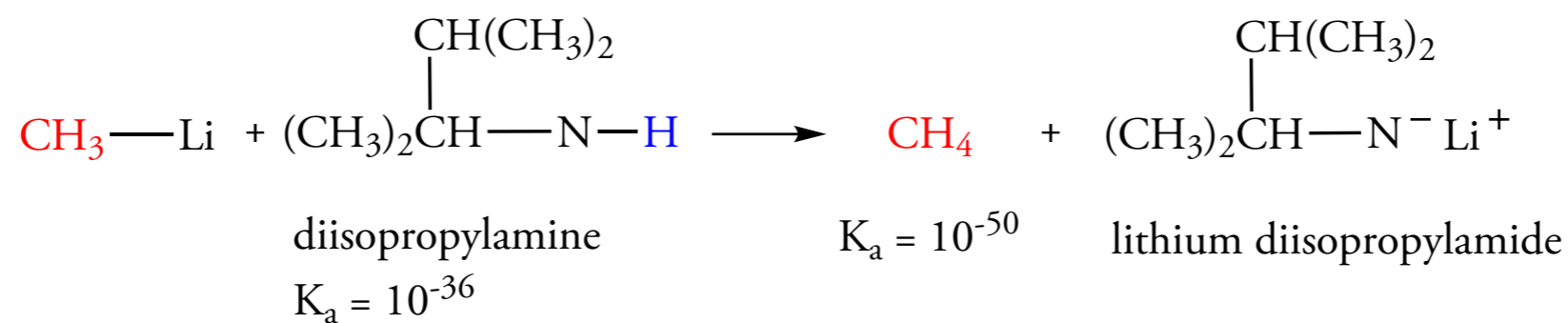
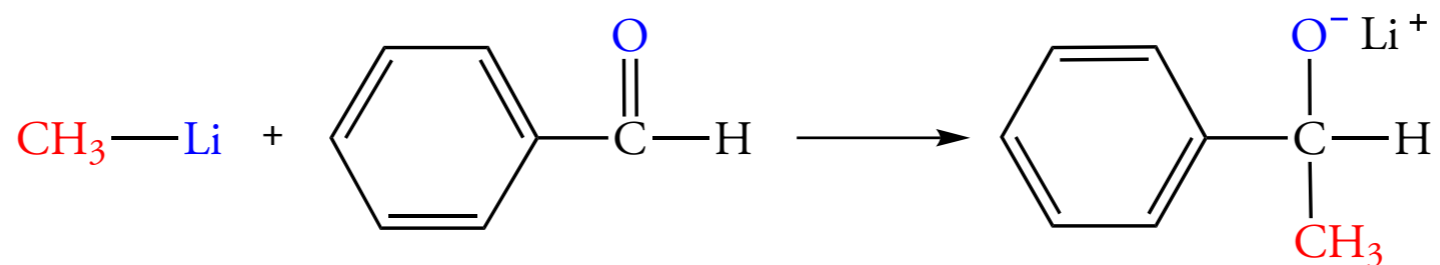
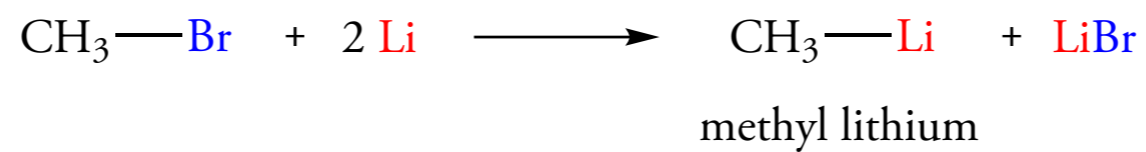


tetrahydrofuran  
bp 65 °C

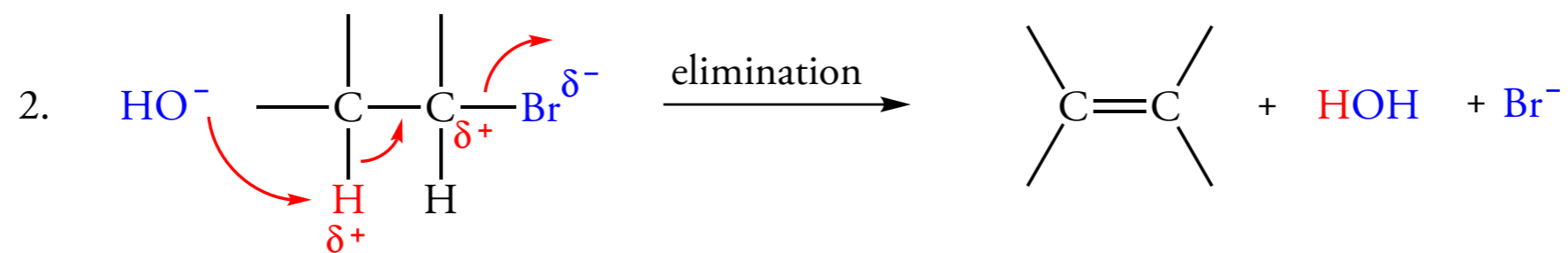
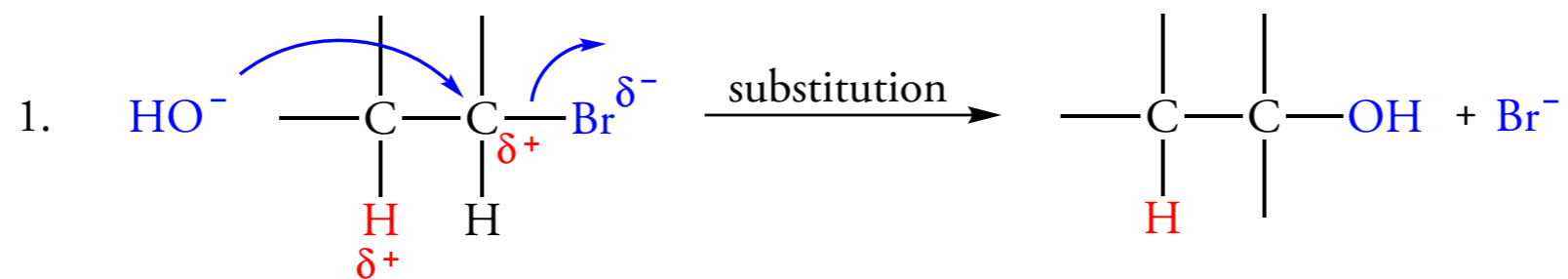
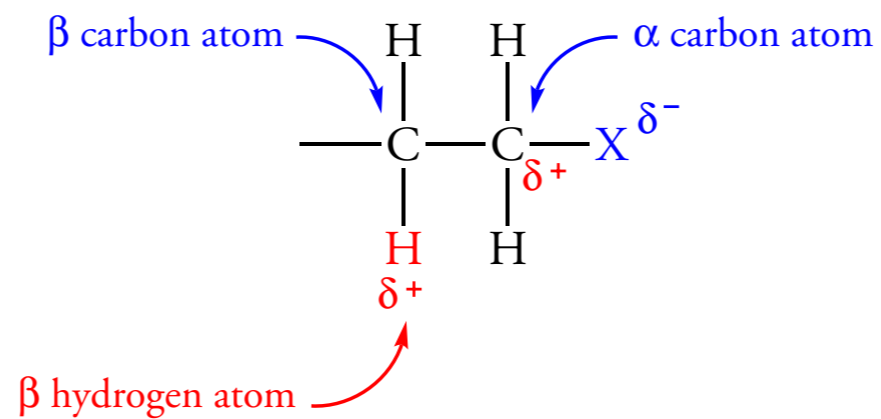


## 9.6 ORGANOMETALLIC COMPOUNDS, II

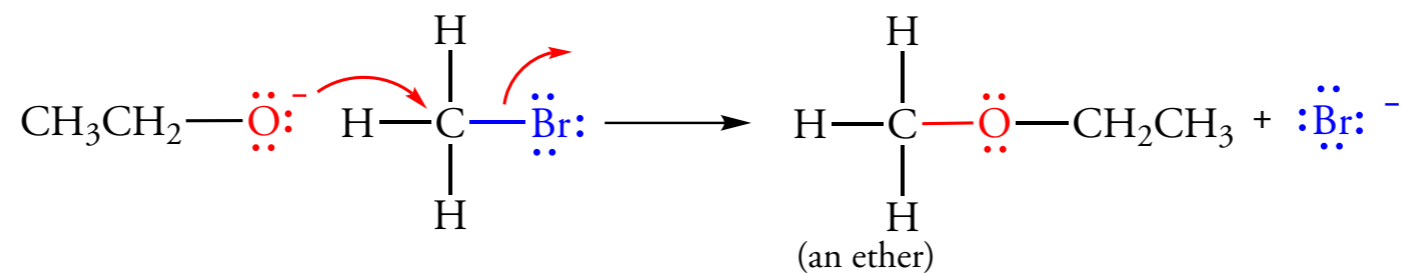
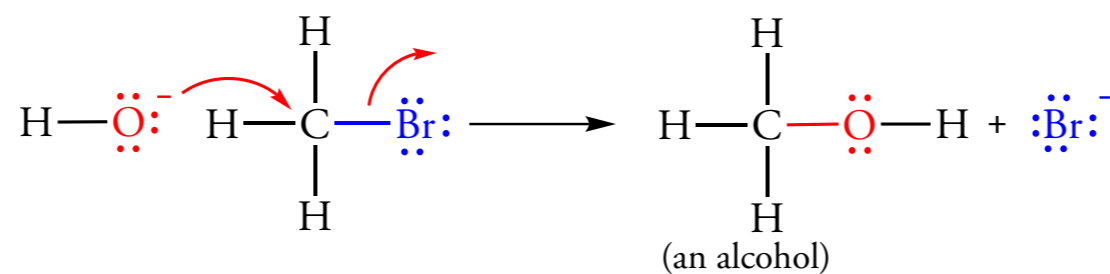
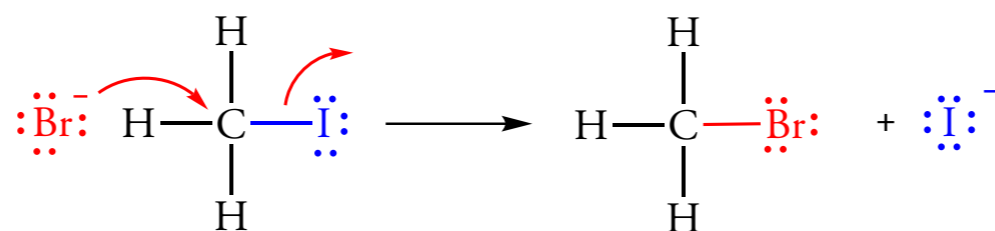
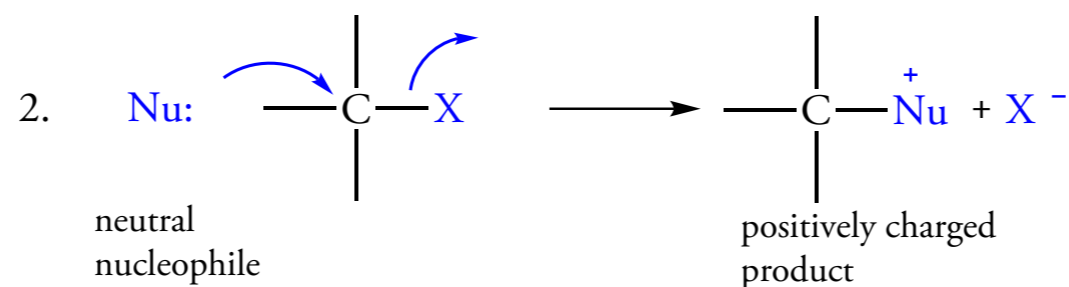
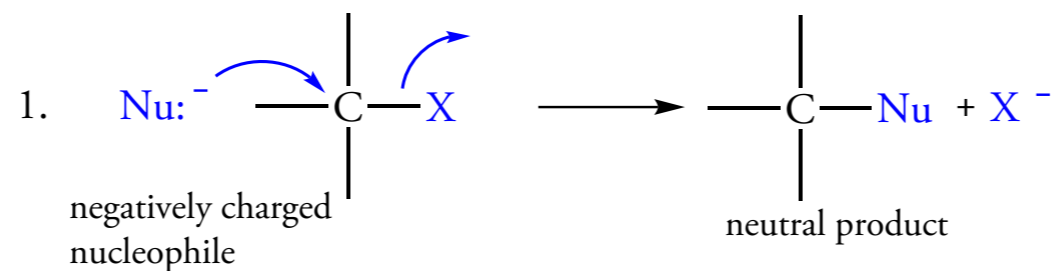
### Organolithium Reagents



