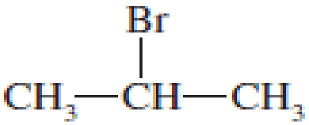
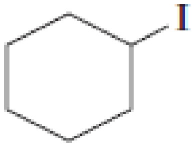
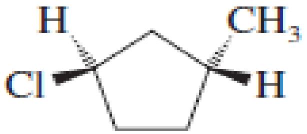
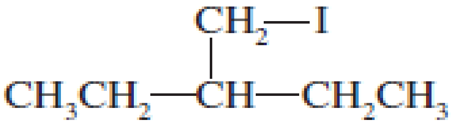
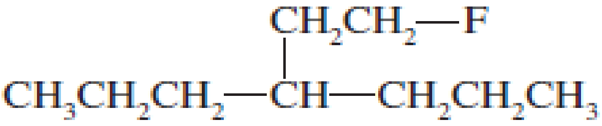
Alkyl halides

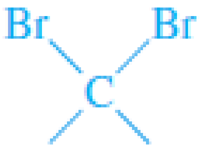
Alkyl halides

Alkyl halides: are compounds in which a halogen substituent is attached directly to an alkyl group.

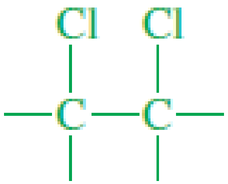
	CH_3CH_2-F	 $\overset{\displaystyle Cl}{\overset{|}{C}}H_2CH_2CH_2CH_3$	 $CH_3-\overset{\displaystyle Br}{\overset{|}{C}}H-CH_3$
IUPAC name:	fluoroethane	1-chlorobutane	2-bromopropane
common name:	ethyl fluoride	*n*-butyl chloride	isopropyl bromide

		
IUPAC name:	iodocyclohexane	*trans*-1-chloro-3-methylcyclopentane
common name:	cyclohexyl iodide	(none)

	 $CH_3CH_2-\overset{\displaystyle CH_2-I}{\overset{|}{C}}H-CH_2CH_3$	 $CH_3CH_2CH_2-\overset{\displaystyle CH_2CH_2-F}{\overset{|}{C}}H-CH_2CH_2CH_3$
IUPAC name:	3-(iodomethyl)pentane	4-(2-fluoroethyl)heptane



a geminal dibromide



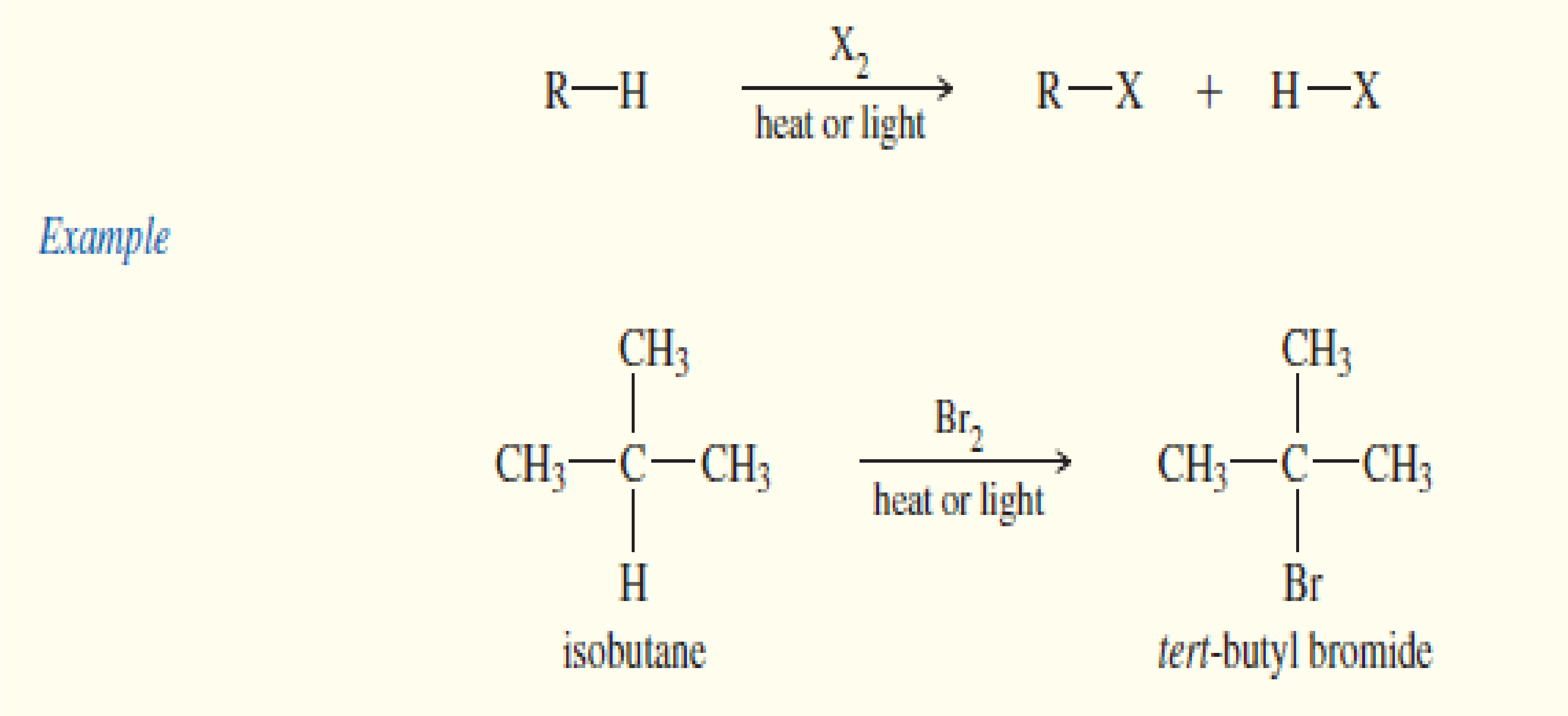
a vicinal dichloride

Physical properties of alkyl halides

- The physical properties of alkyl halides considerably differ from those of the corresponding alkanes. The strength and length of the carbon-halogen bond (C-X bond), the dipole moment and the boiling point of an alkyl halide are determined by the polarity of the bond as well as by the size of the various halogen atoms.
- The C-X bond strength decreases with an increase of the size of the halogen (X)
- Halogens (F, Cl and Br) are more electronegative than carbon. Consequently, carbon atoms that carry halogens are charged partially positive while the halogen is charged partially negative. The polarity of the C-X bond causes a measureable dipole moment.
- Molecules with higher molecular weights generally have higher boiling points because they are heavier (and therefore slower moving),

Preparation of alkyl halides

1- From alkanes: free-radical halogenation:



$$\mathrm{R{-}H} \xrightarrow[\text{heat or light}]{X_2} \mathrm{R{-}X} + \mathrm{H{-}X}$$

Example

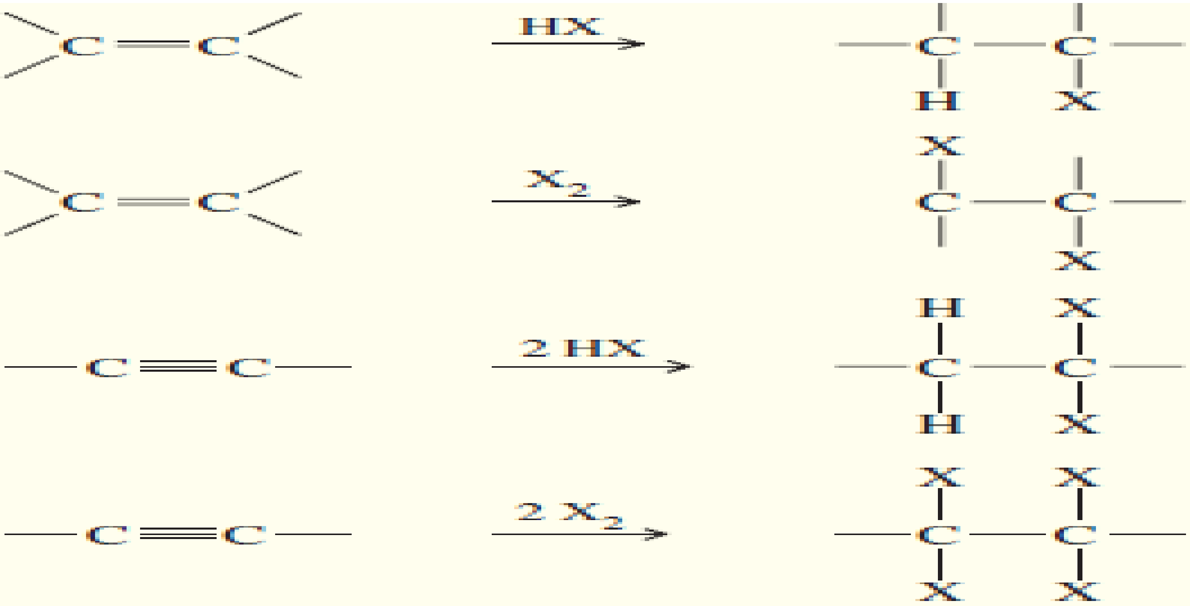
$$CH_3-\overset{\overset{\displaystyle CH_3}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-CH_3 \xrightarrow[\text{heat or light}]{Br_2} CH_3-\overset{\overset{\displaystyle CH_3}{|}}{\underset{\underset{\displaystyle Br}{|}}{C}}-CH_3$$

