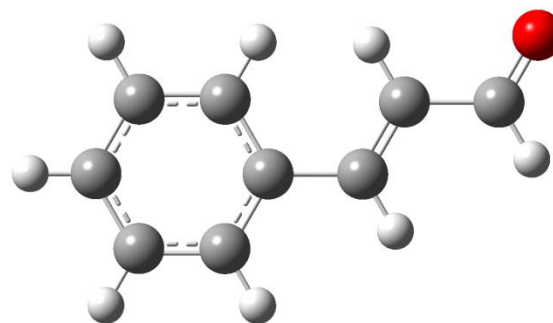
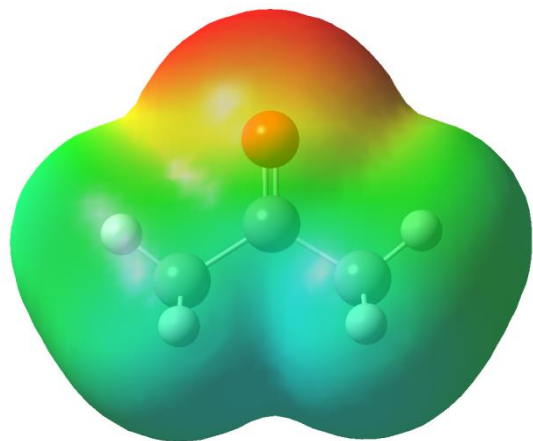
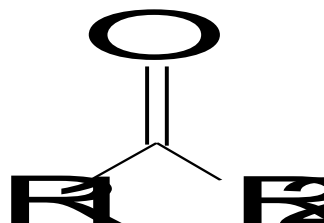


Chapter 9: Aldehydes and Ketones



Aldehydes and Ketones

Both contain a *carbonyl group*

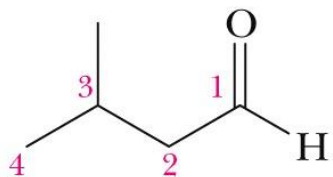


- *Aldehydes* have at least 1 H atom attached to the carbonyl C atom, i.e. R1 or R2 = H
- *Ketones* have two carbon groups attached to the carbonyl C atom
- R1 / R2 can be alkyl, alkenyl, alkynyl or aromatic

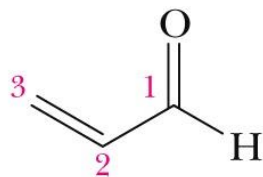
Nomenclature

- IUPAC names:
 - The parent chain is the longest chain that contains the carbonyl group.
 - For an aldehyde, change the suffix from **-e** to **-al**; for a ketone change the suffix from **-e** to **-one**
 - For an unsaturated aldehyde or ketone, show the carbon-carbon double bond by changing the infix from **-an-** to **-en-**; the location of the suffix determines the numbering pattern.
 - For a cyclic molecule in which **-CHO** is bonded to the ring, add the suffix **-carbaldehyde**.

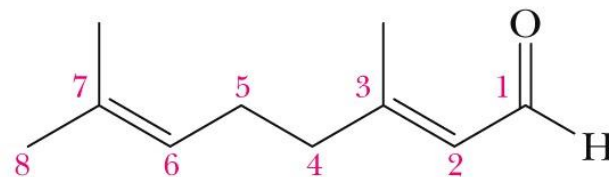
Nomenclature



3-Methylbutanal

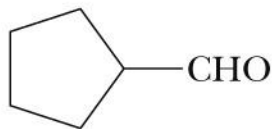


2-Propenal
(Acrolein)

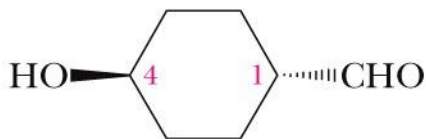


(*E*)-3,7-Dimethyl-2,6-octadienal
(Geranial)

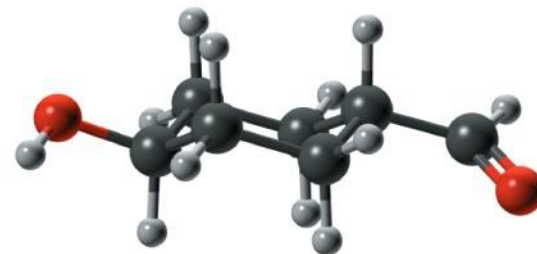
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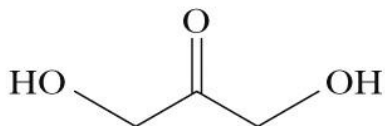
Cyclopentanecarbaldehyde



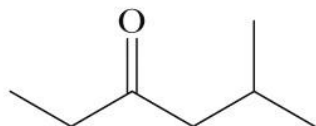
trans-4-Hydroxycyclohexanecarbaldehyde



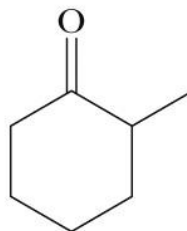
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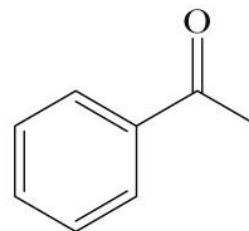
Dihydroxyacetone



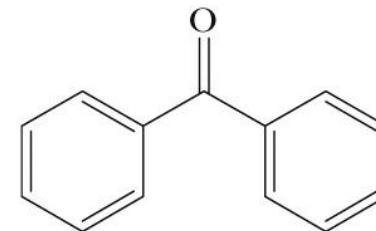
5-Methyl-3-hexanone



2-Methyl-
cyclohexanone



Acetophenone

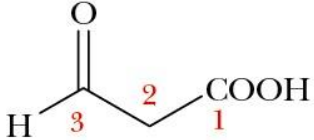
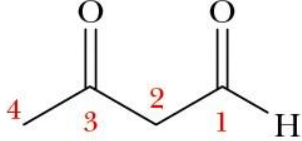
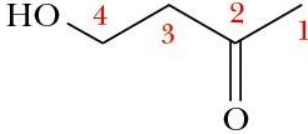
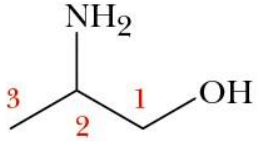



Benzophenone

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Nomenclature

TABLE 12.1 Increasing Order of Precedence of Six Functional Groups

Functional Group	Suffix	Prefix	Example of When the Functional Group Has Lower Priority	
Carboxyl	-oic acid	—		
Aldehyde	-al	oxo- or formyl	3-Oxopropanoic acid	
Ketone	-one	oxo-	3-Oxobutanal	
Alcohol	-ol	hydroxy-	4-Hydroxy-2-butanone	
Amino	-amine	amino-	2-Amino-1-propanol	
Sulfhydryl	-thiol	mercapto-	2-Mercaptoethanol	

Nomenclature

- Common names

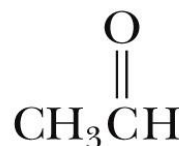
- For aldehydes, the common name is derived from the common name of the corresponding carboxylic acid.
- For ketones, name the alkyl or aryl groups bonded to the carbonyl carbon and add the word ketone.