## 9.7 REACTIONS OF HALOALKANES



## 9.8 NUCLEOPHILIC SUBSTITUTION REACTIONS OF HALOALKANES

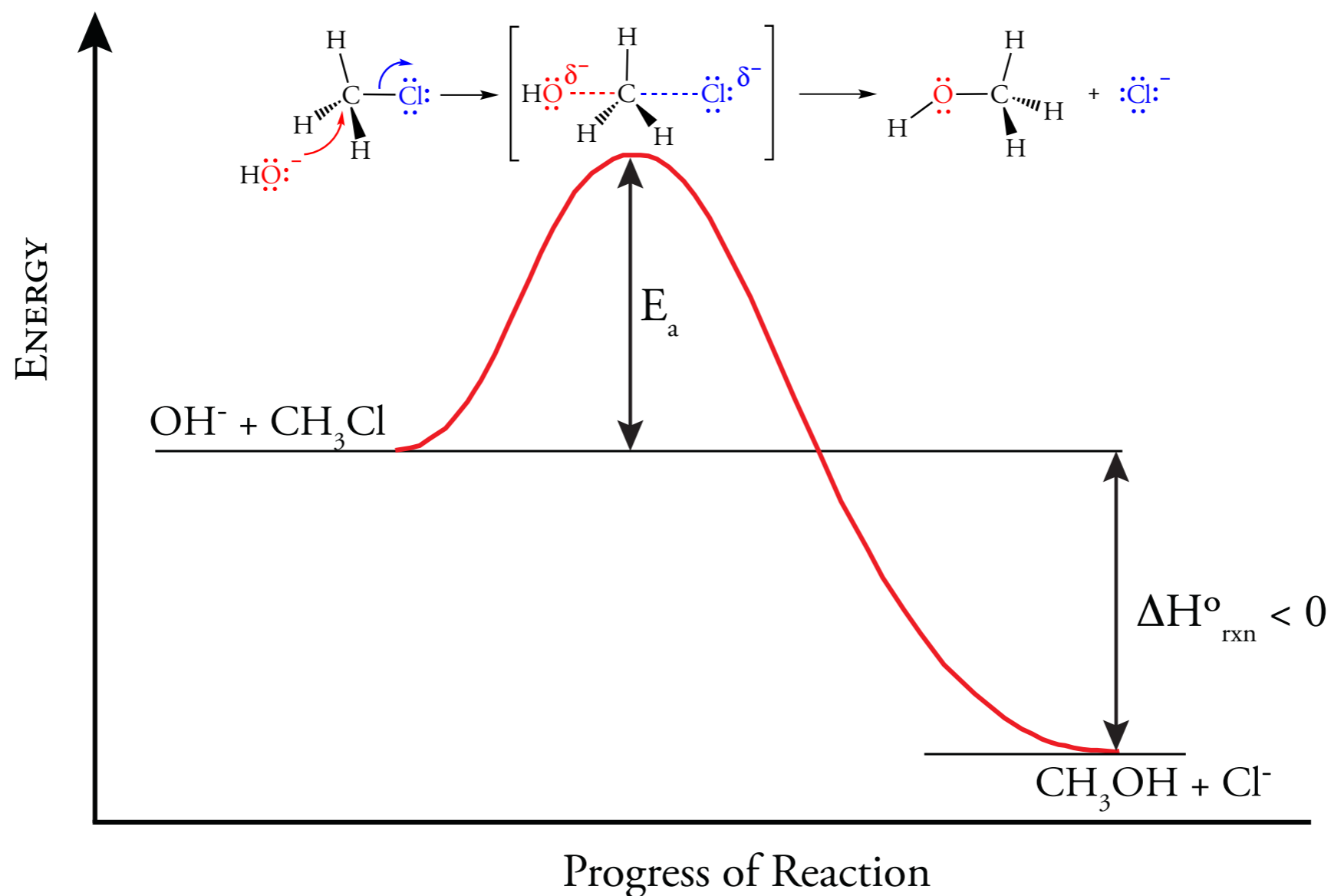


## 9.9

## MECHANISMS OF NUCLEOPHILIC SUBSTITUTION REACTIONS OF HALOALKANES

The S<sub>N</sub>2 MechanismFigure 9.3 Reaction Coordinate Diagram of an S<sub>N</sub>2 Reaction

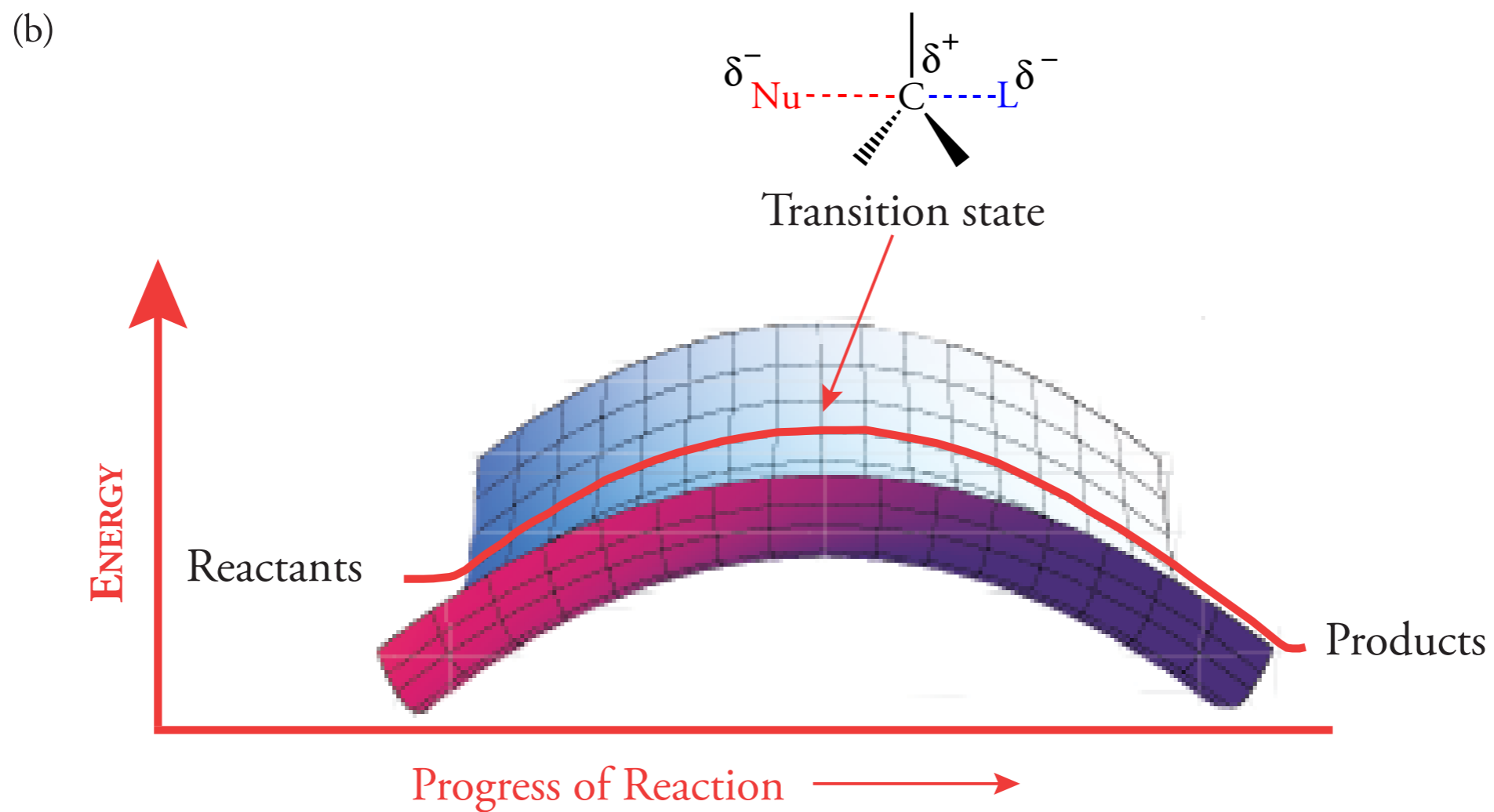
(a) The reaction of hydroxide ion with chloromethane occurs in a single step. The activation energy,  $E_a$ , reflects the stability of the transition state, which depends upon the structure of the substrate, the nucleophile, and the leaving group.





## Figure 9.3 Reaction Coordinate Diagram of an S<sub>N</sub>2 Reaction

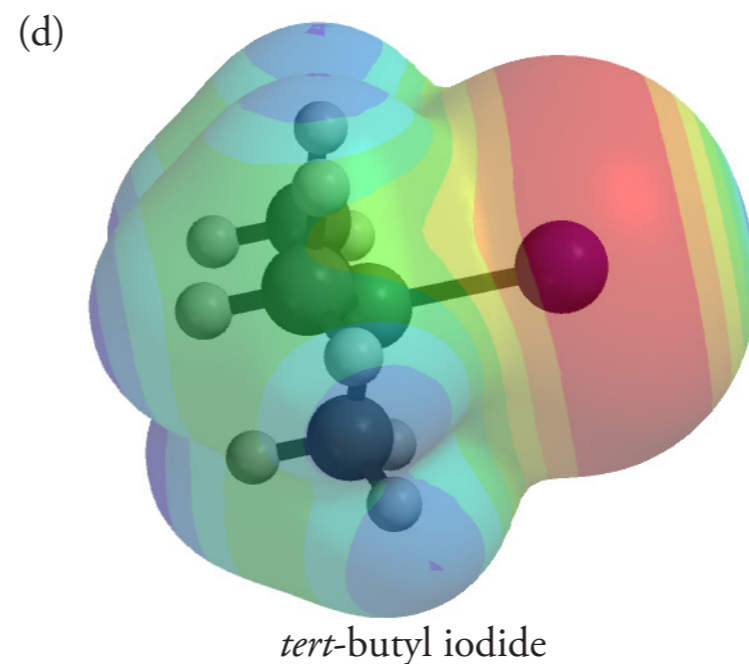
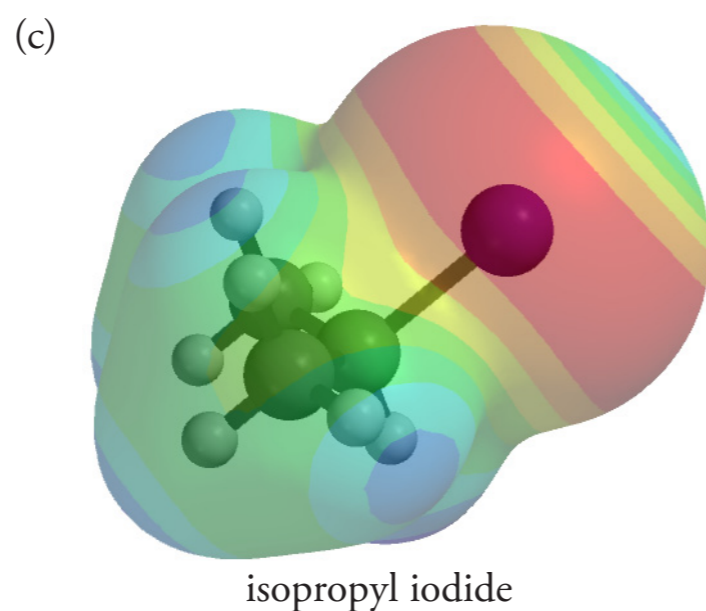
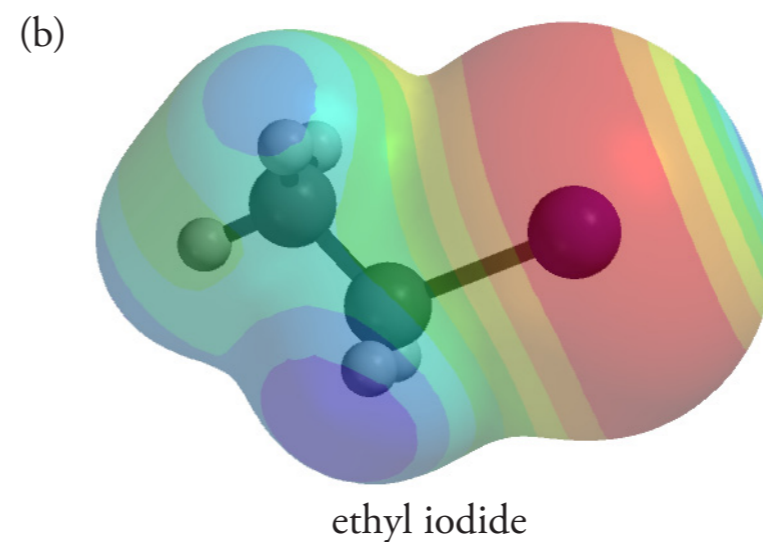
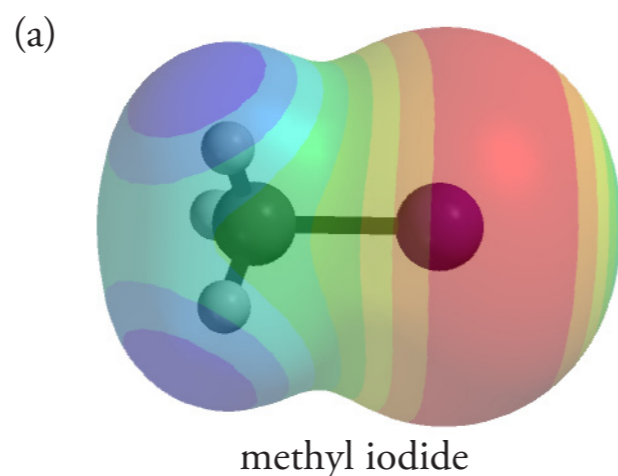
(b) The point of maximum energy in the reaction profile in part (a) is the transition state. It is the point of maximum energy on the pathway of minimum energy on the landscape from reactants to products.