isobutane

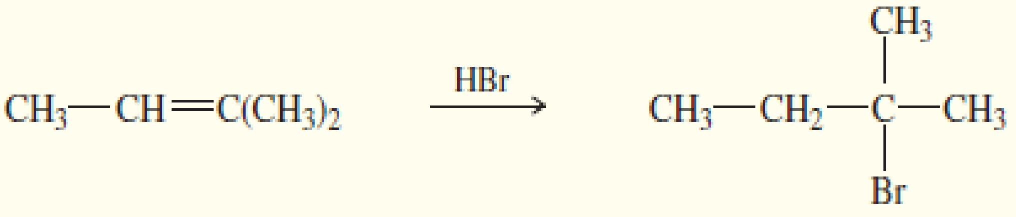
tert-butyl bromide

Preparation of alkyl halides

2- From alkenes and alkynes:



Examples:



$$CH_3-CH=C(CH_3)_2 \xrightarrow{HBr} CH_3-CH_2-\underset{Br}{\overset{CH_3}{C}}-CH_3$$

2-methylbut-2-ene 2-bromo-2-methylbutane

$$CH_3-CH=CH-CH_3 \xrightarrow{Cl_2} CH_3-CHCl-CHCl-CH_3$$

but-2-ene 2,3-dichlorobutane

$$H-C\equiv C-CH_2CH_2CH_3 \xrightarrow{2\ HBr} CH_3-CBr_2-CH_2CH_2CH_3$$

pent-1-yne 2,2-dibromopentane

Preparation of alkyl halides

3- From alcohols:

$$\mathrm{R{-}OH} \xrightarrow{\text{HX, PX}_3\text{, or others}} \mathrm{R{-}X}$$

Example:

$$\underset{\text{butan-1-ol}}{\mathrm{CH_3CH_2CH_2CH_2OH}} \xrightarrow{\mathrm{HBr,\ H_2SO_4}} \underset{\text{1-bromobutane}}{\mathrm{CH_3CH_2CH_2CH_2Br}}$$

4- From other halides:

$$\mathrm{R{-}X} + \mathrm{I^-} \xrightarrow[\text{acetone}]{} \mathrm{R{-}I} + \mathrm{X^-}$$

$$\mathrm{R{-}Cl} + \mathrm{KF} \xrightarrow[\mathrm{CH_3CN}]{\text{18-crown-6}} \mathrm{R{-}F}$$

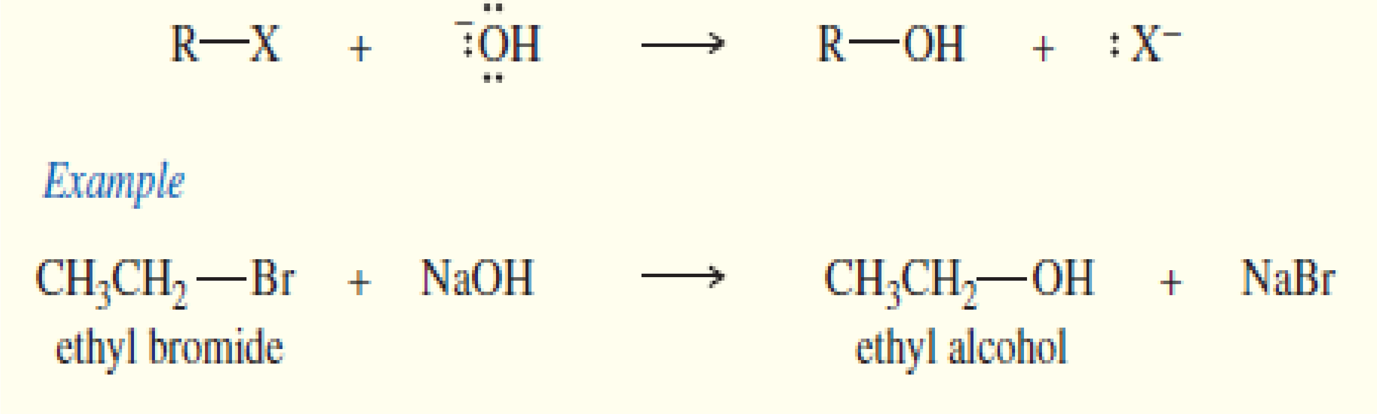
Example:

$$\underset{\text{allyl chloride}}{\mathrm{H_2C{=}CH{-}CH_2Cl}} + \mathrm{NaI} \xrightarrow[\text{acetone}]{} \underset{\text{allyl iodide}}{\mathrm{H_2C{=}CH{-}CH_2I}}$$

Reactions of alkyl halides

1- substitution reactions

a. Alcohol formation:

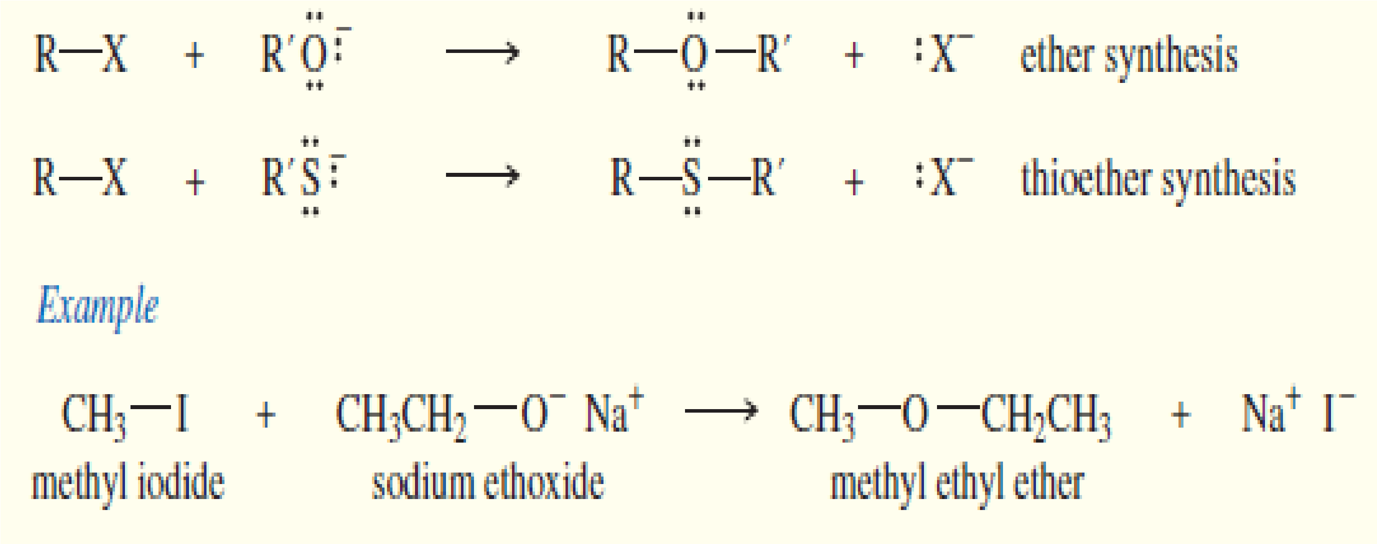


$$\mathrm{R{-}X} \;+\; {}^{-}{:}\ddot{\underset{\cdot\cdot}{\mathrm{O}}}\mathrm{H} \;\longrightarrow\; \mathrm{R{-}OH} \;+\; {:}\mathrm{X}^{-}$$