Formaldehyde



Formic acid



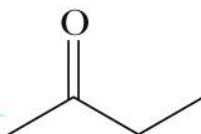
Acetaldehyde



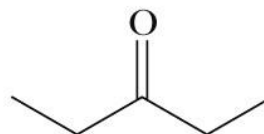
Acetic acid

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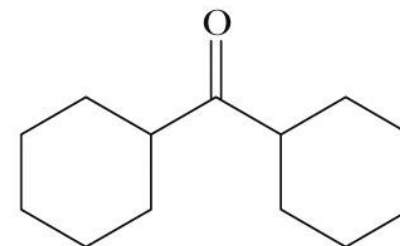
the lower-molecular-weight group bonded to the carbonyl comes first in the common name for a ketone



Methyl ethyl ketone
(MEK)



Diethyl ketone

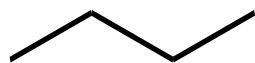


Dicyclohexyl ketone

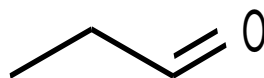
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Physical Properties

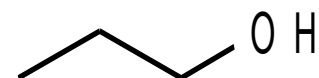
Boiling Points: intermediate between alcohols and alkanes, i.e.



-1 °C

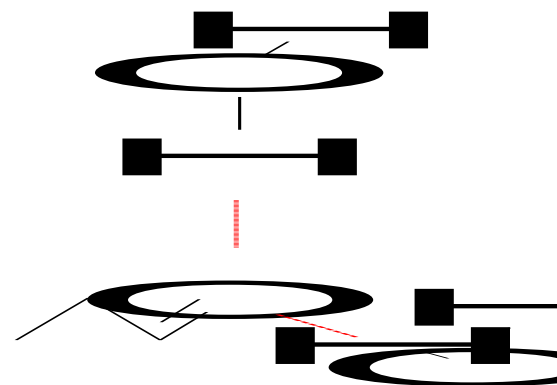


49 °C



97 °C

Solubility: smaller compounds are soluble in water as they are H-bond acceptors, i.e.



Common Aldehydes or Ketones

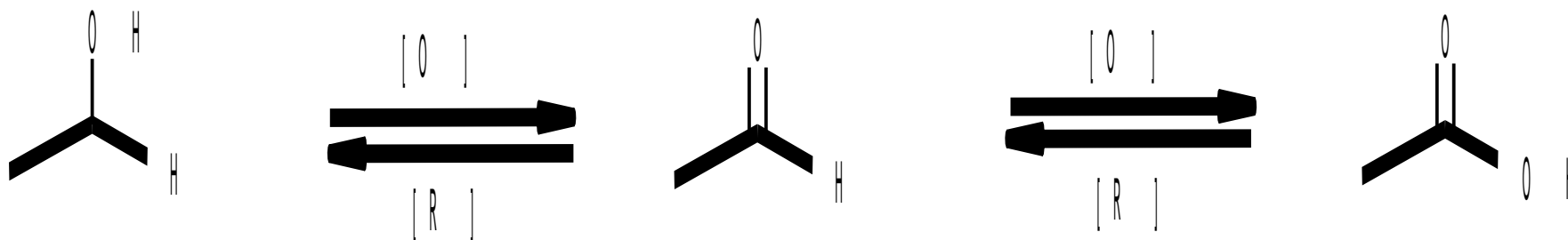
2) *acetone*: used as starting material for other chemicals and as a solvent.

c) oxidation of isopropanol



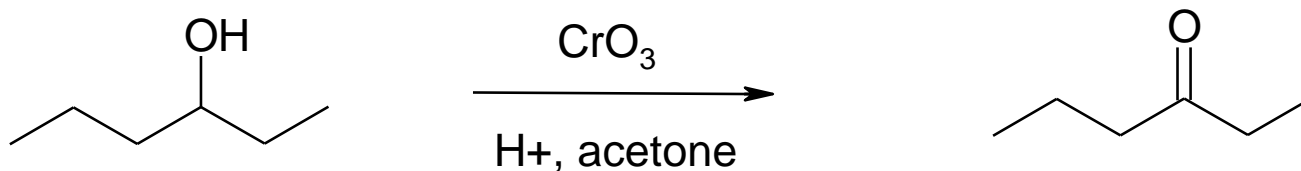
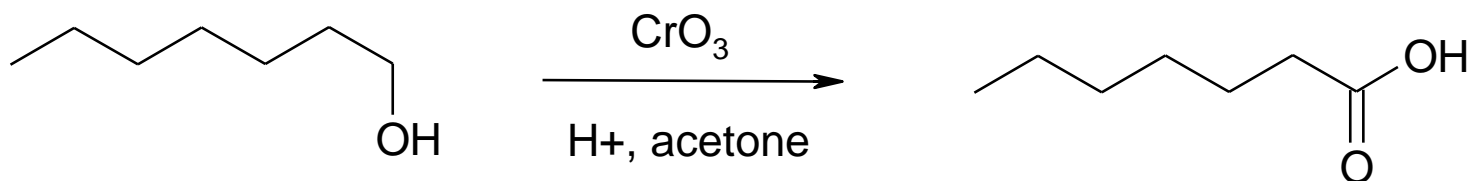
Synthesis of Aldehydes and Ketones

Aldehydes and ketones are commonly synthesized from an alcohol by *oxidation*, i.e.



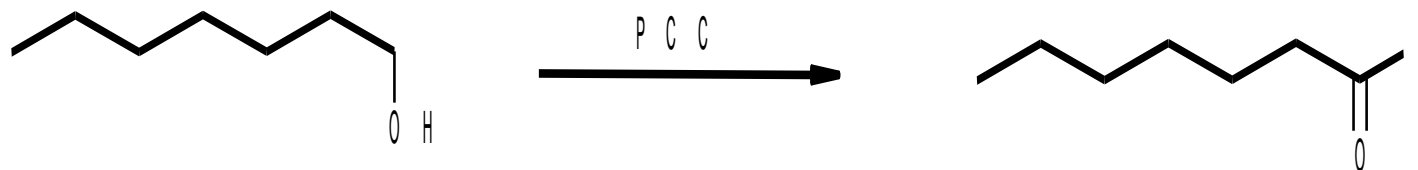
Synthesis of Aldehydes and Ketones

The nature of the alcohol and oxidizing agent determine the product. Jones reagent oxidizes 1° to an acid, 2° alcohol to a ketone.



Synthesis of Aldehydes and Ketones

PCC reagent oxidizes 1° to an aldehyde.

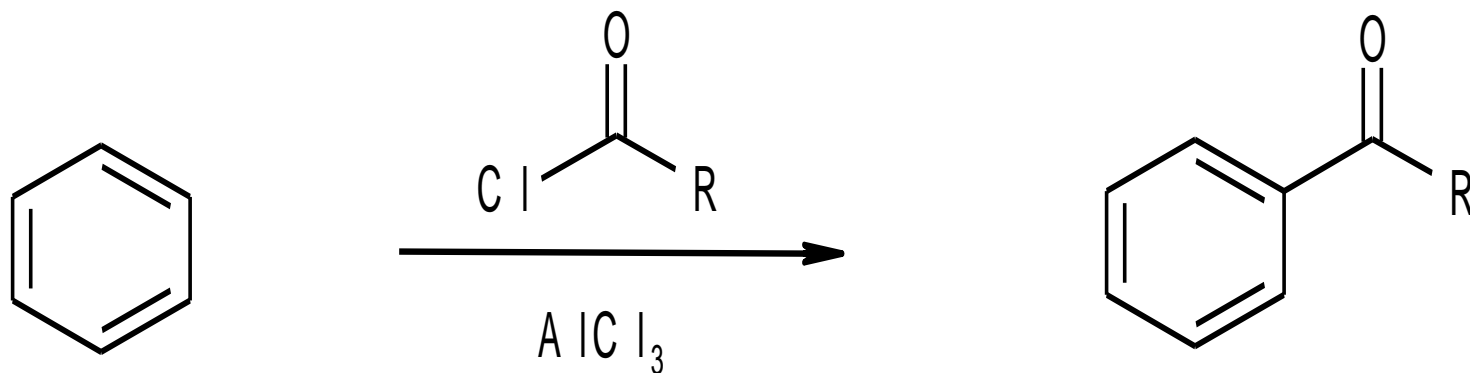


3° alcohols can not be oxidized.