## Figure 9.4 Effect of Steric Hindrance on an $S_N2$ Reaction

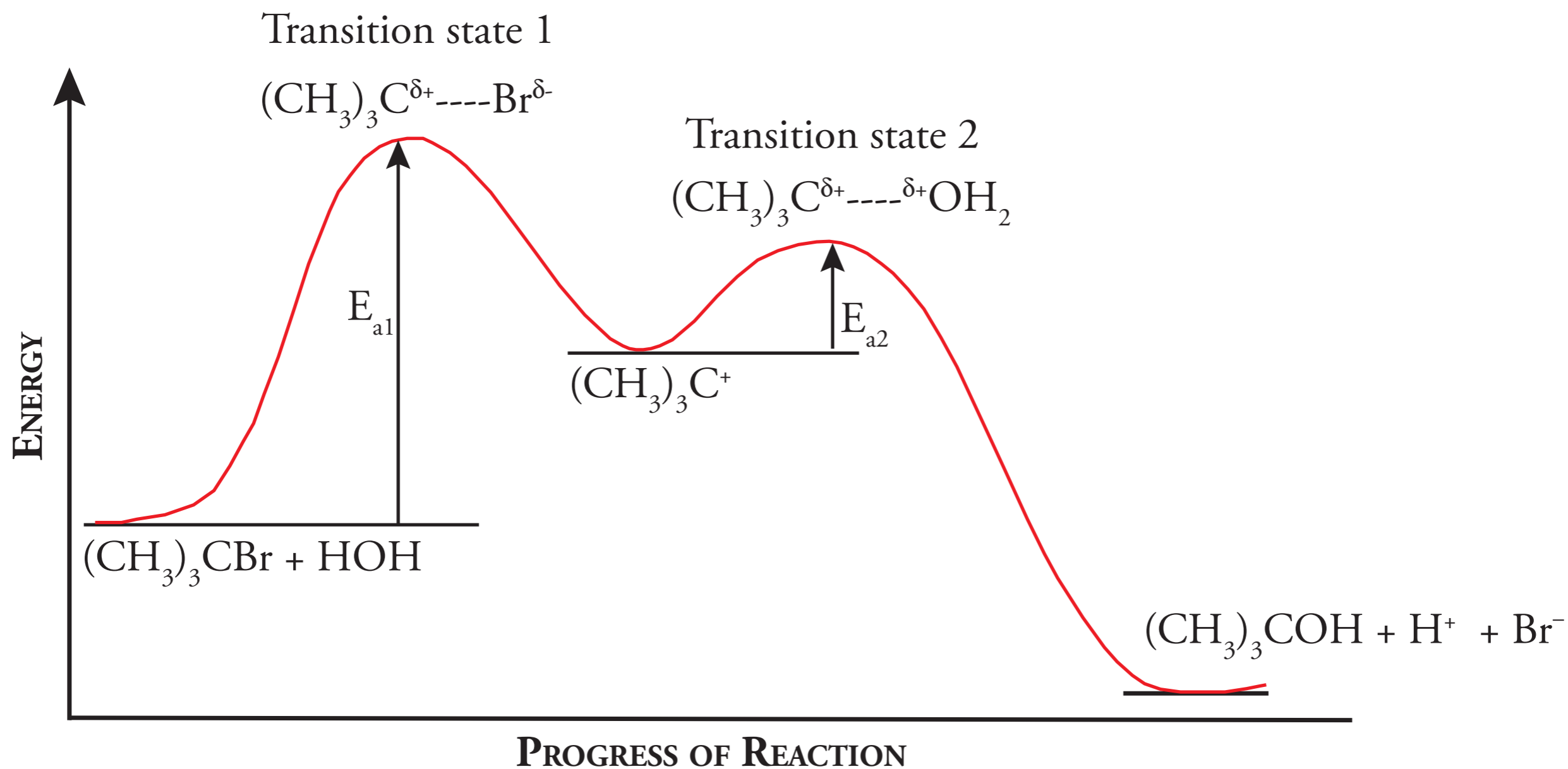
As hydrogen atoms are replaced one by one going from a methyl group to a tertiary halide, the reaction becomes slower because the nucleophile cannot easily reach the electrophilic carbon of the substrate. The electron density maps for these alkyl halides show this effect. The rate of an  $S_N2$  reaction decreases in the order methyl > primary > secondary >> tertiary.

In fact, for a tertiary center, the  $S_N2$  mechanism is not observed. Instead, the mechanism changes from  $S_N2$  to  $S_N1$ , as we will shortly discover. Regions colored in red have high electron density.

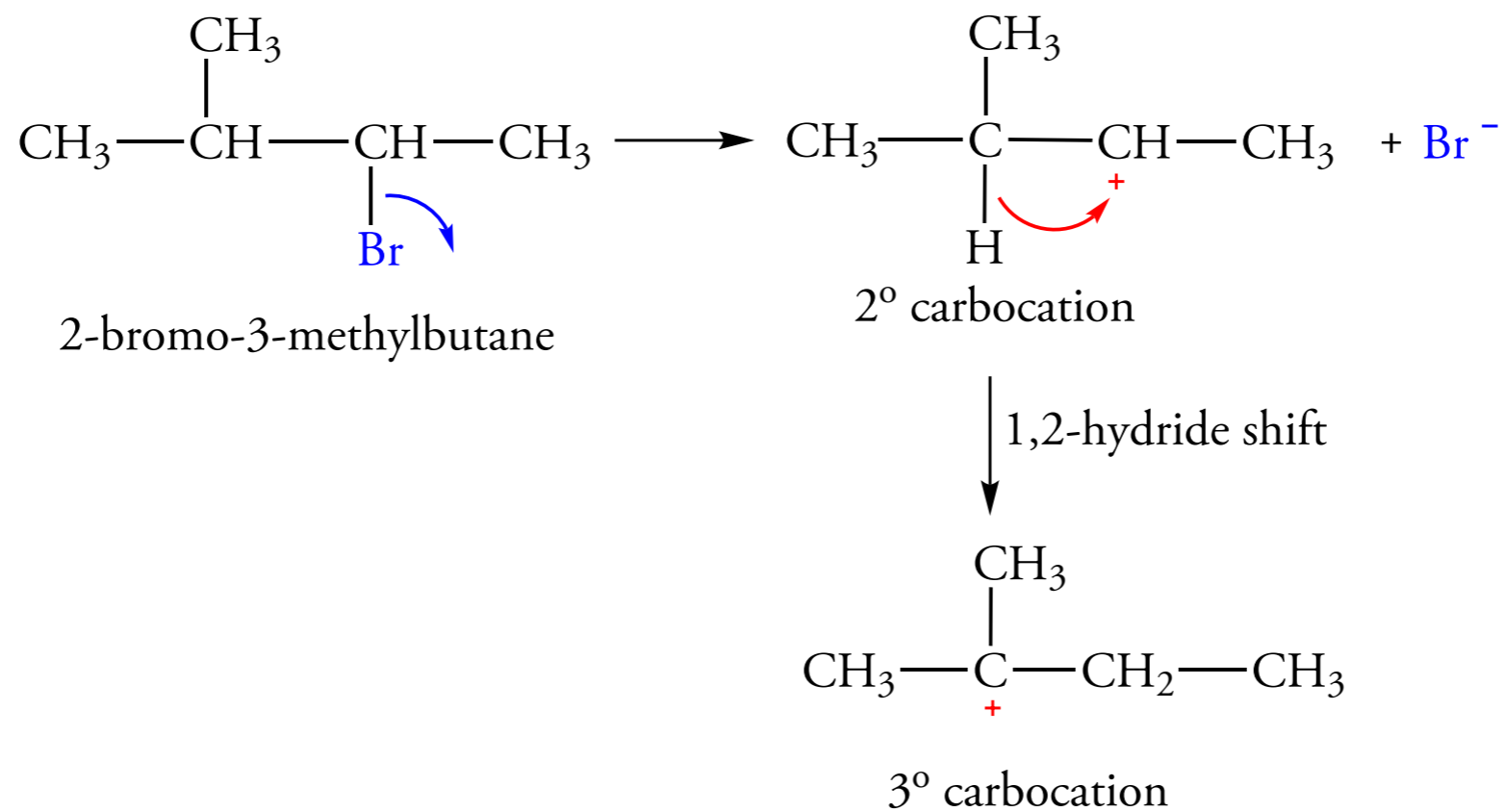
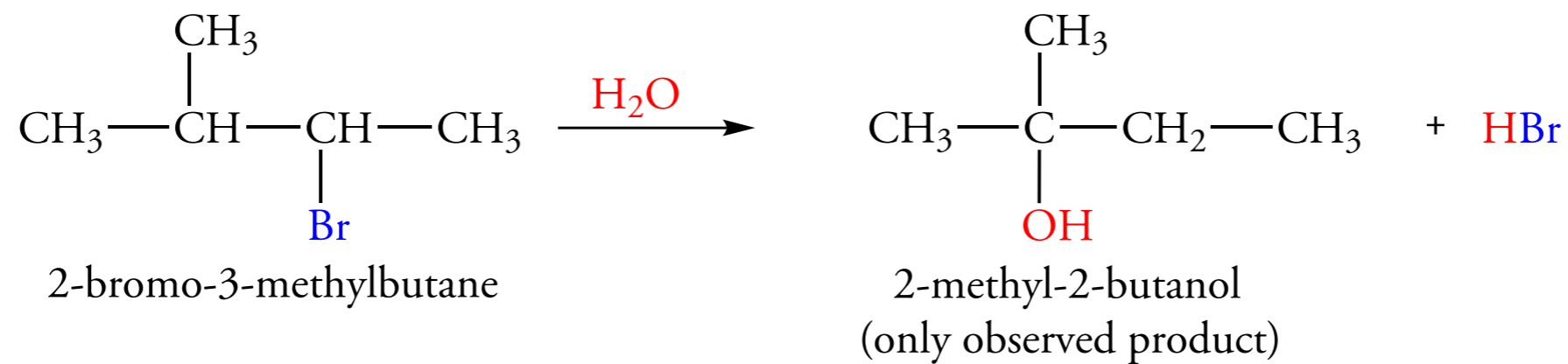


## Figure 9.5 Energy Profile of an S<sub>N</sub>1 Reaction

The reaction of 2-bromo-2-methylpropane occurs in two steps with formation of an intermediate carbocation. It forms in the rate-determining step, which does not involve the nucleophile. In the second, fast step, the carbocation reacts with a nucleophile such as water to form the product.