Example

$$\underset{\text{ethyl bromide}}{\mathrm{CH_3CH_2{-}Br}} \;+\; \mathrm{NaOH} \;\longrightarrow\; \underset{\text{ethyl alcohol}}{\mathrm{CH_3CH_2{-}OH}} \;+\; \mathrm{NaBr}$$

b. Williamson ether synthesis:



$$\mathrm{R{-}X} \;+\; \mathrm{R'}\ddot{\underset{\cdot\cdot}{\mathrm{O}}}{:}^{-} \;\longrightarrow\; \mathrm{R}{-}\ddot{\underset{\cdot\cdot}{\mathrm{O}}}{-}\mathrm{R'} \;+\; {:}\mathrm{X}^{-} \quad \text{ether synthesis}$$

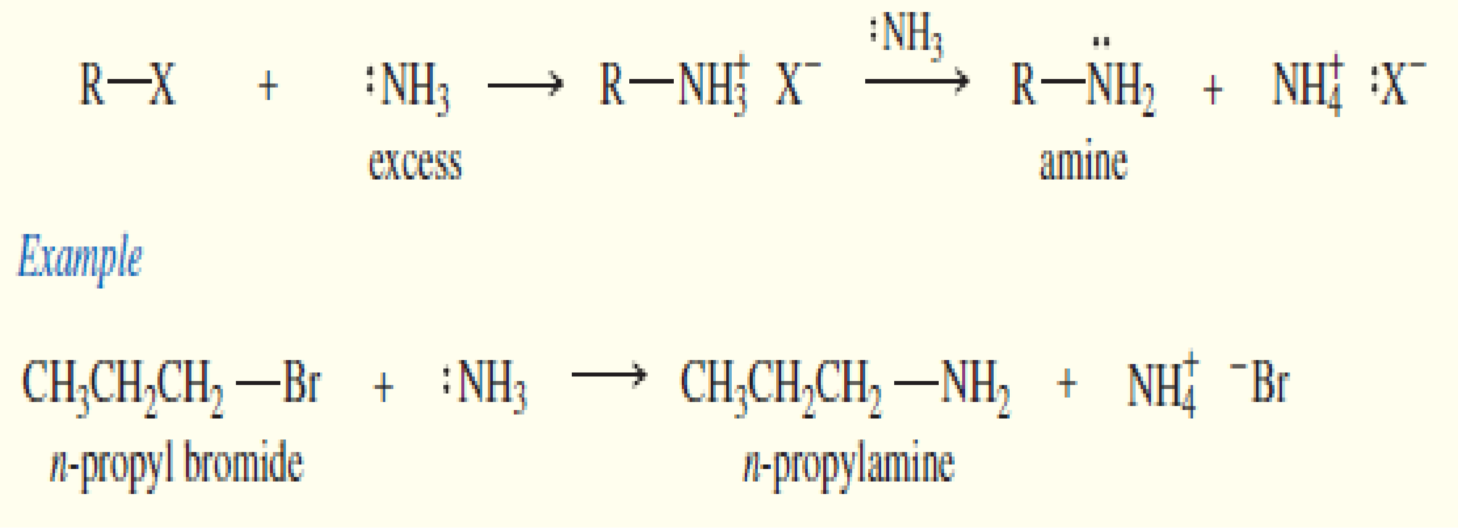
$$\mathrm{R{-}X} \;+\; \mathrm{R'}\ddot{\underset{\cdot\cdot}{\mathrm{S}}}{:}^{-} \;\longrightarrow\; \mathrm{R}{-}\ddot{\underset{\cdot\cdot}{\mathrm{S}}}{-}\mathrm{R'} \;+\; {:}\mathrm{X}^{-} \quad \text{thioether synthesis}$$

Example

$$\underset{\text{methyl iodide}}{\mathrm{CH_3{-}I}} \;+\; \underset{\text{sodium ethoxide}}{\mathrm{CH_3CH_2{-}O^{-}\ Na^{+}}} \;\longrightarrow\; \underset{\text{methyl ethyl ether}}{\mathrm{CH_3{-}O{-}CH_2CH_3}} \;+\; \mathrm{Na^{+}\ I^{-}}$$

Reactions of alkyl halides

c. Amine synthesis:

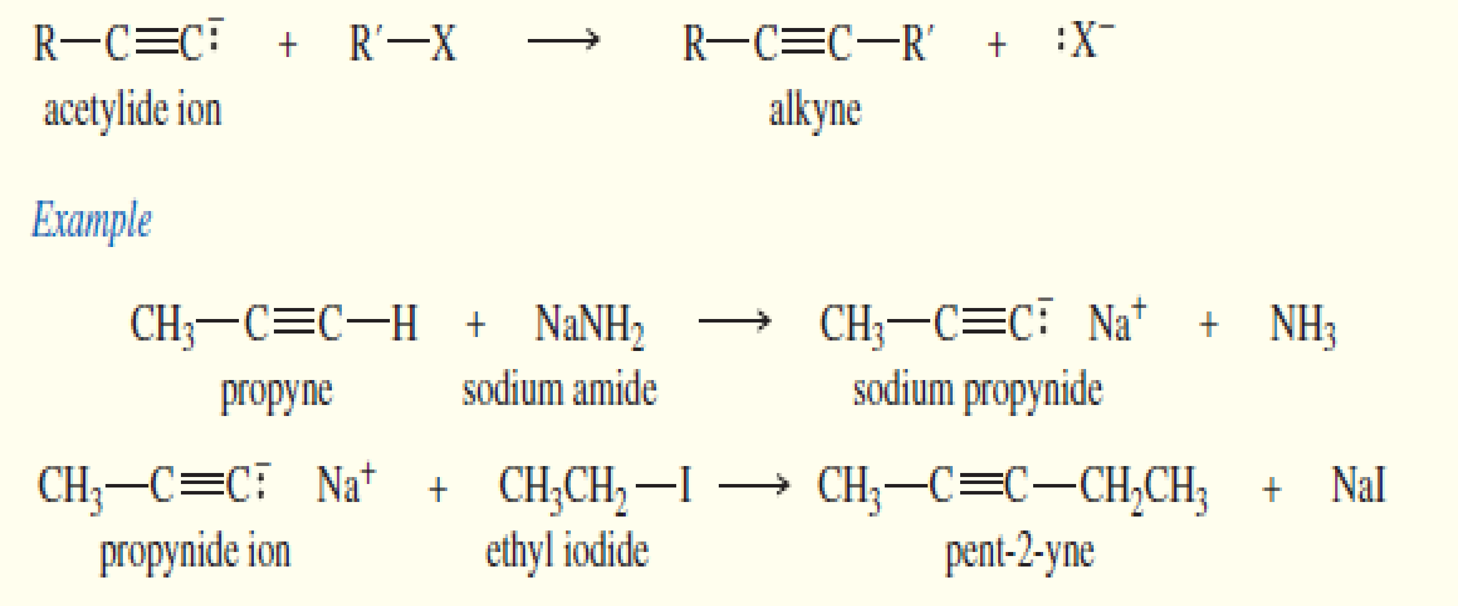


$$R{-}X \; + \; \underset{\text{excess}}{:NH_3} \longrightarrow R{-}NH_3^+ \; X^- \xrightarrow{:NH_3} \underset{\text{amine}}{R{-}\ddot{N}H_2} \; + \; NH_4^+ \; :X^-$$

Example

$$\underset{n\text{-propyl bromide}}{CH_3CH_2CH_2{-}Br} \; + \; :NH_3 \longrightarrow \underset{n\text{-propylamine}}{CH_3CH_2CH_2{-}NH_2} \; + \; NH_4^+ \; {}^-Br$$

d. Alkyne synthesis:



$$\underset{\text{acetylide ion}}{R{-}C{\equiv}C\overset{..}{:}^-} \; + \; R'{-}X \longrightarrow \underset{\text{alkyne}}{R{-}C{\equiv}C{-}R'} \; + \; :X^-$$