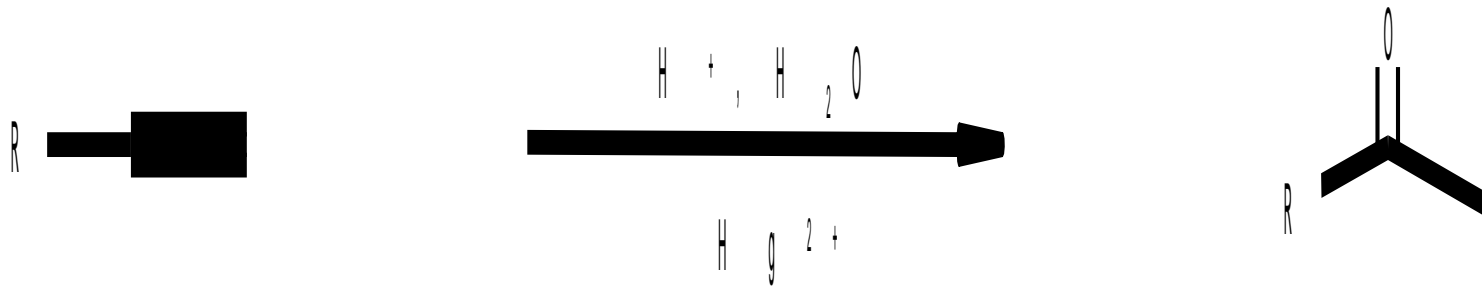
Synthesis of Aldehydes and Ketones

Aromatic ketones can be prepared by Friedel-Crafts acylation reactions, i.e.



Synthesis of Aldehydes and Ketones

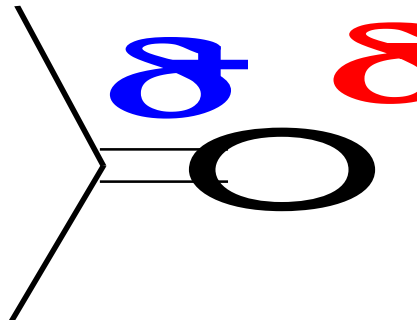
Finally methyl ketones can be prepared from terminal alkynes, i.e.



The Carbonyl Group

The *carbonyl group* is:

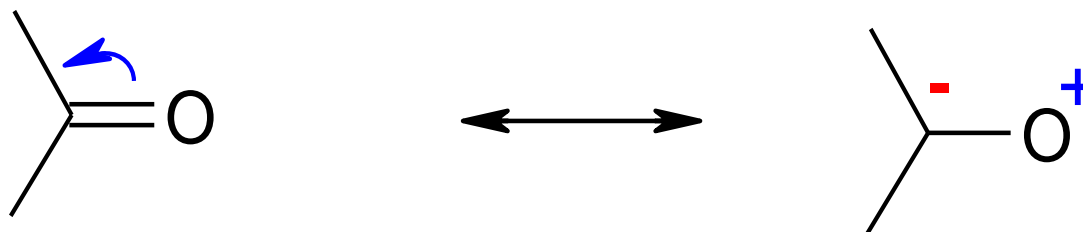
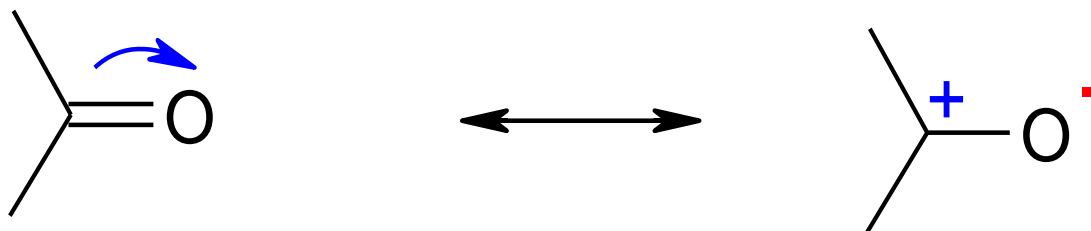
- A double bond between a C and O atom \therefore both are sp^2 hybridized \therefore trigonal planar geometry
- O is more electronegative \therefore a polar covalent bond



The Carbonyl Group

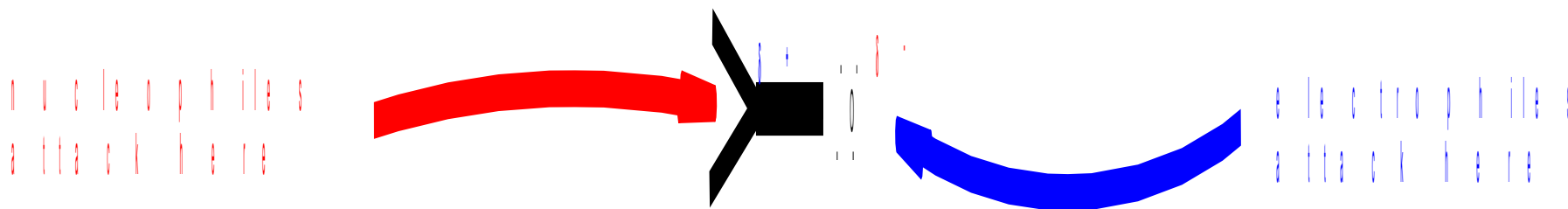
The carbonyl group is:

- Resonance is possible due to the π bond, i.e.

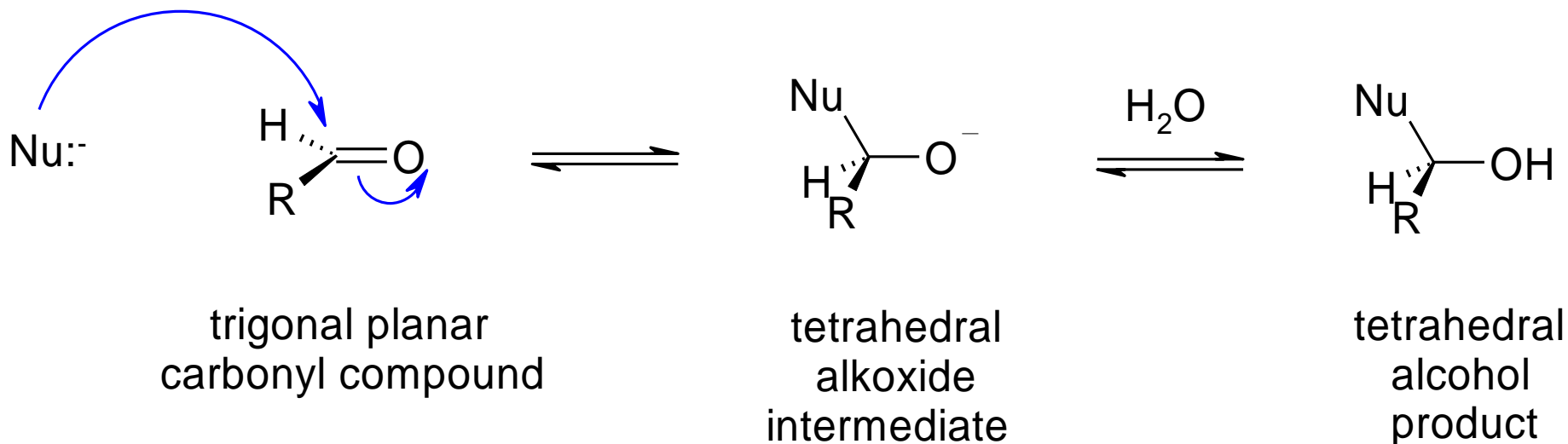


Nucleophilic (Acyl) Addition Reactions

The carbonyl group is subject to:

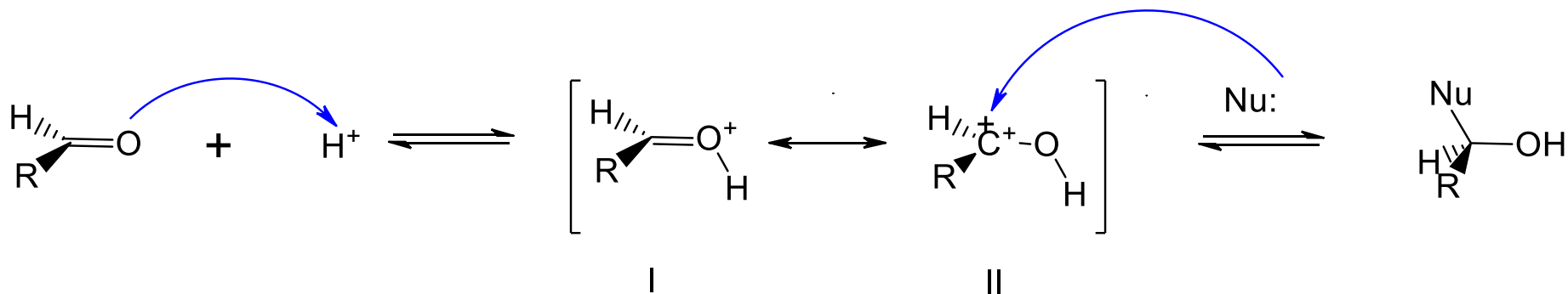


The general reaction mechanism is:



Nucleophilic Addition Reactions

Acids can be used to catalyze the addition of weak nucleophiles, i.e.

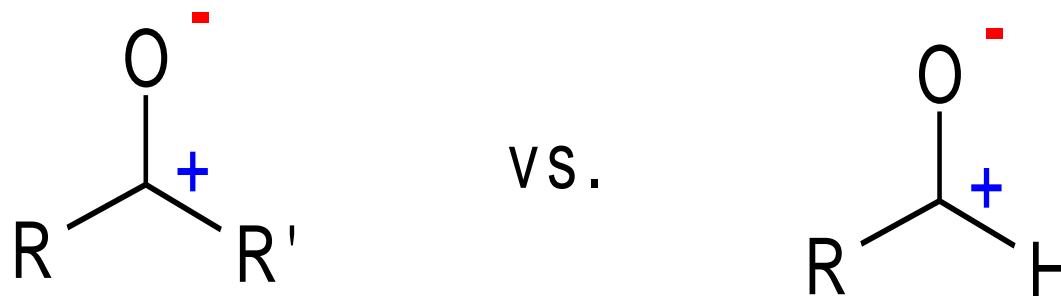


Note: the product is the same, but the resonant structure II enhances the attack of the nucleophile as the C has a formal positive charge.

Nucleophilic Addition Reactions

Aldehydes vs. Ketones:

- Generally ketones are less reactive than aldehydes due to:
 - Steric hindrance at the carbonyl group
 - Stability of the carbocation, i.e.



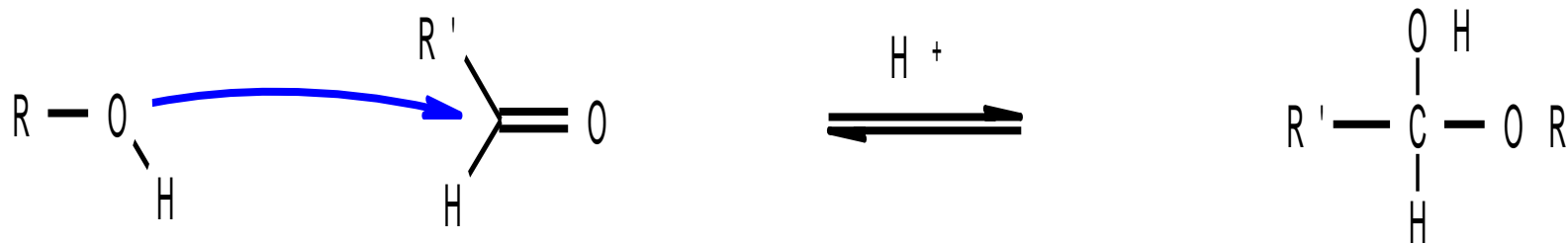
The second alkyl group stabilizes the carbocation making it less reactive (i.e. δ^+ is smaller)

Reactions of Aldehydes & Ketones

The following pages will deal with the nucleophilic addition reactions to carbonyl groups based on the nature of the nucleophile.

Alcohols: Hemiacetals & Acetals

The oxygen atom of the alcohol is nucleophilic.

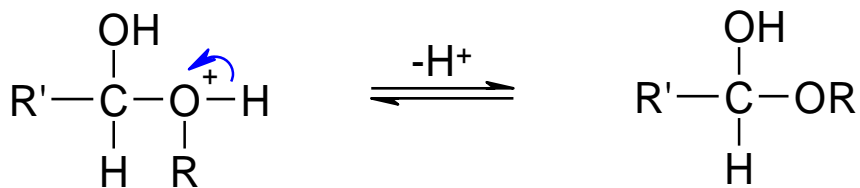
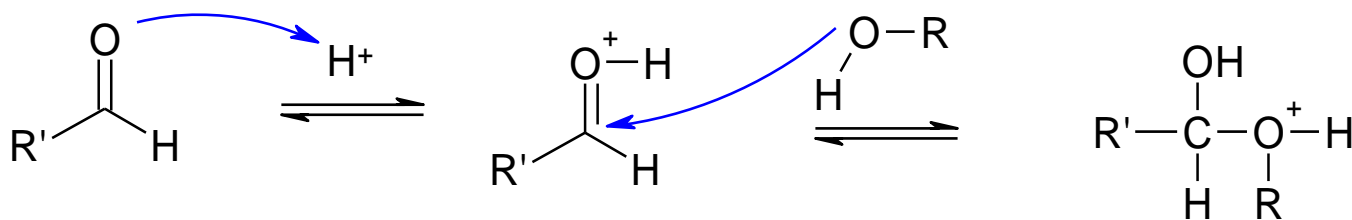


Note: need to use an acid catalyst as ROH is a weak nucleophile.