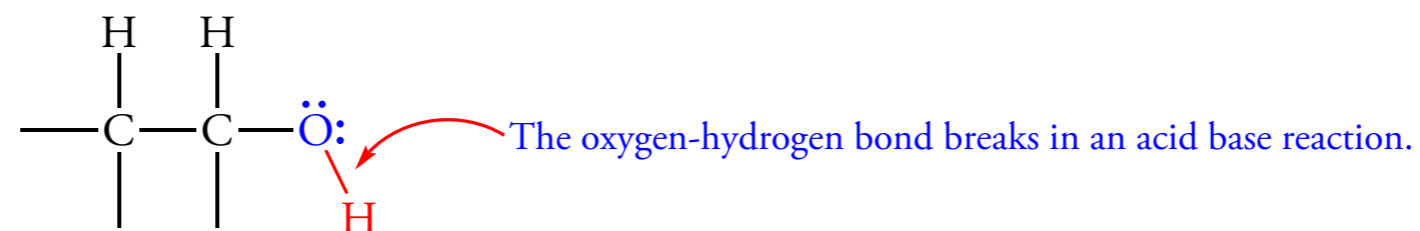


## Carbocation Rearrangements in S<sub>N</sub>1 Reactions

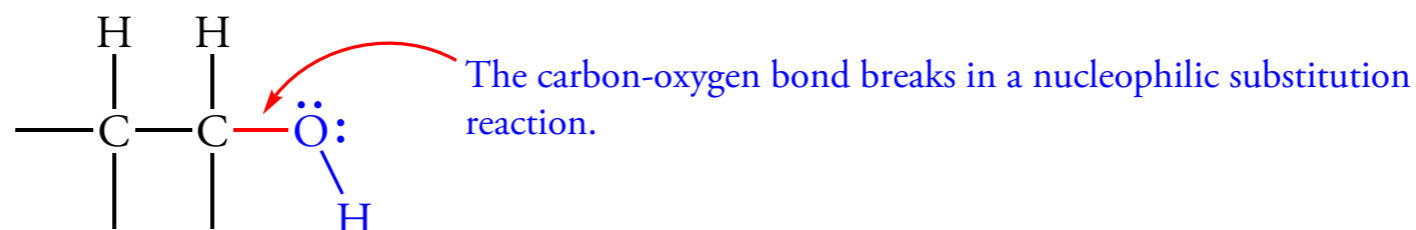


## 9.10 REACTIONS OF ALCOHOLS

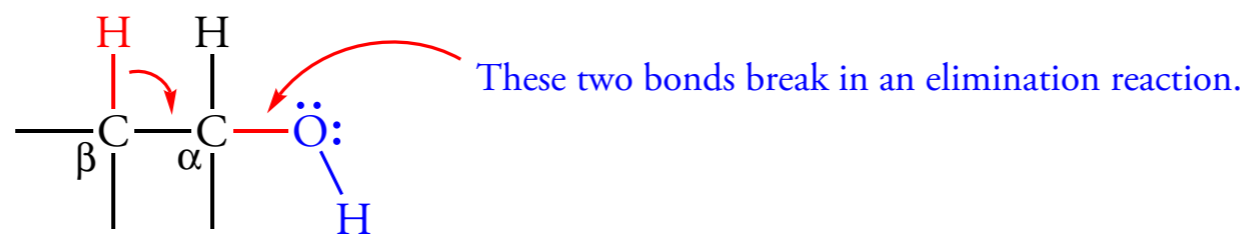
1. The oxygen-hydrogen bond breaks in an acid-base reaction.



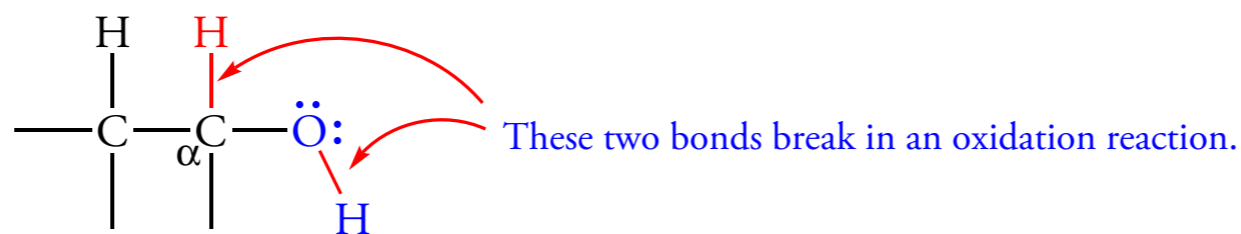
2. The carbon-oxygen bond breaks in a nucleophilic substitution reaction.



3. The carbon-hydrogen bond at the  $\beta$  carbon and the carbon-oxygen bond at the  $\alpha$  carbon both break in an elimination reaction.



4. The carbon-hydrogen bond and the oxygen-hydrogen bond at the  $\alpha$  carbon break in an oxidation reaction.



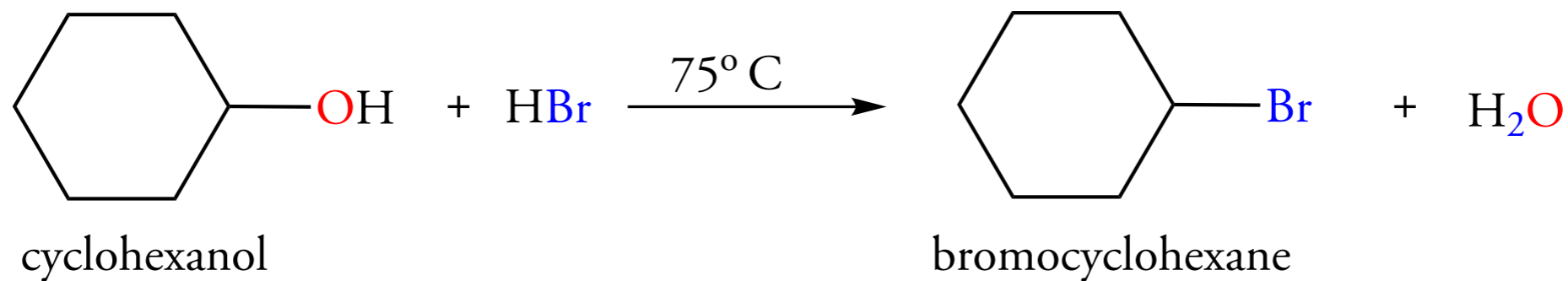
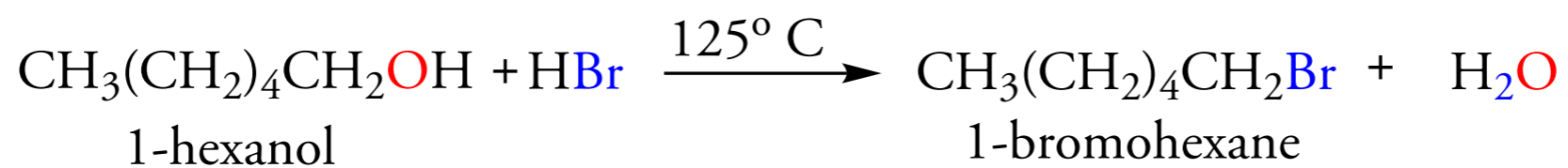
## 9.11 ACID-BASE REACTIONS OF ALCOHOLS



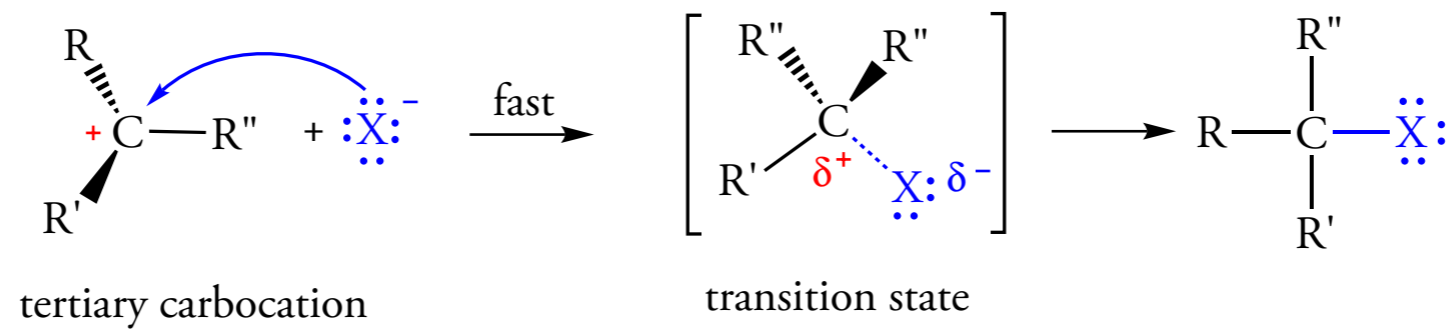
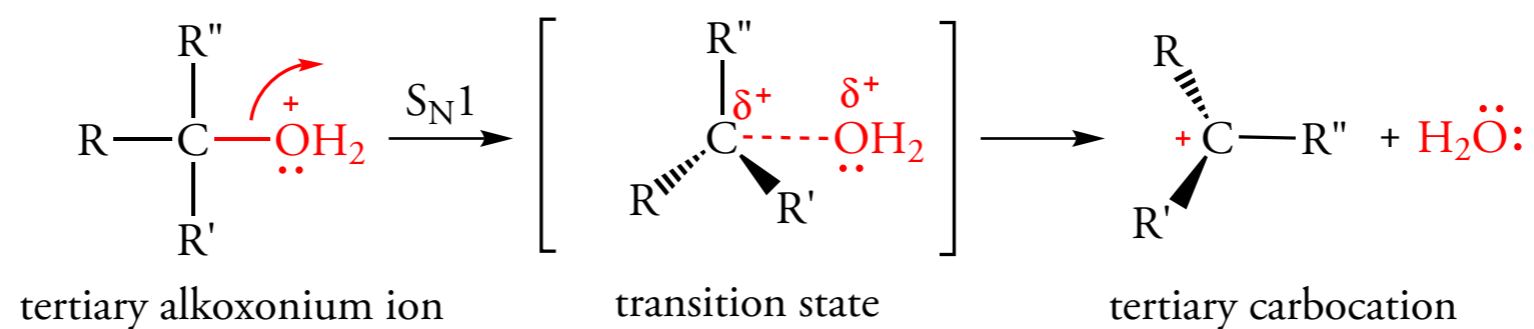
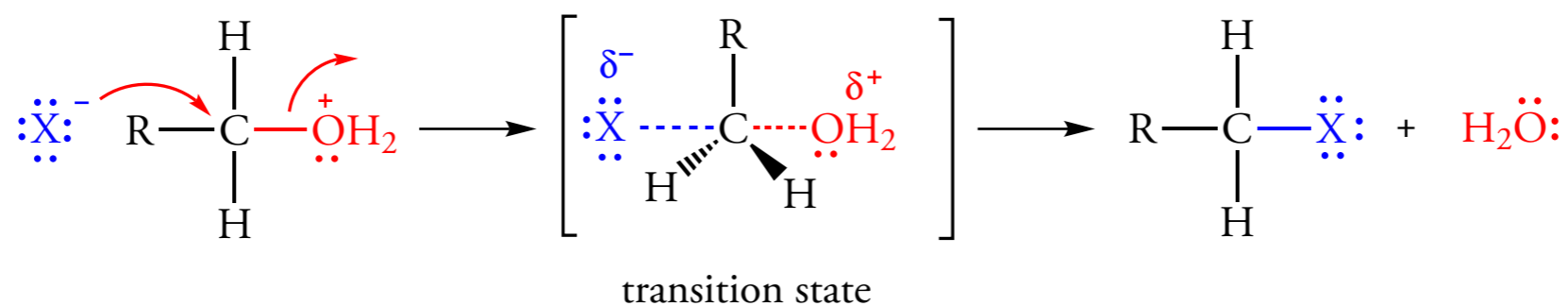
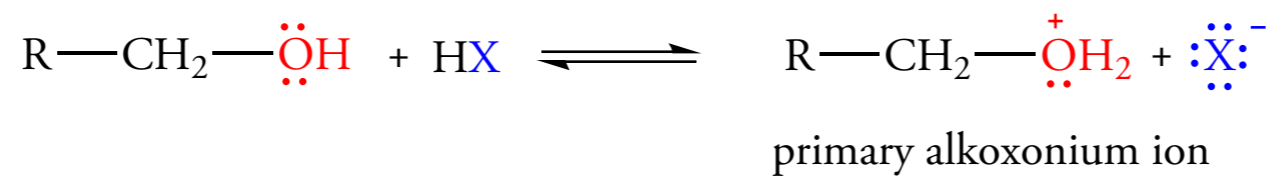
**Table 9.3**  
Effect of Structure on Acidity of Alcohols