Example

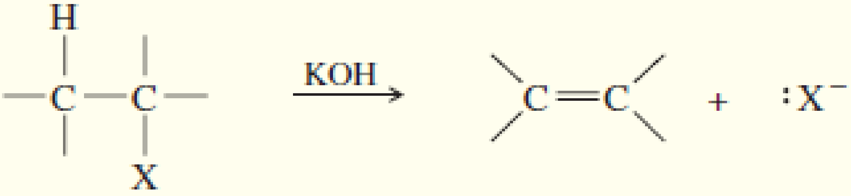
$$\underset{\text{propyne}}{CH_3{-}C{\equiv}C{-}H} \; + \; \underset{\text{sodium amide}}{NaNH_2} \longrightarrow \underset{\text{sodium propynide}}{CH_3{-}C{\equiv}C:^- \; Na^+} \; + \; NH_3$$

$$\underset{\text{propynide ion}}{CH_3{-}C{\equiv}C:^- \; Na^+} \; + \; \underset{\text{ethyl iodide}}{CH_3CH_2{-}I} \longrightarrow \underset{\text{pent-2-yne}}{CH_3{-}C{\equiv}C{-}CH_2CH_3} \; + \; NaI$$

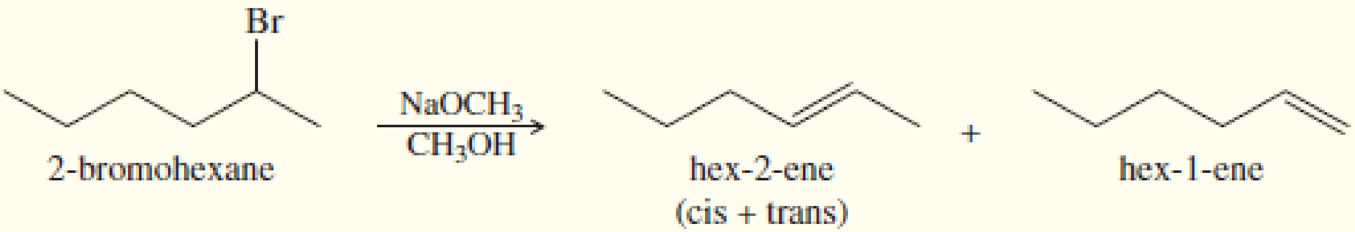
Reactions of alkyl halides

2- Elimination reactions:

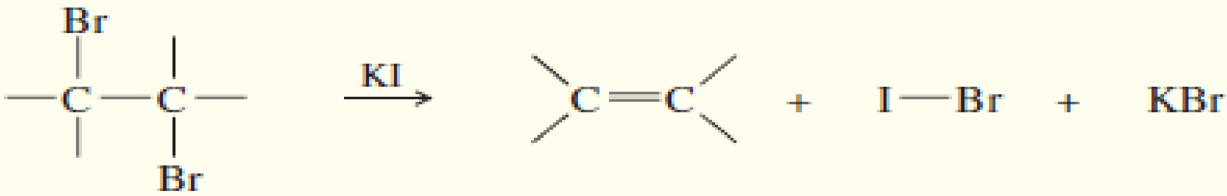
a. Dehydrohalogenation:



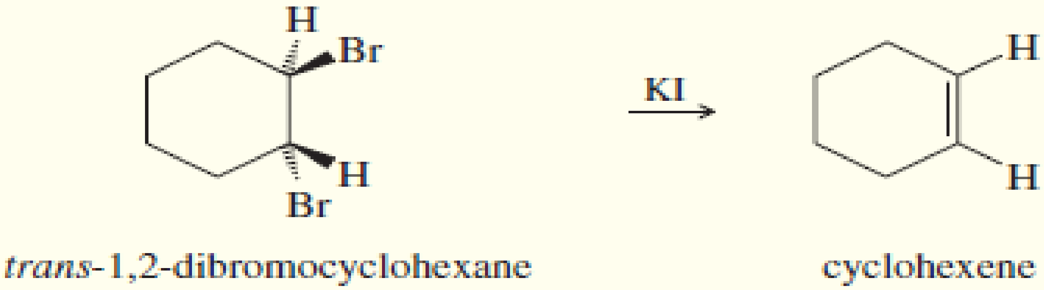
Example



b. Dehalogenation:



Example



Reactions of alkyl halides

3- Formation of Grignard reagents:

$$\underset{(X = Cl,\ Br,\ or\ I)}{R{-}X} + Mg \xrightarrow{CH_3CH_2{-}O{-}CH_2CH_3} \underset{\substack{\text{organomagnesium halide} \\ \text{(Grignard reagent)}}}{R{-}Mg{-}X}$$

Example

bromocyclohexane

cyclohexylmagnesium bromide

$$R{-}X \xrightarrow[(2)\ H_2O]{(1)\ Mg\ or\ Li} R{-}H$$

Example

$$\underset{n\text{-decyl bromide}}{C_9H_{19}{-}CH_2{-}Br} \xrightarrow[(2)\ H_2O]{(1)\ Mg,\ ether} \underset{n\text{-decane}}{C_9H_{19}{-}CH_3}$$

Alcohols

Alcohols

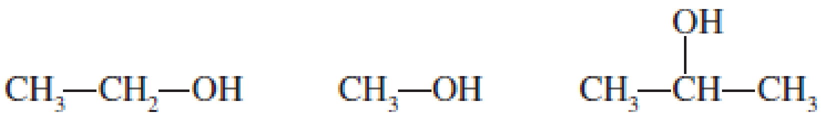
Introduction:

- **Alcohols:** are organic compounds containing hydroxyl groups.
- Alcohols viewed as organic derivatives of water.

H-O-H R-O-H

Water Alcohol

- Alcohols have a common functional group, the hydroxyl group, -OH.
- In alcohols the hydroxyl group is attached to an alkyl group, -R.



$CH_3—CH_2—OH$ $CH_3—OH$ $CH_3—\overset{OH}{\overset{|}{C}}H—CH_3$

ethyl alcohol methyl alcohol isopropyl alcohol

ethanol methanol propan-2-ol

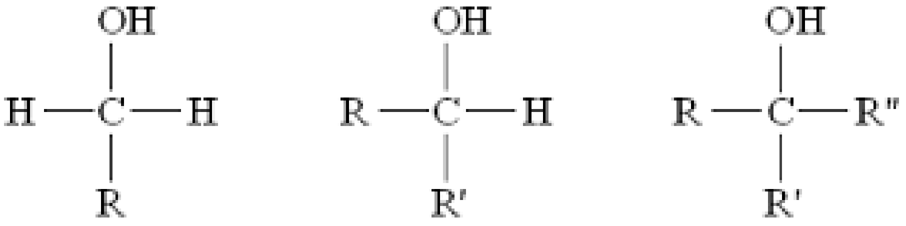
- When the hydroxyl group is attached to an aromatic ring, Ar, it is called phenol.

Ar-O-H

Phenol

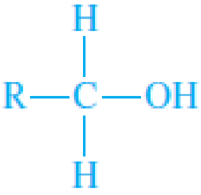
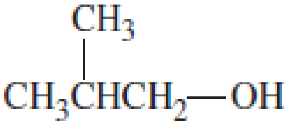
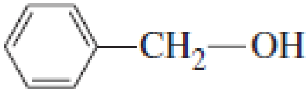
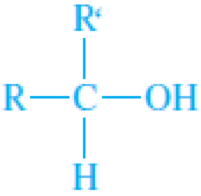
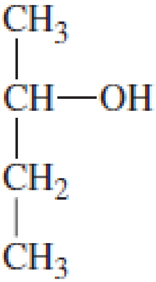
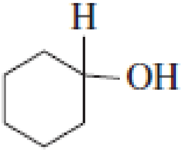
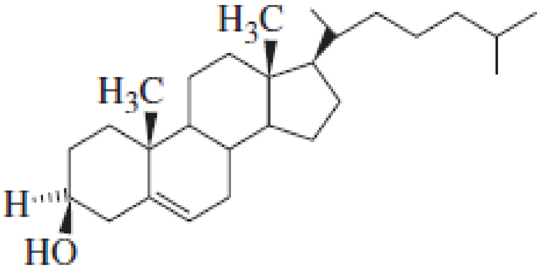
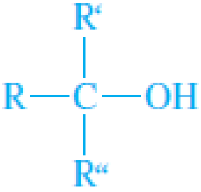
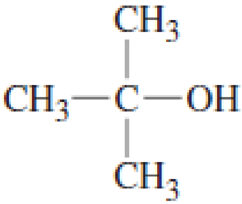
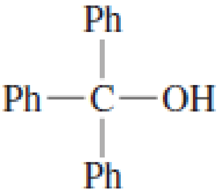
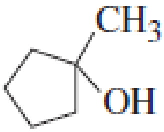
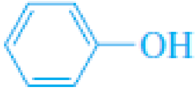
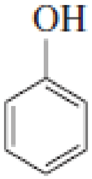
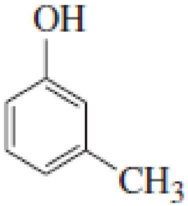
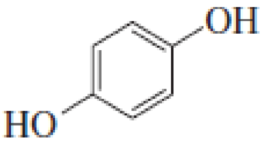
Classification of alcohols:

- Alcohols are subdivided into three classes: primary (1°), secondary (2°) and tertiary (3°).
- The classification depends on the number of alkyl groups bonded to the carbon bearing the –OH , which called carbinol carbon.
- Primary alcohols have one alkyl group attached to the carbinol carbon.
- Secondary alcohols have two.
- Tertiary alcohols have three.



primary (1°) alcohol secondary (2°) alcohol tertiary (3°) alcohol

Alcohols

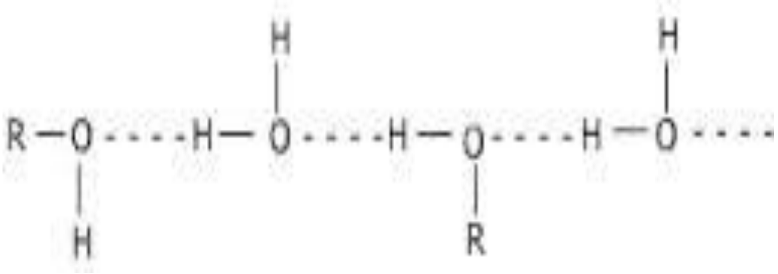
Type	*Structure*	*Examples*
Primary alcohol	 $R-\overset{\overset{H}{\mid}}{\underset{\underset{H}{\mid}}{C}}-OH$	CH_3CH_2-OH ethanol  $CH_3\overset{\overset{CH_3}{\mid}}{C}HCH_2-OH$ 2-methylpropan-1-ol  benzyl alcohol
Secondary alcohol	 $R-\overset{\overset{R'}{\mid}}{\underset{\underset{H}{\mid}}{C}}-OH$	 $\begin{array}{l}CH_3\\ \mid\\ CH-OH\\ \mid\\ CH_2\\ \mid\\ CH_3\end{array}$ butan-2-ol  cyclohexanol  cholesterol
Tertiary alcohol	 $R-\overset{\overset{R'}{\mid}}{\underset{\underset{R''}{\mid}}{C}}-OH$	 $CH_3-\overset{\overset{CH_3}{\mid}}{\underset{\underset{CH_3}{\mid}}{C}}-OH$ 2-methylpropan-2-ol  $Ph-\overset{\overset{Ph}{\mid}}{\underset{\underset{Ph}{\mid}}{C}}-OH$ triphenylmethanol  1-methylcyclopentanol
Phenols		 phenol  3-methylphenol  hydroquinone

Physical properties alcohols

1- Solubility:

At room temperature the alcohols are liquids.

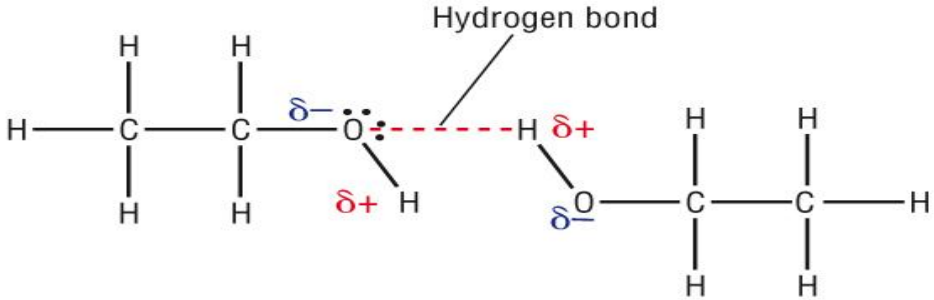
Alcohols are soluble in water unlike the alkanes due to alcohols ability to do hydrogen bond with water. As the number of carbons in the alcohol increases, the solubility in water decreases. The –O-H bond is highly polar.



2- Boiling point:

The boiling points increase with increase in molecular weights.

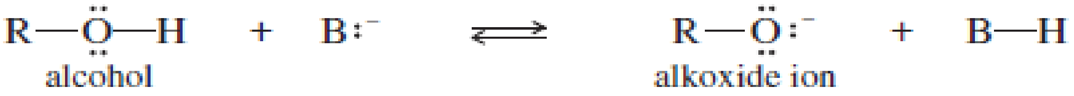
The values of boiling points of alcohols are higher than in alkanes due to presence of –OH group, which is able to do hydrogen bond between molecules.



Physical properties alcohols

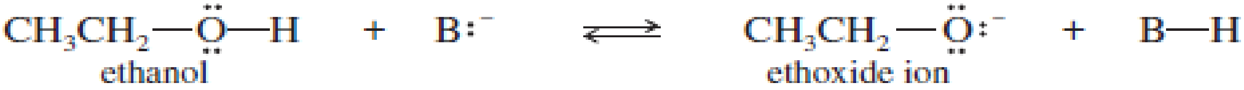
3- Acidity of Alcohols and Phenols:

Like the hydroxyl proton of water, the hydroxyl proton of an alcohol is weakly acidic. A strong base can remove the hydroxyl proton to give an **alkoxide ion.**



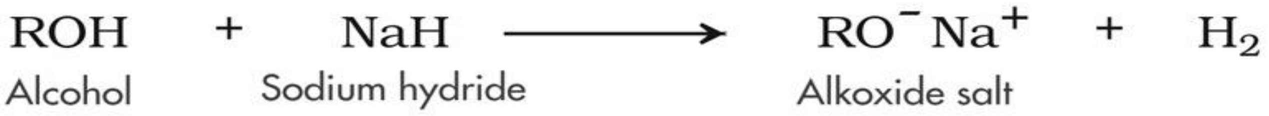
$$R-\ddot{\underset{..}{O}}-H + B:^- \rightleftharpoons R-\ddot{\underset{..}{O}}:^- + B-H$$

Example



$$CH_3CH_2-\ddot{\underset{..}{O}}-H + B:^- \rightleftharpoons CH_3CH_2-\ddot{\underset{..}{O}}:^- + B-H$$

Alcohols as acids: formation of salt:



$$ROH + NaH \longrightarrow RO^-Na^+ + H_2$$

The Williamson synthesis of ethers:

$R\text{-}O^-Na^+ + R'\text{-}X \longrightarrow R\text{-}O\text{-}R' + NaX$

Sodium alkoxide Alkyl halide Ether Sodium halide

Alkoxides are strong bases stronger than hydroxides, which is used in the synthesis of ethers R-O-R'.

Alkoxyl group RO- , Hydroxyl group HO-

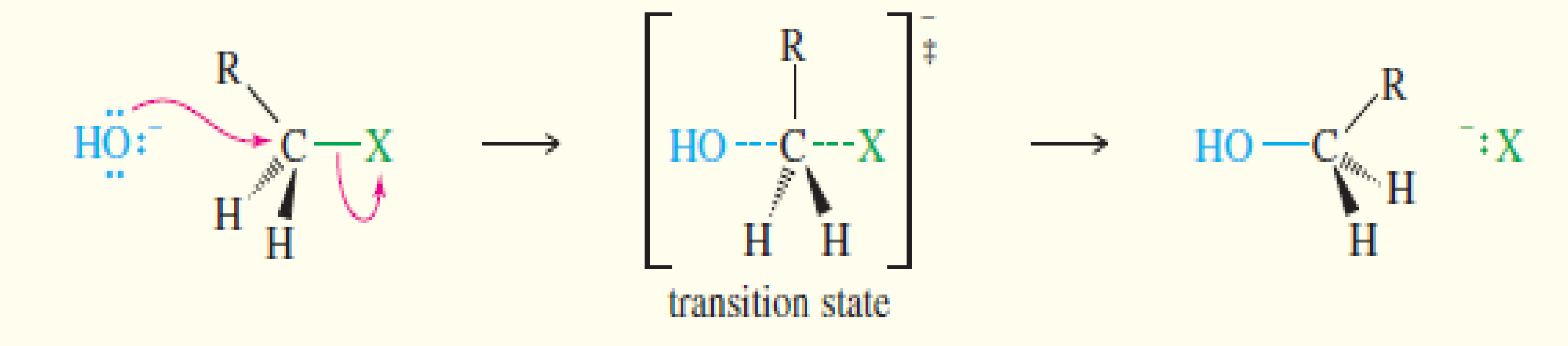
Preparation of alcohols

1- Nucleophilic substitution on an alkyl halide:

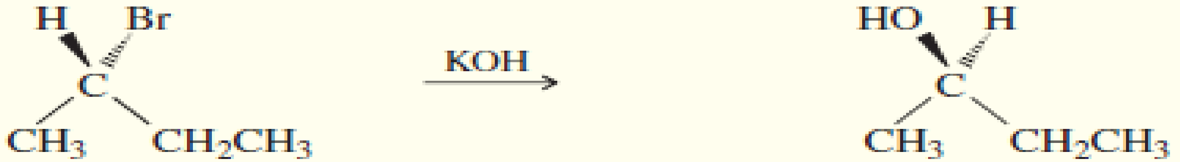
$$R\text{-}X + H\text{-}OH \longrightarrow R\text{-}OH + H\text{-}X$$

$$CH_3CH_2CH_2CH_2CH_2Br + {}^{-}OH \longrightarrow CH_3CH_2CH_2CH_2CH_2OH + Br^{-}$$

1-bromopentane → pentane-1-ol



Example



(*S*)-2-bromobutane

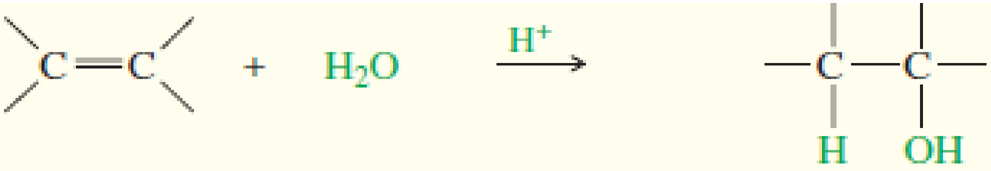
(*R*)-butan-2-ol, 100% inverted configuration (plus elimination products)

Preparation of alcohols

2- From alkenes:

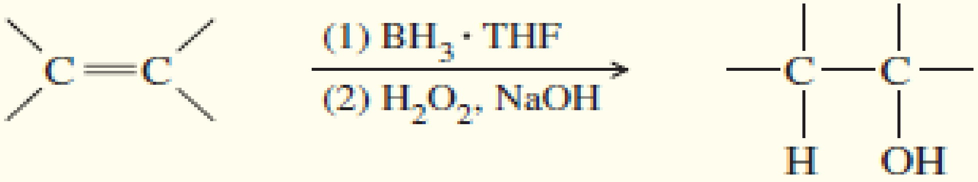
a. Acid-catalyzed Hydration of alkenes:

Water adds to alkenes in the presence of an acid catalyst following Markovnikov’s rule.



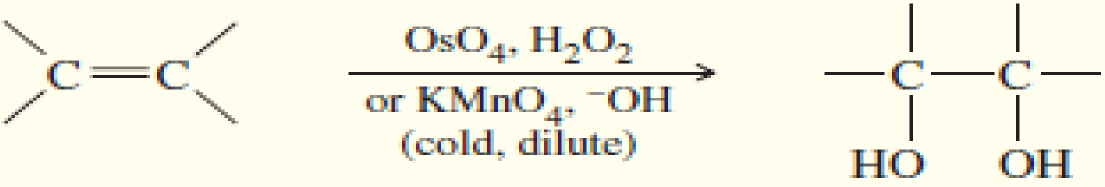
Markovnikov orientation

b. Hydroboration–oxidation:



syn addition, anti-Markovnikov orientation

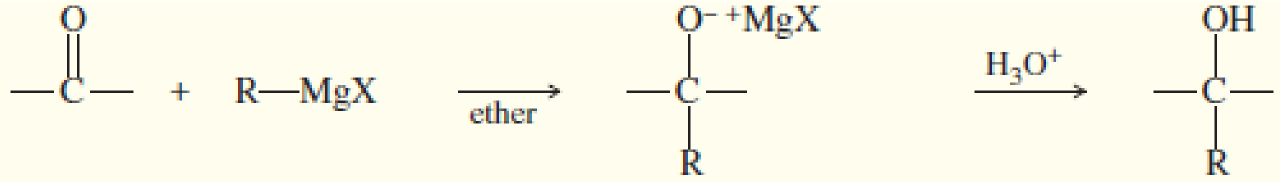
c. Dihydroxylation: synthesis of 1,2-diols from alkenes:



syn dihydroxylation

Preparation of alcohols

3- Addition of a Grignard reagent to carbonyl groups:



$$-\overset{\overset{\displaystyle O}{\|}}{C}- + R-MgX \xrightarrow[\text{ether}]{} -\overset{\overset{\displaystyle O^{-}\ {}^{+}MgX}{|}}{\underset{\underset{\displaystyle R}{|}}{C}}- \xrightarrow{H_3O^+} -\overset{\overset{\displaystyle OH}{|}}{\underset{\underset{\displaystyle R}{|}}{C}}-$$

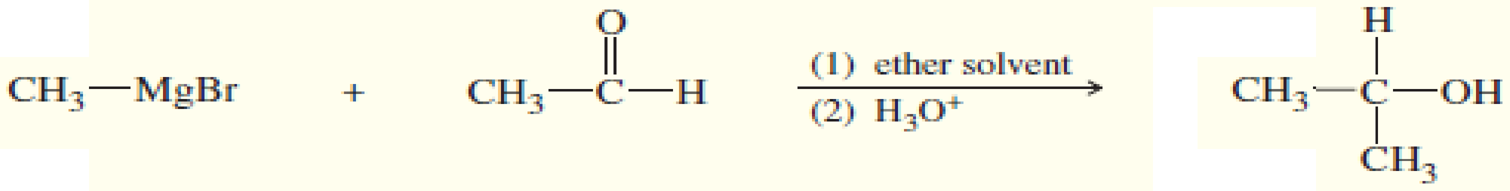
a. Addition to formaldehyde gives a primary alcohol:

$$CH_3CH_2MgBr + H_2C{=}O \xrightarrow[\text{(2) } H_3O^+]{\text{(1) ether solvent}} CH_3CH_2-CH_2-OH$$

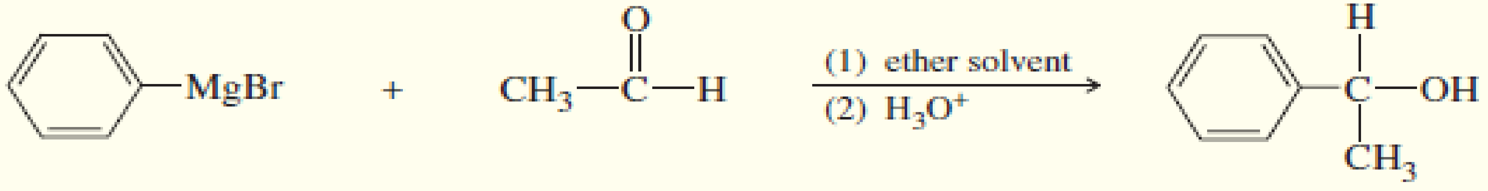
ethylmagnesium bromide

propan-1-ol

b. Addition to an aldehyde gives a secondary alcohol:



$$CH_3-MgBr + CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-H \xrightarrow[\text{(2) } H_3O^+]{\text{(1) ether solvent}} CH_3-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle CH_3}{|}}{C}}-OH$$