reaction is reversible

Alcohols: Hemiacetals & Acetals

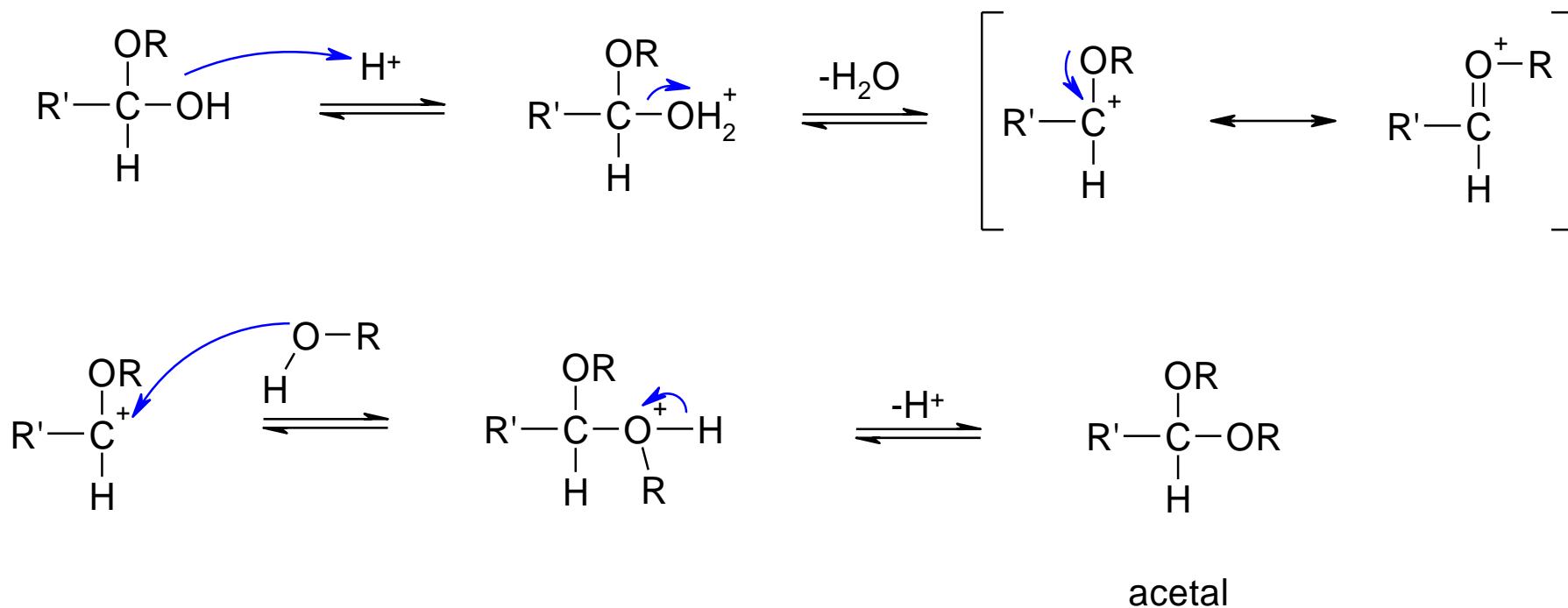
The mechanism is:



hemiacetal

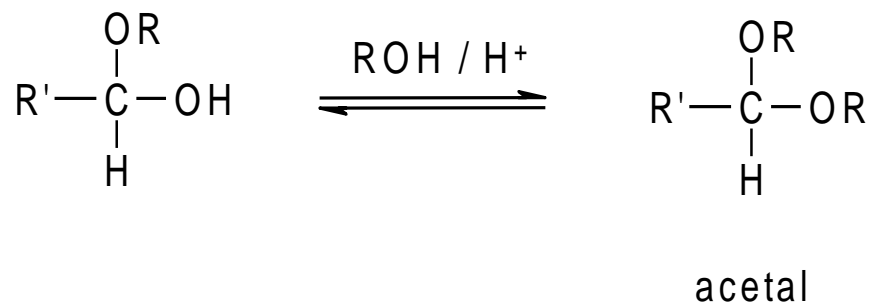
Alcohols: Hemiacetals & Acetals

In the presence of excess alcohol the hemiacetal can react one more time to product an acetal, i.e.



Alcohols: Hemiacetals & Acetals

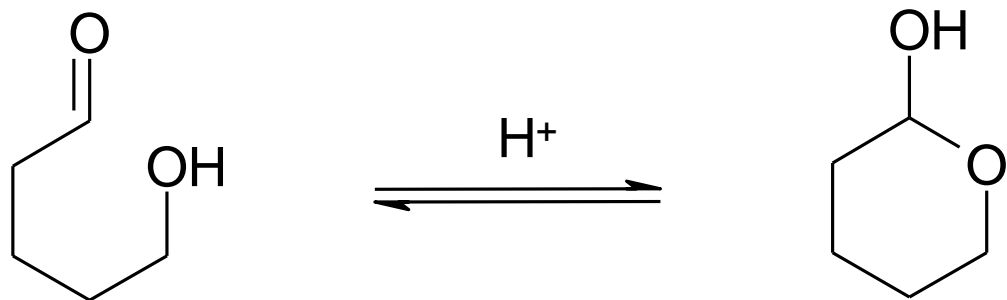
The overall reaction is:



Note: the mechanism is an $\text{S}_{\text{N}}1$

Alcohols: Hemiacetals & Acetals

The reaction can occur intramolecular if a hydroxy group is present, i.e.

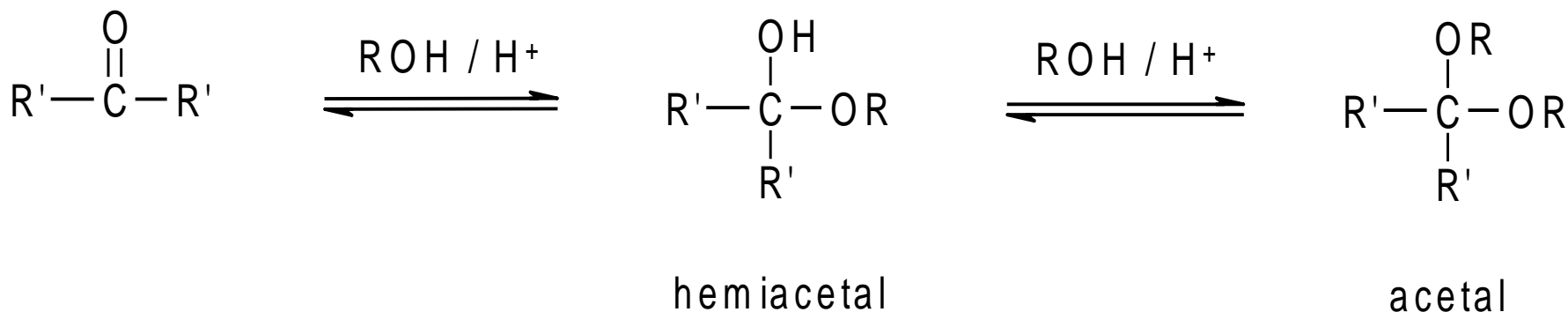


cyclic hemiacetal

Sugars do this naturally, very common for 5 or 6 membered rings

Alcohols: Hemiacetals & Acetals

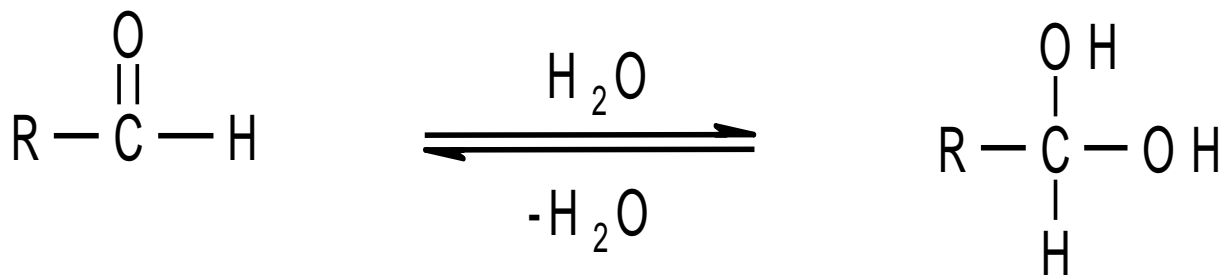
Ketones react the same way, i.e.