Alcohol	Formula	$K_a$	$\text{p}K_a$
methanol	$\text{CH}_3\text{OH}$	$3.2 \times 10^{-16}$	15.5
ethanol	$\text{CH}_3\text{CH}_2\text{OH}$	$1.3 \times 10^{-16}$	15.9
isopropyl alcohol	$(\text{CH}_3)_2\text{CHOH}$	$1 \times 10^{-18}$	18.0
<i>tert</i> -butyl alcohol	$(\text{CH}_3)_3\text{COH}$	$1 \times 10^{-19}$	19.0
2-chloropropanol	$\text{ClCH}_2\text{CH}_2\text{OH}$	$5 \times 10^{-15}$	14.3
2,2,2-trifluoroethanol	$\text{CF}_3\text{CH}_2\text{OH}$	$4 \times 10^{-13}$	12.4
3,3,3-trifluoropropanol	$\text{CF}_3\text{CH}_2\text{CH}_2\text{OH}$	$2.5 \times 10^{-15}$	14.6
4,4,4-trifluorobutanol	$\text{CF}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$	$4 \times 10^{-16}$	15.4

## 9.12 SUBSTITUTION REACTIONS OF ALCOHOLS



## Reaction Mechanisms

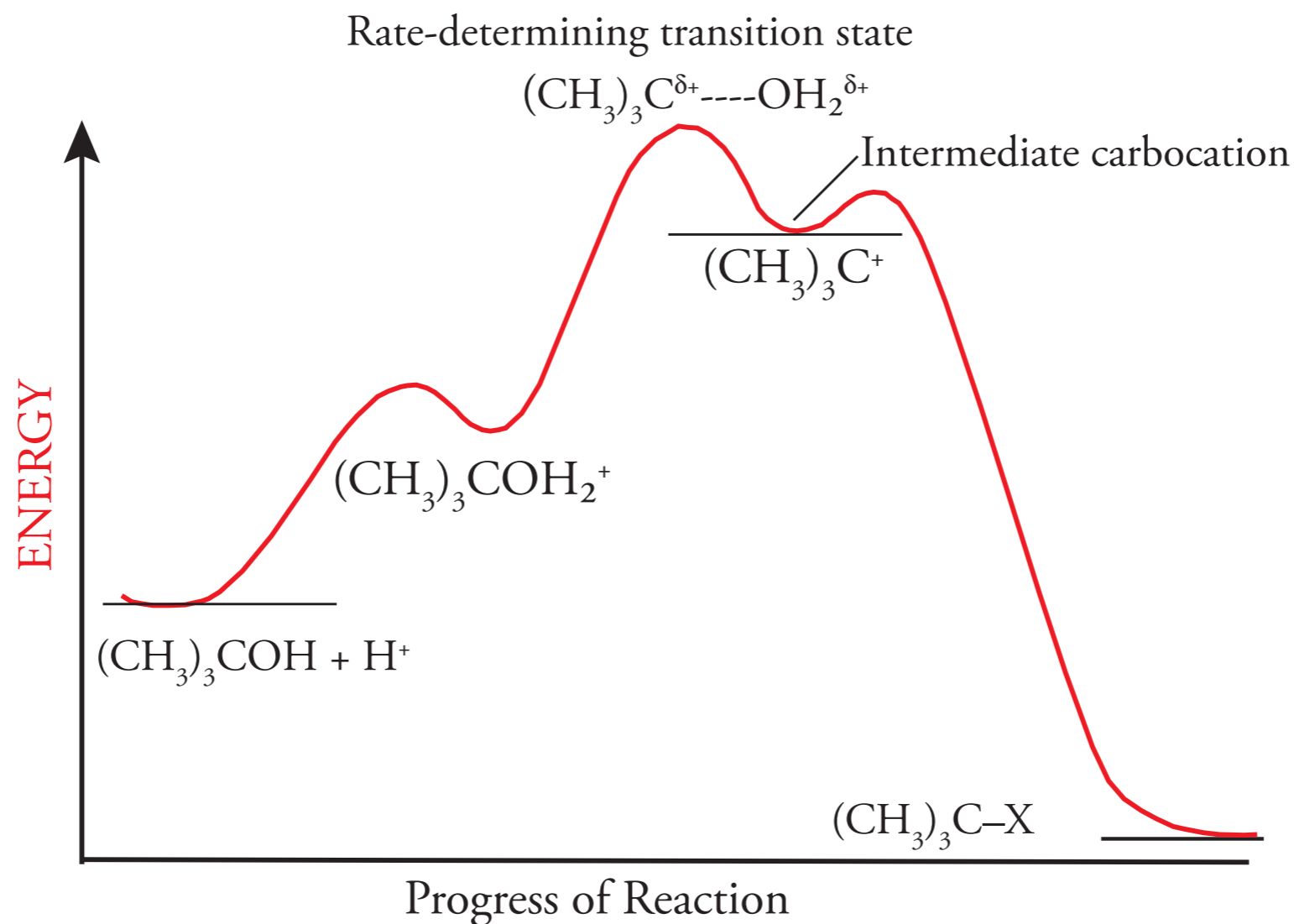




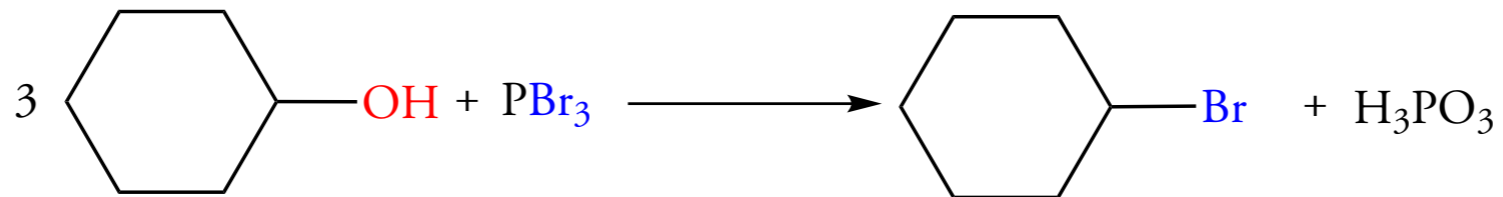
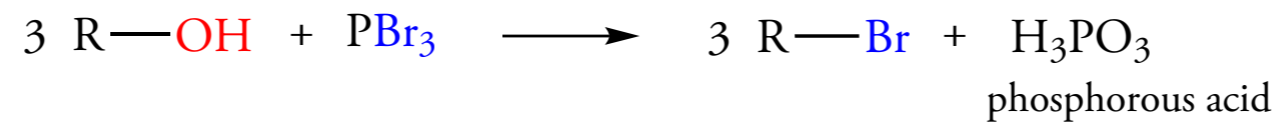
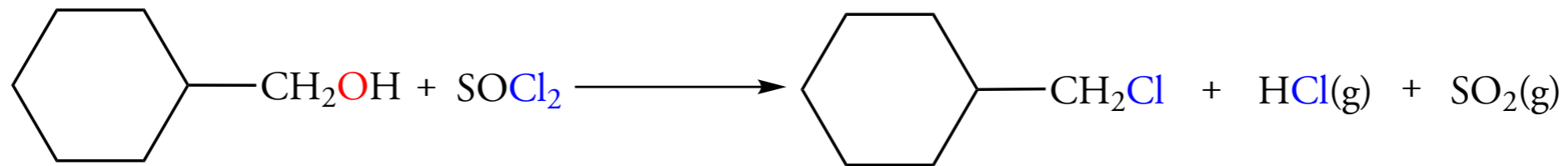
## Structural Effects in S<sub>N</sub>2 and S<sub>N</sub>1 Mechanisms

### Figure 9.6 Reaction Coordinate Diagram for Substitution Reaction of an Alcohol

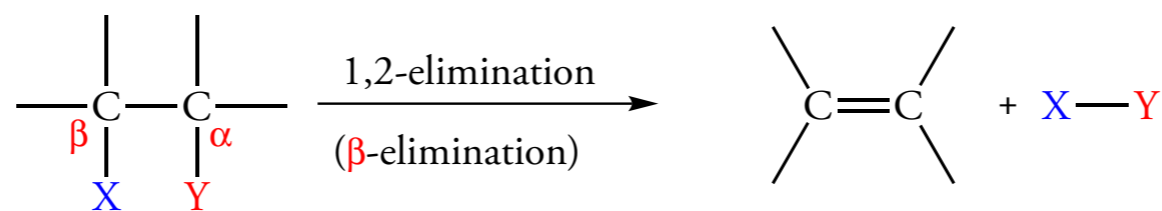
The acid-catalyzed substitution reaction of 2-methyl-2-propanol occurs in two steps from the alkyloxonium ion with formation of an intermediate carbocation. The carbocation forms in the rate-determining step, which does not involve the nucleophile. In the second, fast step, the carbocation reacts with a nucleophile such as a halide ion to form the product.



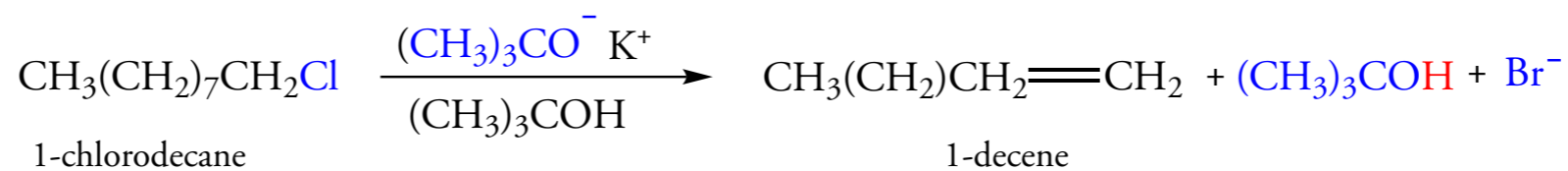
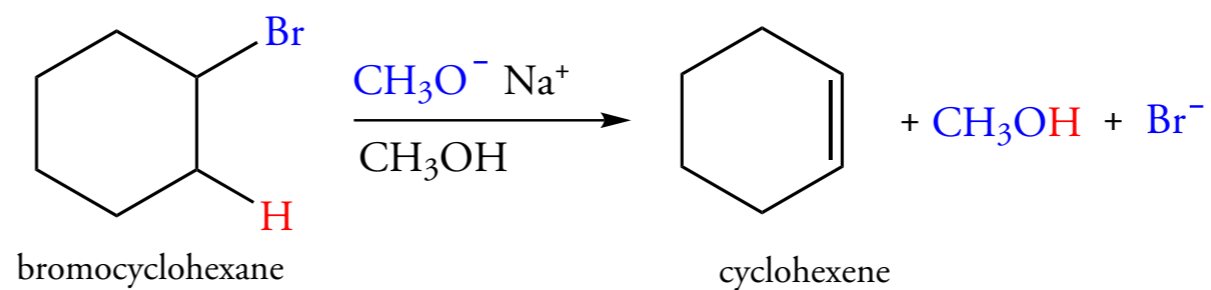
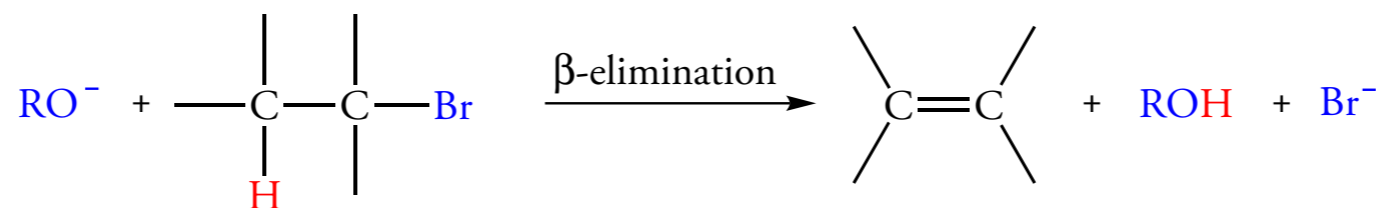
## 9.13 ALTERNATE METHODS FOR THE SYNTHESIS OF ALKYL HALIDES