$$\text{(1) ether solvent} \quad \text{(2) } H_3O^+$$

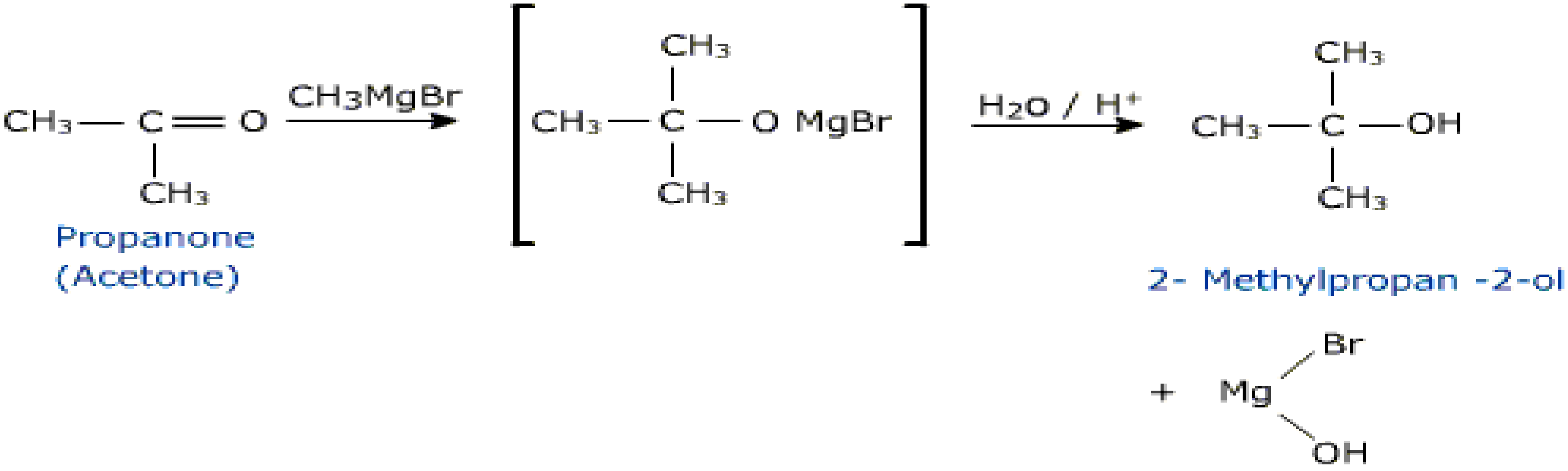
phenylmagnesium bromide

acetaldehyde

1-phenylethanol

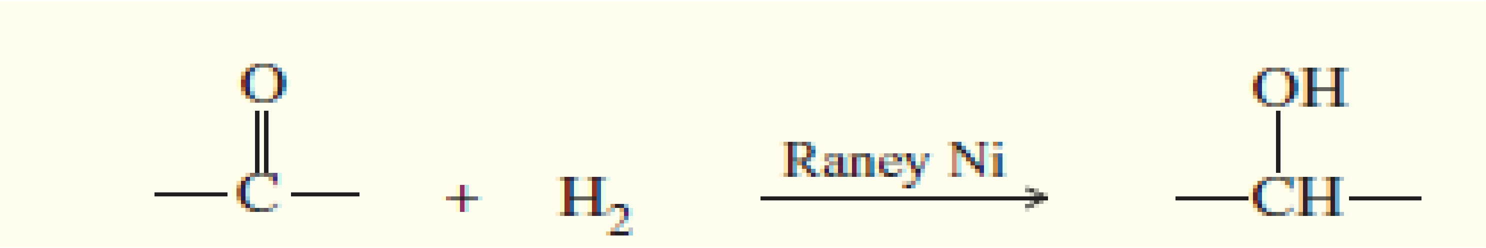
Preparation of alcohols

c. Addition to a ketone gives a tertiary alcohol:



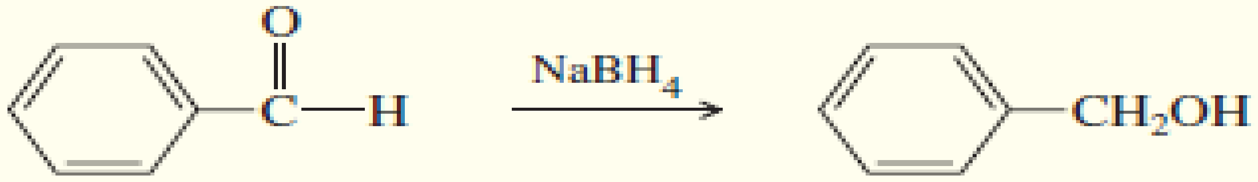
Preparation of alcohols

4- Reduction of carbonyl compounds:



$$-\overset{\overset{\displaystyle O}{\|}}{C}- + H_2 \xrightarrow{\text{Raney Ni}} -\overset{\overset{\displaystyle OH}{|}}{CH}-$$

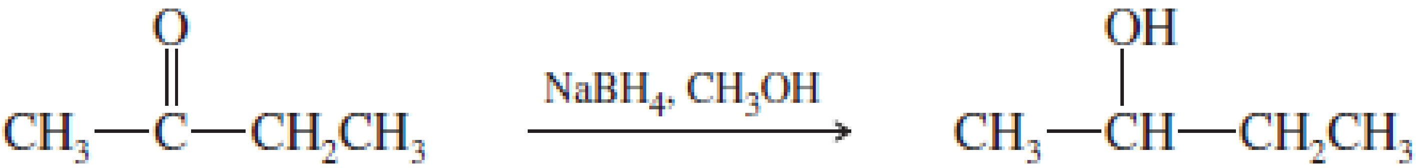
a. Reduction of an aldehyde gives a primary alcohol:



benzaldehyde

benzyl alcohol

b. Reduction of a ketone gives a secondary alcohol:



$$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-CH_2CH_3 \xrightarrow{NaBH_4,\ CH_3OH} CH_3-\overset{\overset{\displaystyle OH}{|}}{CH}-CH_2CH_3$$

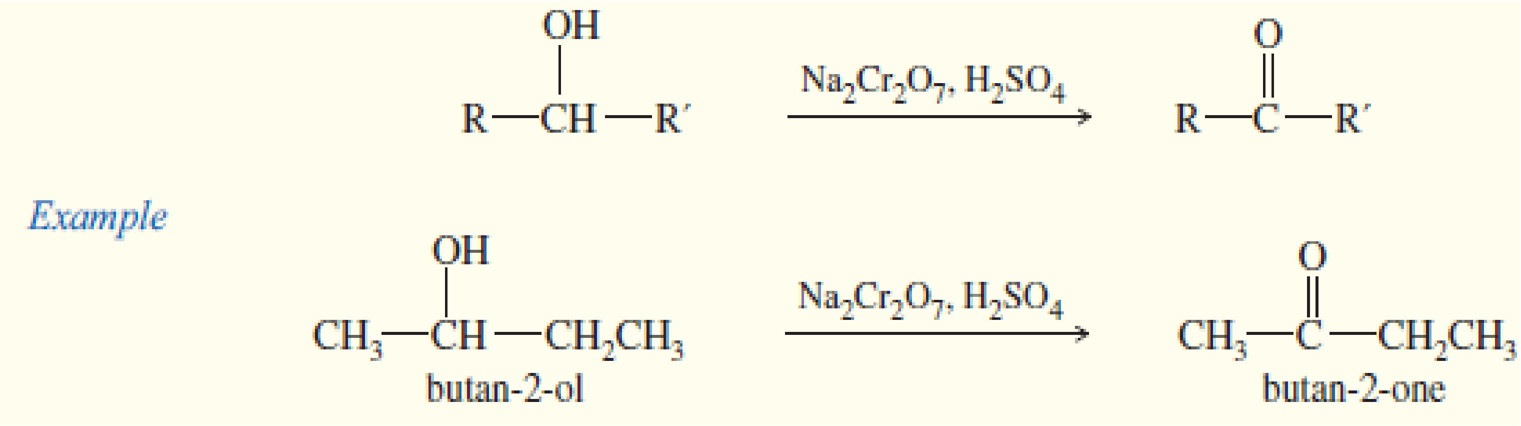
butan-2-one

(±)-butan-2-ol (100%)

Reactions of alcohols

1- Oxidation–reduction reactions:

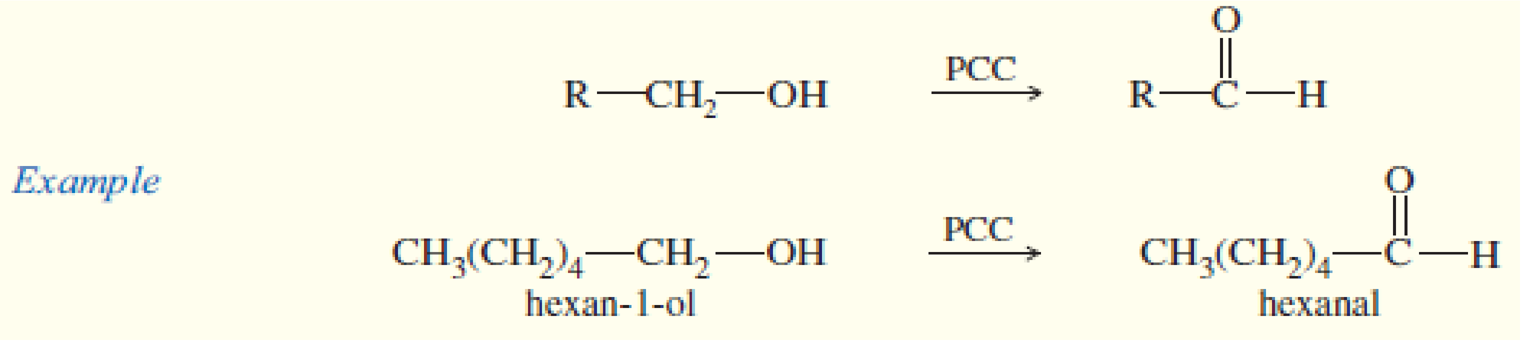
a. Oxidation of secondary alcohols to ketones:



$$R-CH(OH)-R' \xrightarrow{Na_2Cr_2O_7,\ H_2SO_4} R-C(=O)-R'$$

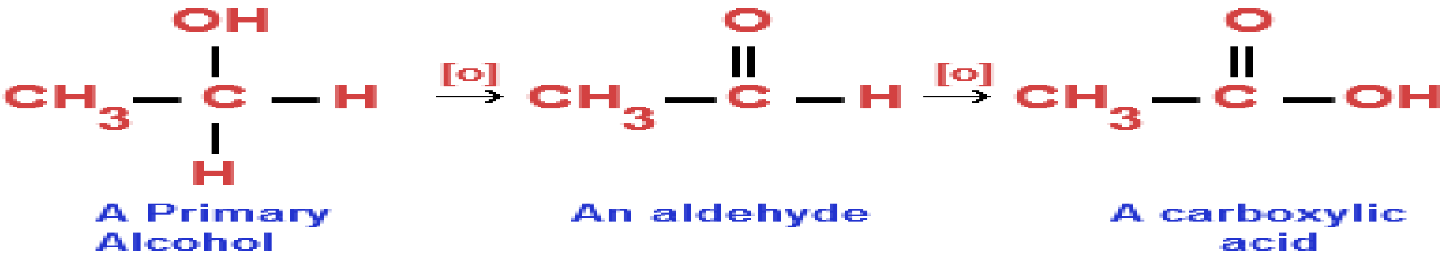
$$CH_3-CH(OH)-CH_2CH_3 \xrightarrow{Na_2Cr_2O_7,\ H_2SO_4} CH_3-C(=O)-CH_2CH_3$$

b. Oxidation of primary alcohols to aldehydes:



$$R-CH_2-OH \xrightarrow{PCC} R-C(=O)-H$$

$$CH_3(CH_2)_4-CH_2-OH \xrightarrow{PCC} CH_3(CH_2)_4-C(=O)-H$$



$$CH_3-CH(OH)-H \xrightarrow{[o]} CH_3-C(=O)-H \xrightarrow{[o]} CH_3-C(=O)-OH$$

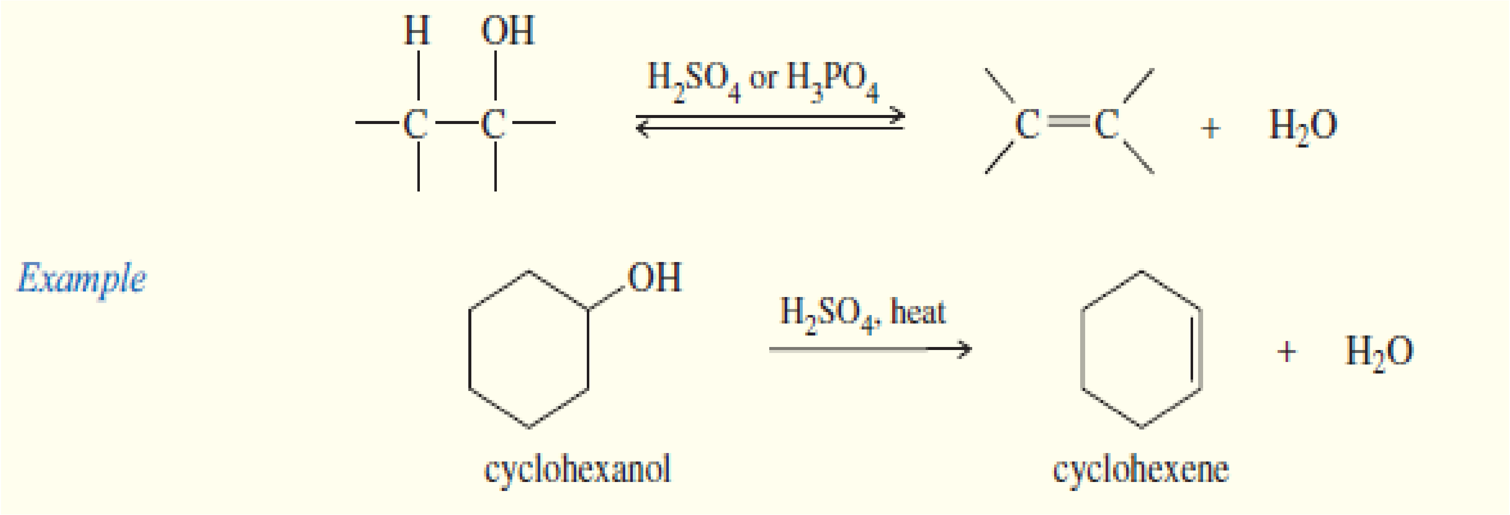
Reactions of alcohols

2- Conversion of alcohols to alkyl halides:

$$R-OH \xrightarrow{HBr\ \text{or}\ PBr_3} R-Br$$

$$\underset{\textit{tert}\text{-butyl alcohol}}{(CH_3)_3CH-OH} \xrightarrow{HCl} \underset{\textit{tert}\text{-butyl chloride}}{(CH_3)_3C-Cl}$$

3- Dehydration of alcohols to form alkenes:



Reactions of alcohols

4- Condensation of alcohols to form ethers (Dehydration of alcohols):

$$2\,R{-}OH \underset{}{\overset{H^+}{\rightleftharpoons}} R{-}O{-}R + H_2O$$

Example

$$\underset{\text{ethanol}}{2\,CH_3CH_2OH} \xrightarrow[140\,^\circ C]{H_2SO_4} \underset{\text{diethyl ether}}{CH_3CH_2{-}O{-}CH_2CH_3} + H_2O$$

5- Williamson ether synthesis:

$$R{-}O^- + R'X \longrightarrow R{-}O{-}R' + X^-$$

(R′ must be unhindered, usually primary)

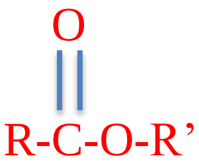
Example

$$\underset{\text{sodium ethoxide}}{Na^+\,{}^-O{-}CH_2CH_3} + \underset{\text{methyl iodide}}{CH_3I} \longrightarrow \underset{\text{ethyl methyl ether}}{CH_3CH_2{-}O{-}CH_3} + NaI$$

Reaction of alcohols

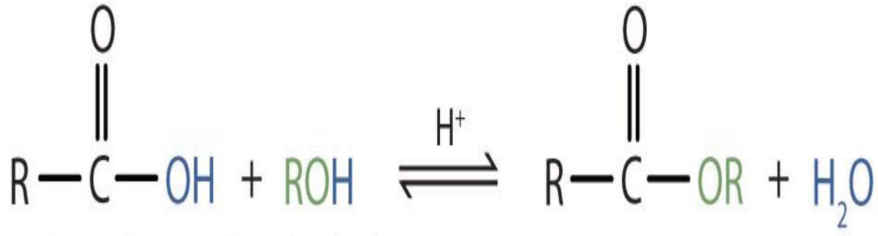
6- Esterification: formation of ester:

Reaction of carboxylic acid with alcohol will form ester.



$$\overset{\displaystyle O}{\overset{\|}{R\text{-}C\text{-}O\text{-}R'}}$$

Ester



Carboxylic acid Alcohol Ester