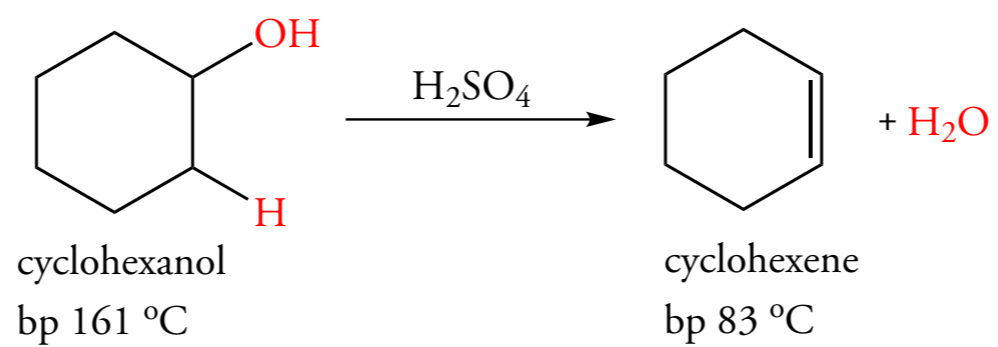
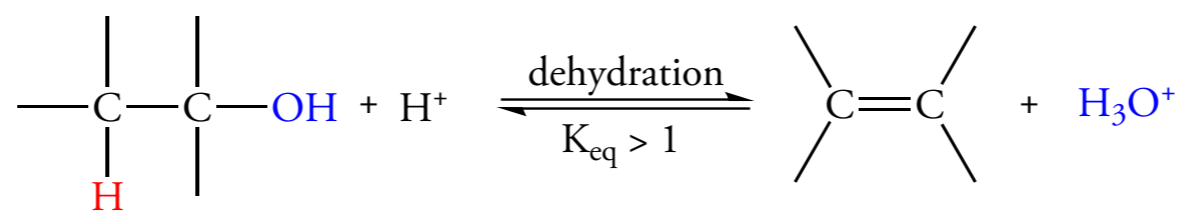
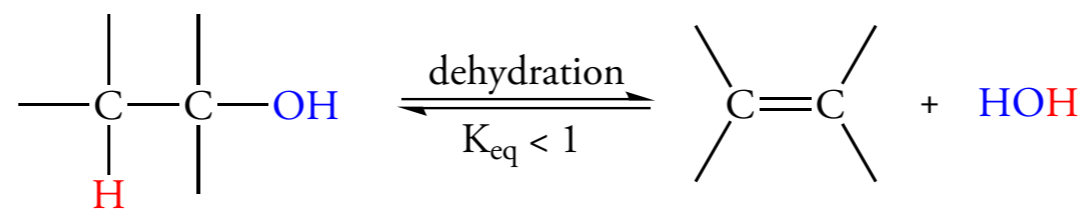
## 9.14 ELIMINATION REACTIONS



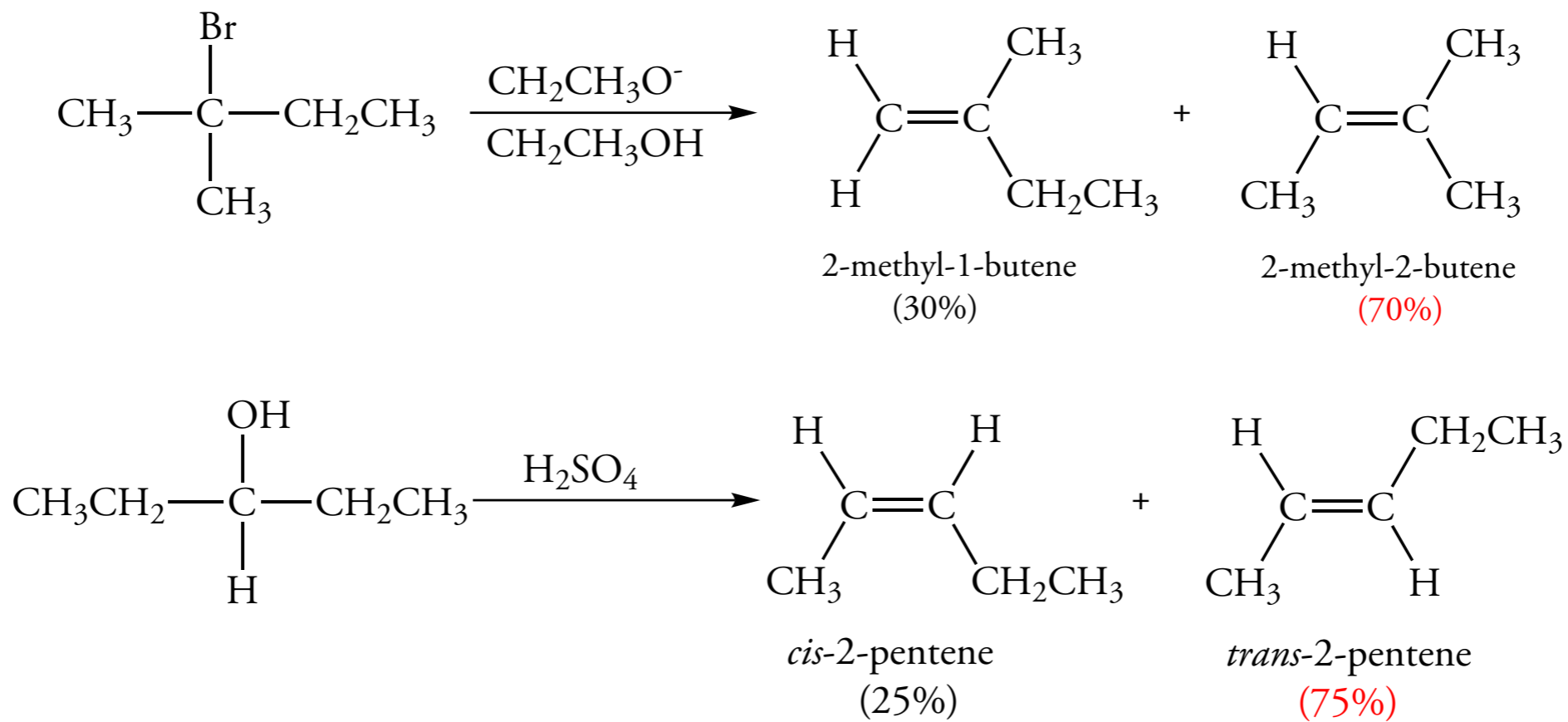
### Dehydrohalogenation



## Dehydration

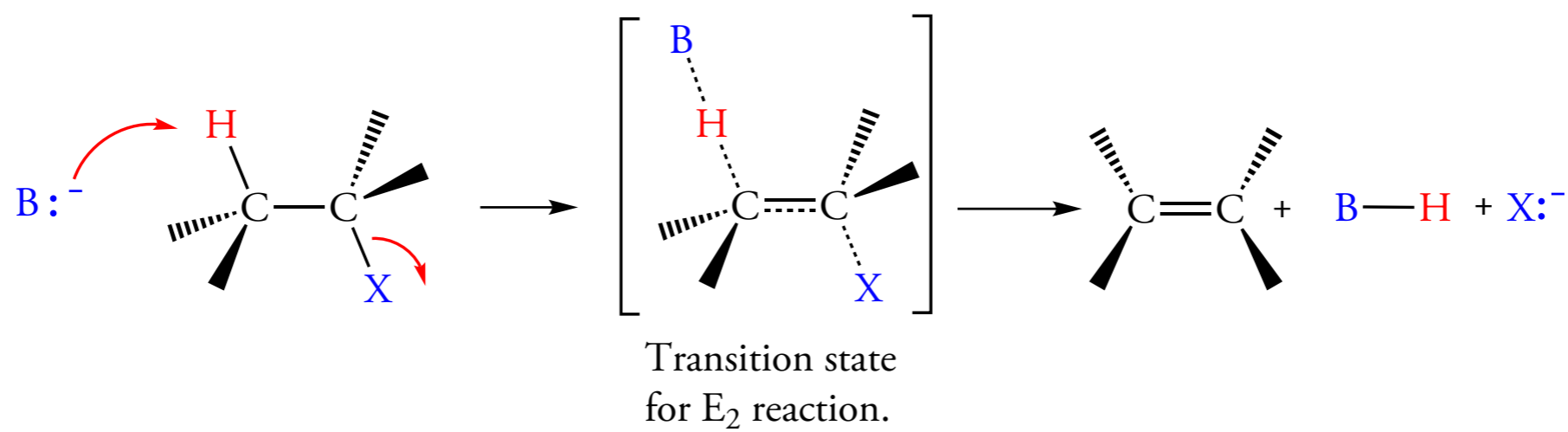


## 9.15 REGIOSELECTIVITY IN DEHYDROHALOGENATION



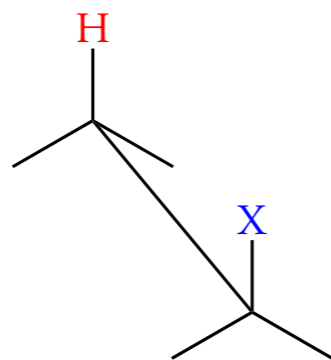
## 9.16 MECHANISMS OF DEHYDROHALOGENATION REACTIONS

### The E2 Mechanism

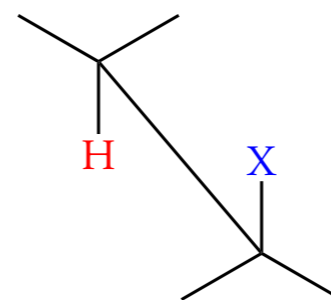


## 9.16 MECHANISMS OF DEHYDROHALOGENATION REACTIONS, II

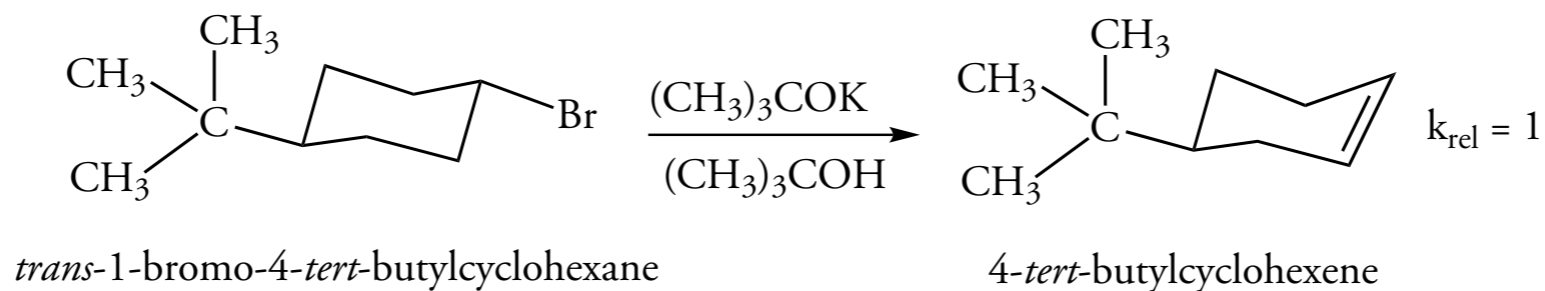
### Stereoelectronic Effects in the E2 Reaction



Syn periplanar, dihedral angle between H and X is 0°.

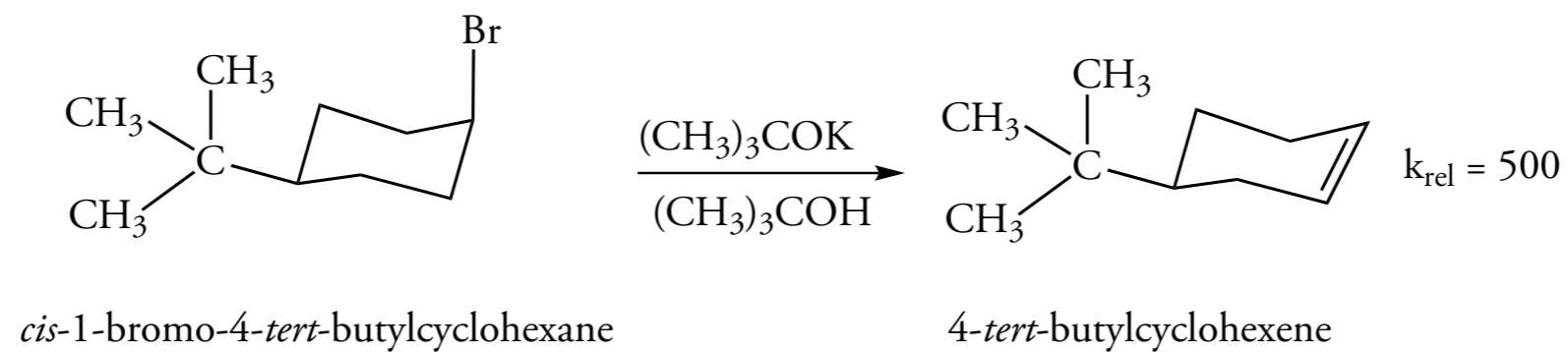


Anti periplanar, dihedral angle between H and X is 180°.



*trans*-1-bromo-4-*tert*-butylcyclohexane

4-*tert*-butylcyclohexene

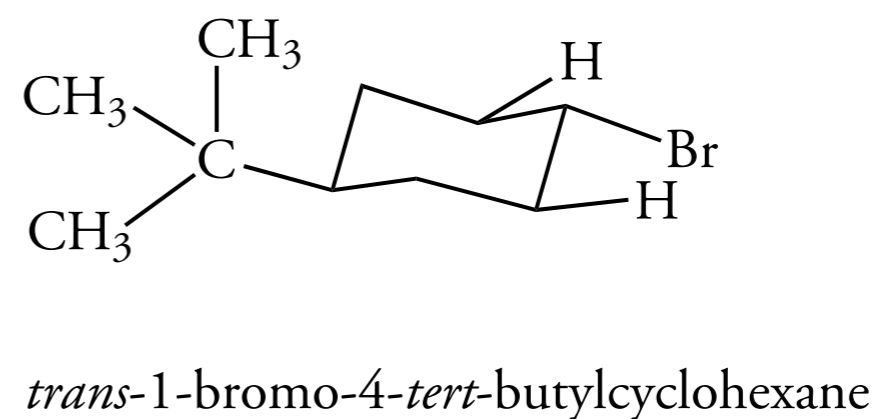
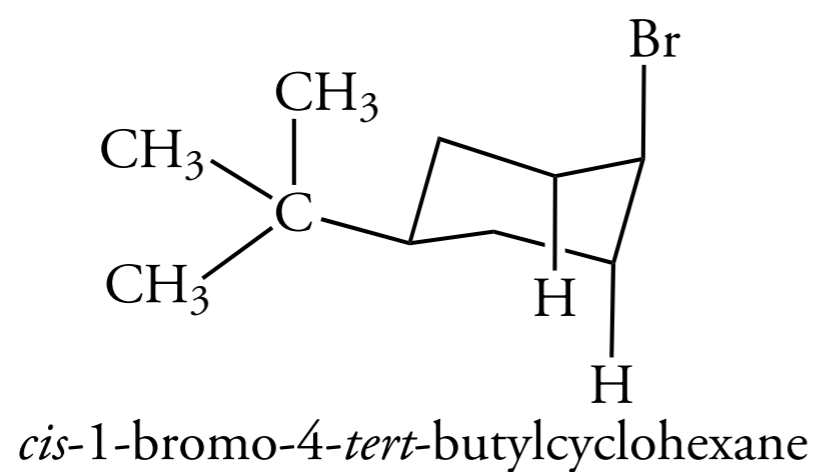


*cis*-1-bromo-4-*tert*-butylcyclohexane

4-*tert*-butylcyclohexene

## Figure 9.7 Stereochemistry of E2 Elimination Reactions

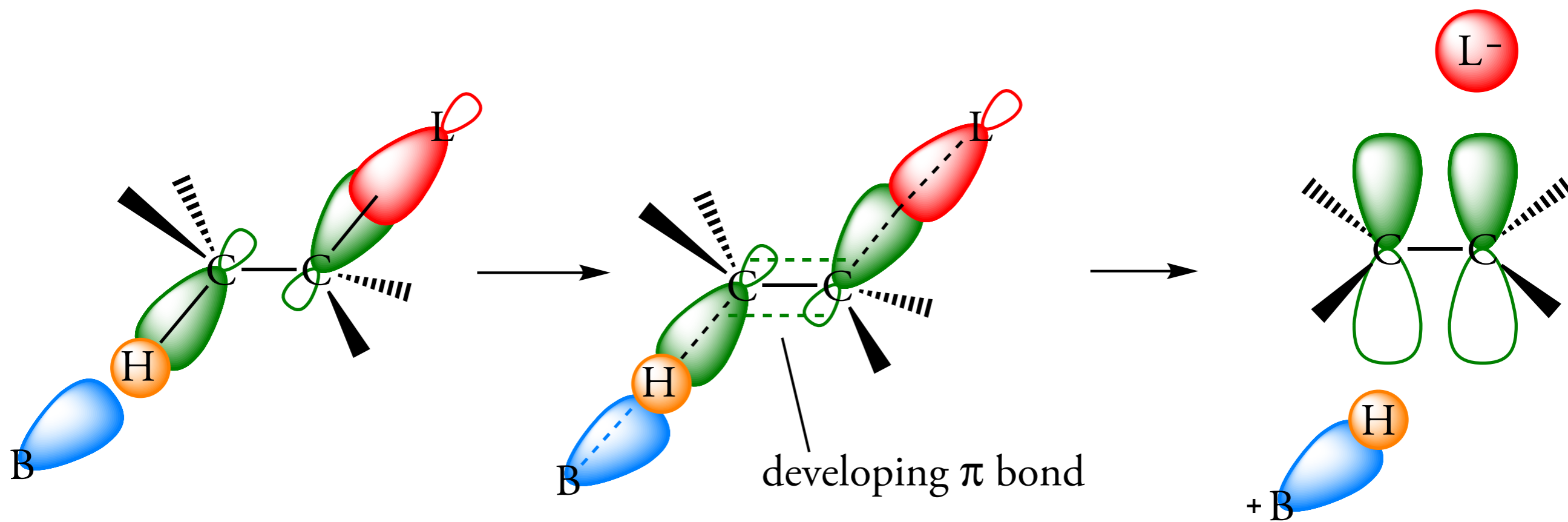
The preferred relationship between a proton and a leaving group, in this case a bromine atom, is anti periplanar. This situation exists in *cis*-1-bromo-4-*tert*-butylcyclohexane, in which the halogen and flanking hydrogens have a dihedral angle of  $180^\circ$ . However, in *trans*-1-bromo-4-*tert*-butylcyclohexane the dihedral angle between the halogen and the flanking hydrogen atoms is  $60^\circ$ , so the *trans* isomer cannot easily undergo an E2 reaction.





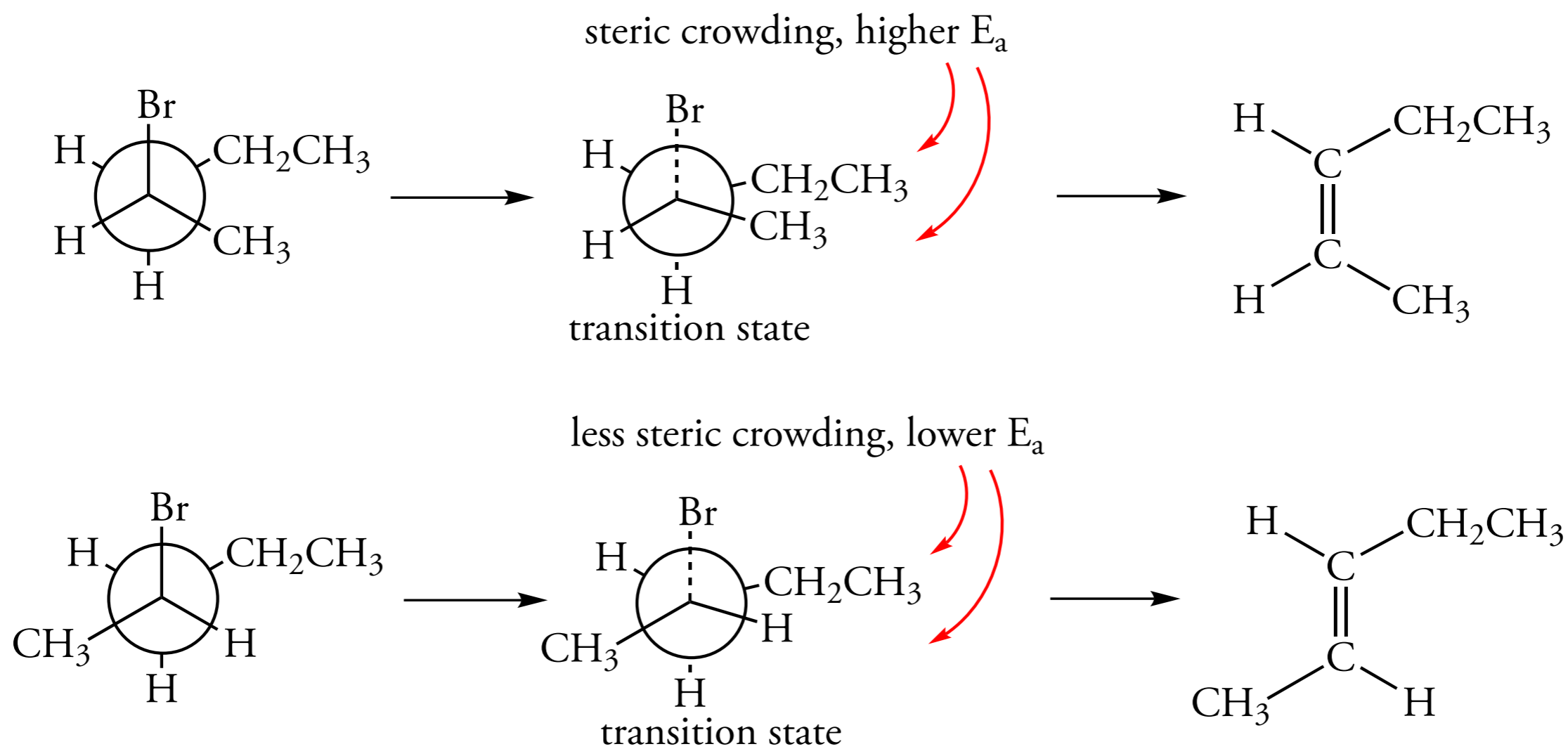
## Figure 9.8 Orbital Geometry in E2 Reactions

Partial overlap of the developing  $\pi$  orbitals in the transition state for an E2 reaction in which the leaving group and the proton are in an anti periplanar relationship.



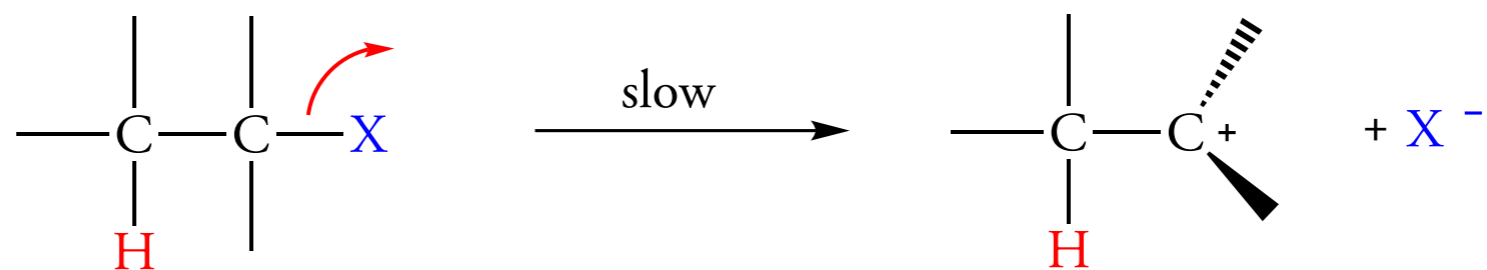
## Figure 9.9 Steric Effects in E2 Reactions

The stability of the *cis*- and *trans*- alkenes produced in the E2 reaction reflects the stabilities of the transition states leading to them. Steric crowding in the transition state leading to the *cis* isomer raises the activation energy relative to the transition state for forming the *trans* isomer. Therefore, the *trans* isomer forms faster, and is the major product.

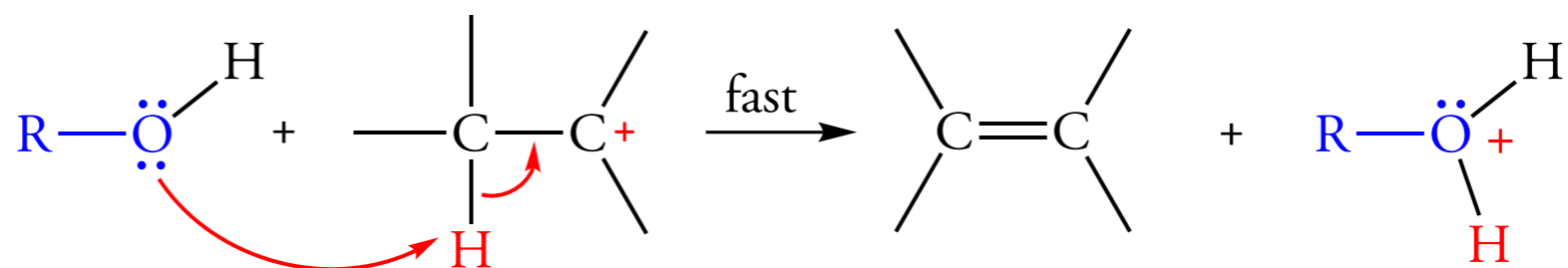
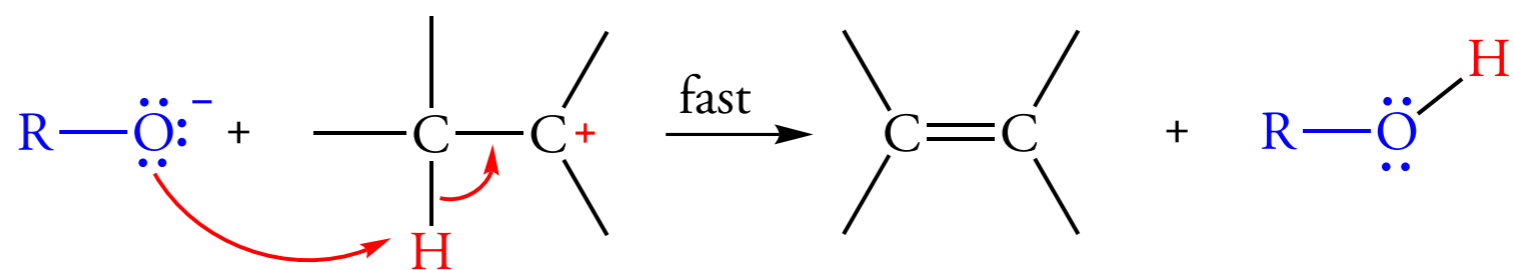


# The E1 Mechanism

Step 1. Ionization

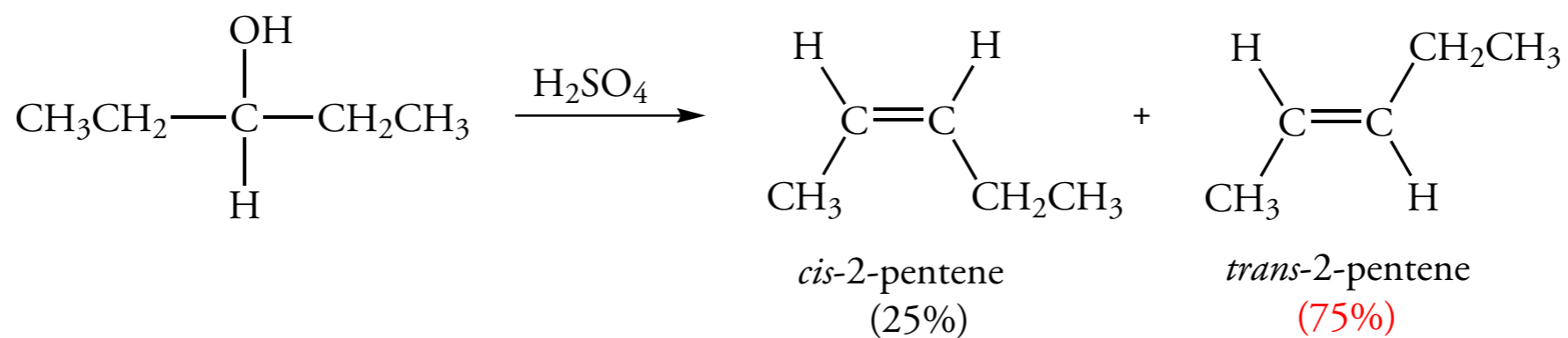
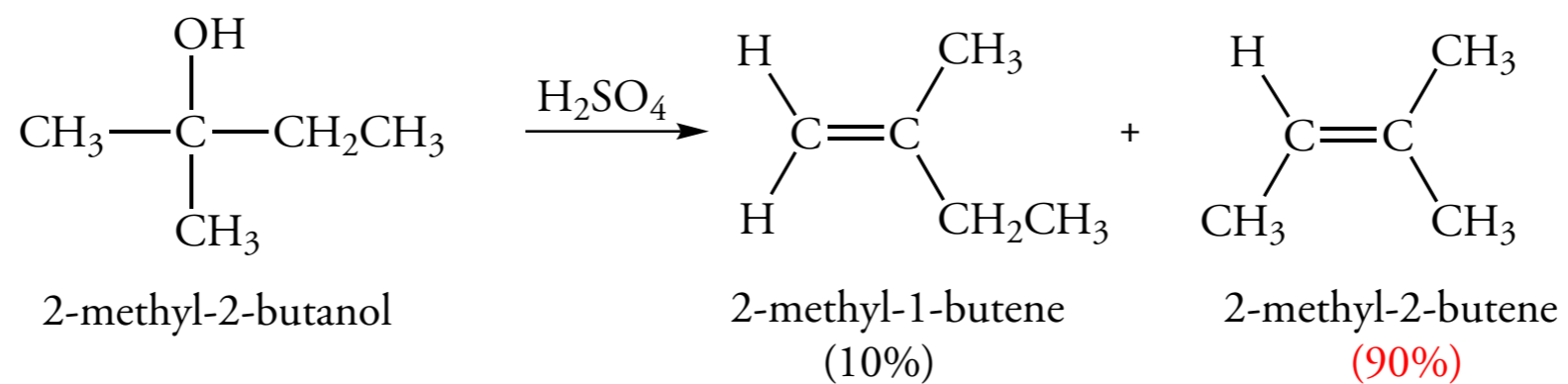


Step 2. Deprotonation



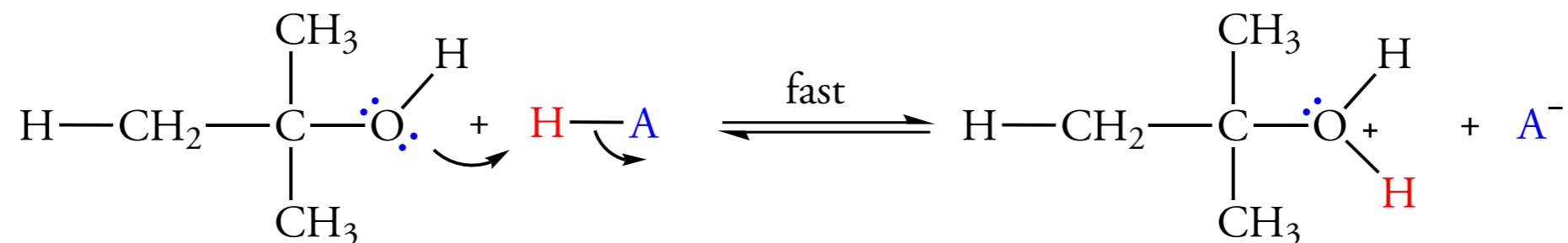
## 9.17 REGIOSELECTIVITY IN DEHYDRATION REACTIONS

### Regioselectivity in the Dehydration of Alcohols

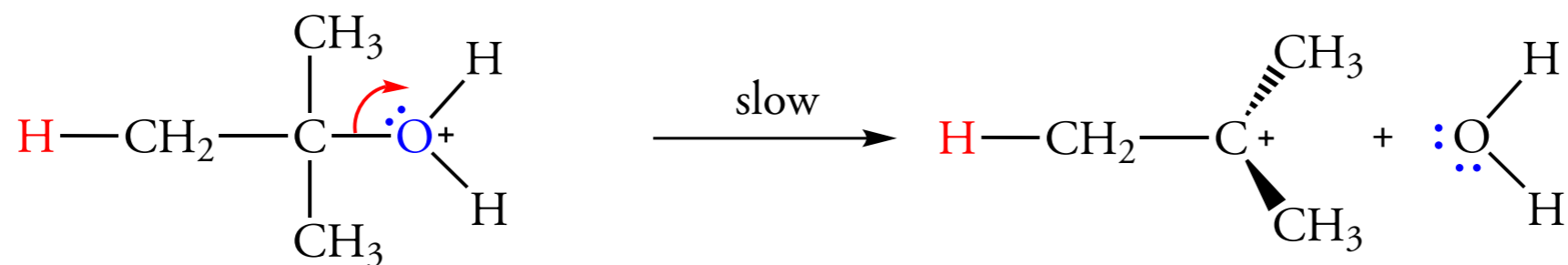


## Mechanism of Alcohol Dehydration Reactions

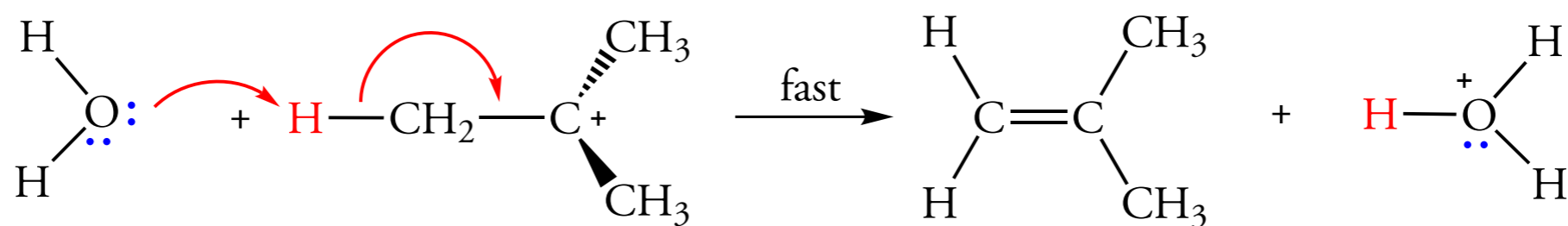
Rapid, reversible protonation of the alcohol by the acid catalyst



Step 1. Loss of water to give a  $3^\circ$  carbocation



Step 2. Loss of a proton to give an alkene



# Rearrangements in Dehydration Reactions