Note: an older convention called these a hemiketal and ketal
the reaction is easily reversed

Water: Hydrates or Gem Diols

This is a reversible reaction, i.e.



Gem diols are not stable and will lose the H_2O to reform the more stable carbonyl group.

Organometallic Reagents

Organometallic reagents are sources of carbon nucleophiles.

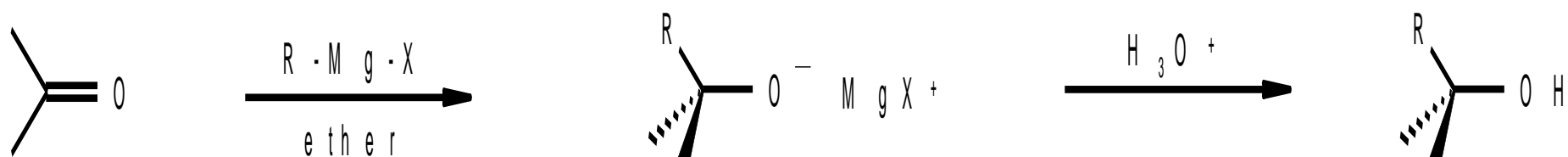
They are strong nucleophiles (and bases) and produce irreversible reactions.

Products are alcohols, depending on the substrate:

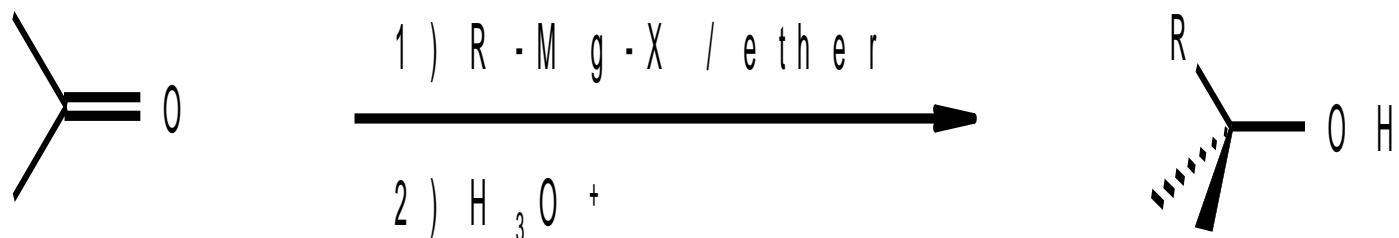
- Formaldehyde \Rightarrow 1° alcohol
- Other aldehydes \Rightarrow 2° alcohol
- Ketones \Rightarrow 3° alcohols

Organometallic Reagents

Grignard reagents:

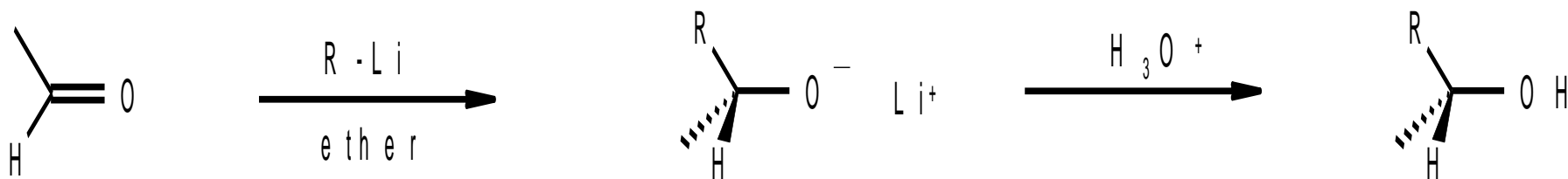


or

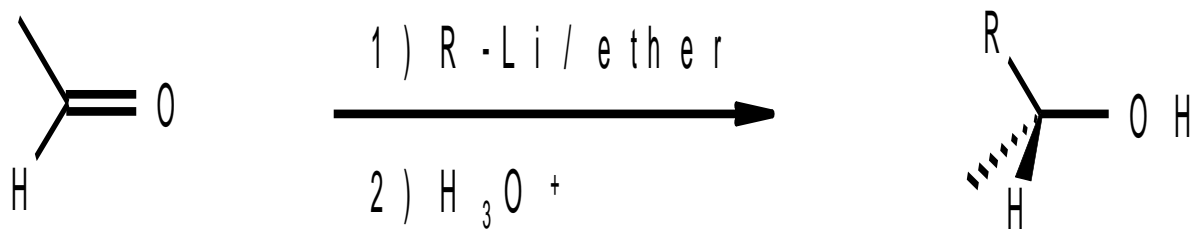


Organometallic Reagents

Organolithium reagents:

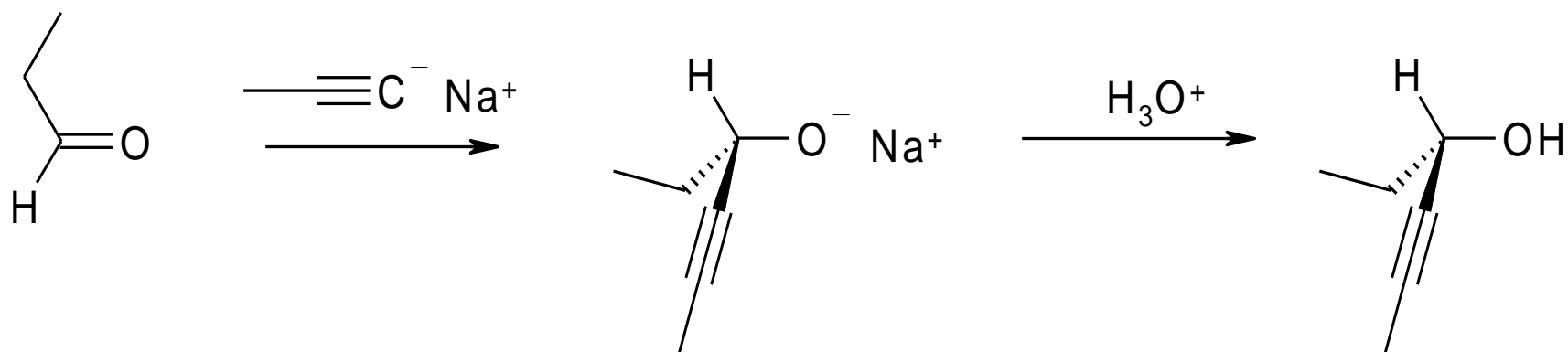


or

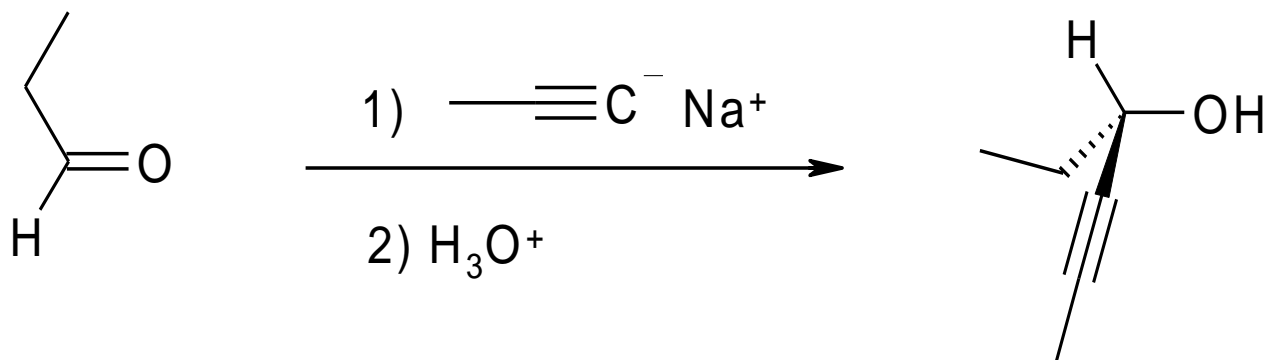


Organometallic Reagents

Acetylide reagents:



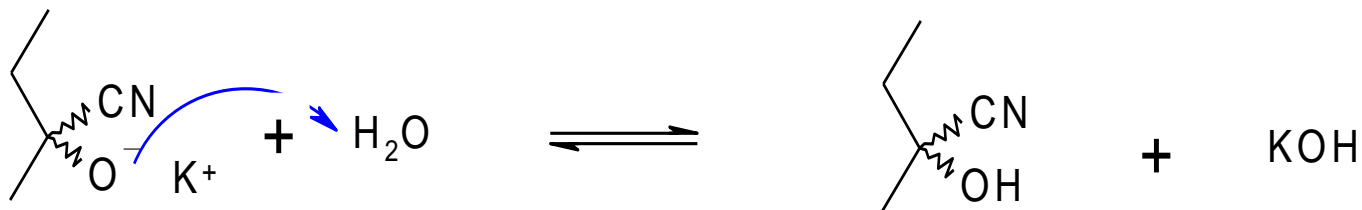
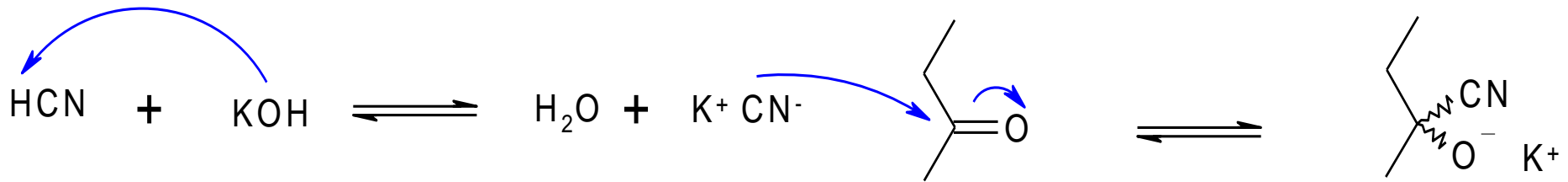
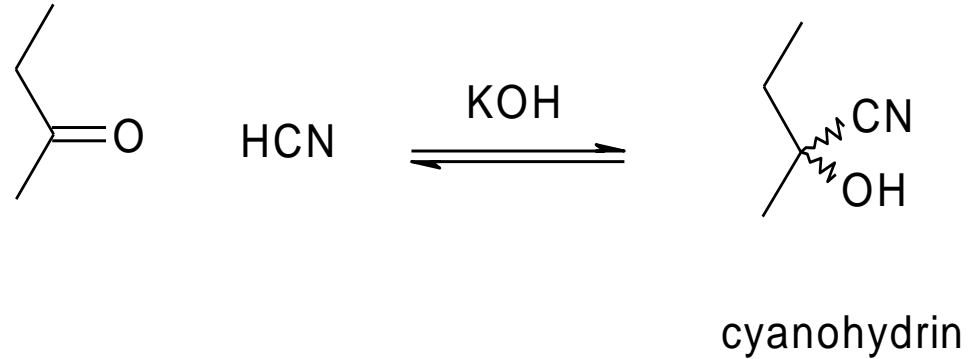
or



Cyanide: Cyanohydrins

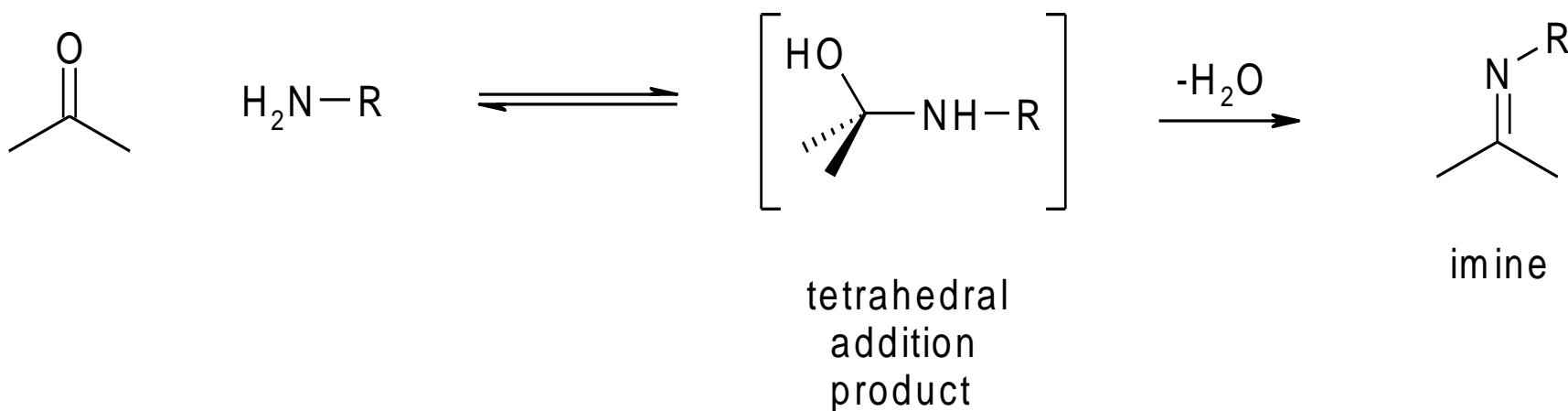
Reversible reaction, i.e.

Mechanism:



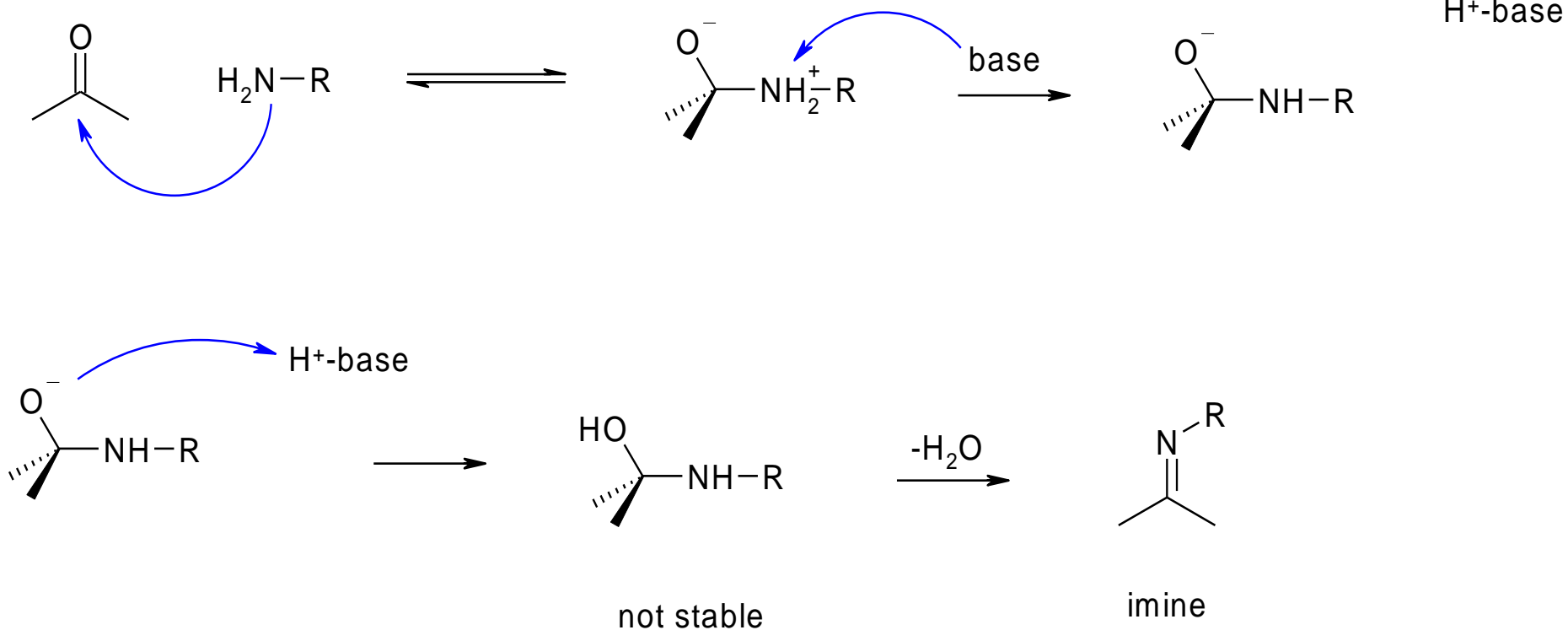
Nitrogen Nucleophiles

Amines are nucleophilic due to the lone pair of electrons. The reaction is irreversible overall and produce an imine, i.e.



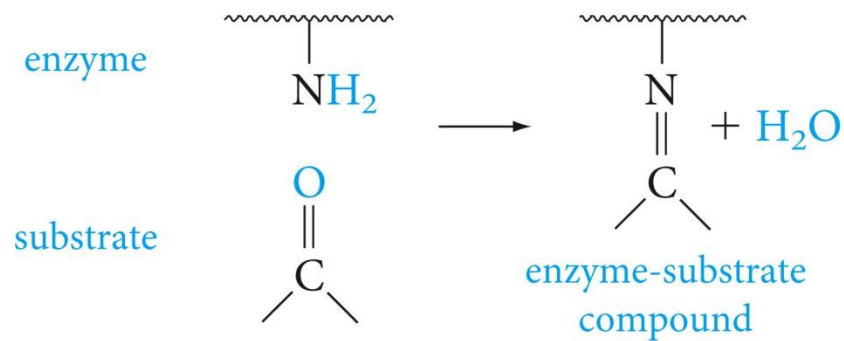
Nitrogen Nucleophiles

Mechanism:



Nitrogen Nucleophiles

Imines are important in biology as intermediates in some biochemical reactions, i.e.



All reactions have a common feature, the loss of a water molecule, the 2 H atoms from the amino group and the O atom from the carbonyl.

Nitrogen Nucleophiles

A number of different “imine” type compounds are possible depending on the nature of the nitrogen group, i.e.

Formula	Name	Derivative	Name
RNH_2 or ArNH_2	1° amine	$\text{C}=\text{NR}$ or $\text{C}=\text{Nar}$	Imine
NH_2OH	Hydroxylamine	$\text{C}=\text{NOH}$	Oxime
NH_2NH_2	Hydrazine	$\text{C}=\text{NNH}_2$	Hydrazone
$\text{NH}_2\text{NHC}_6\text{H}_5$	phenylhydrazine	$\text{C}=\text{NNHPh}$	phenylhydrazone

These derivatives have been use in the past for structure identification purposes.

Reduction of Carbonyls

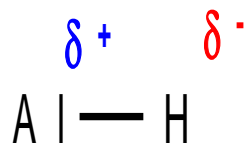
Aldehydes and ketones can be reduced to 1° and 2° alcohols respectively.

Common reducing agents are:

- Lithium aluminium hydride: LiAlH_4
- Sodium borohydride: NaBH_4

Reduction of Carbonyls

In both cases the metal – hydrogen bond is polarized so that the electron density is on the H atom, i.e.

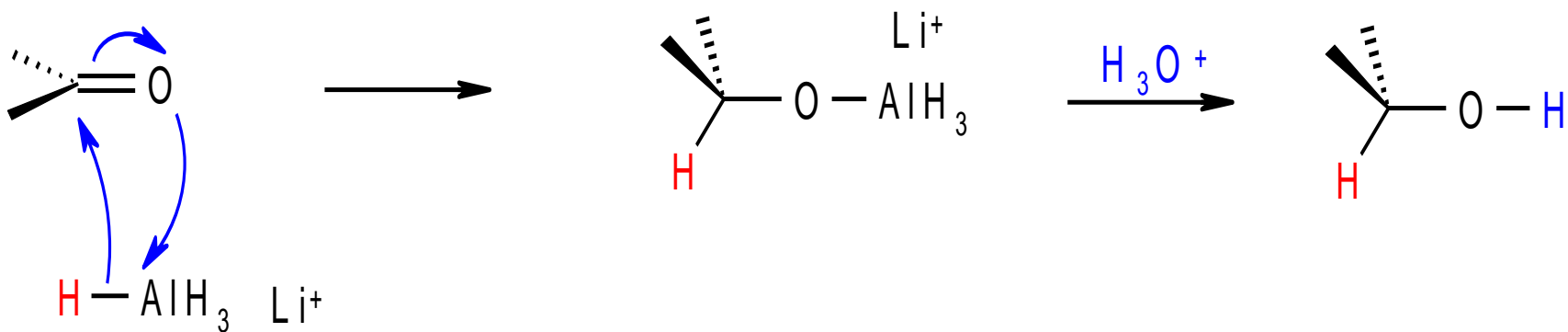


Both reagents act as hydride (H^-) donors, which is a nucleophile (and very strong base).

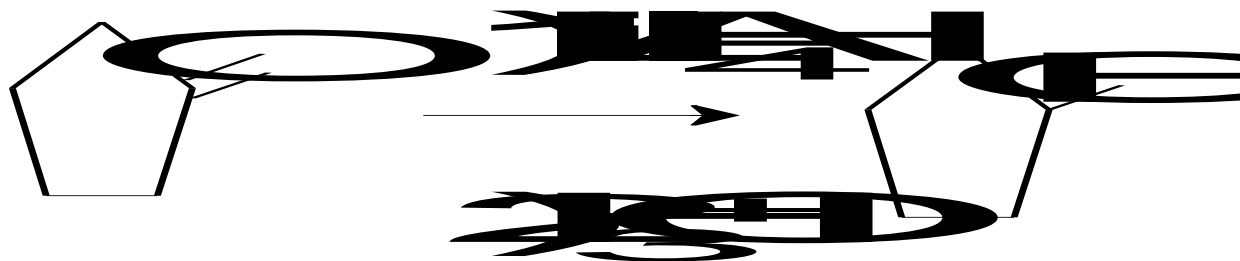
Note: NaBH_4 is a “milder” reagent and can be used in alcohol solvents while LiAlH_4 cannot.

Reduction of Carbonyls

The reaction mechanism is:

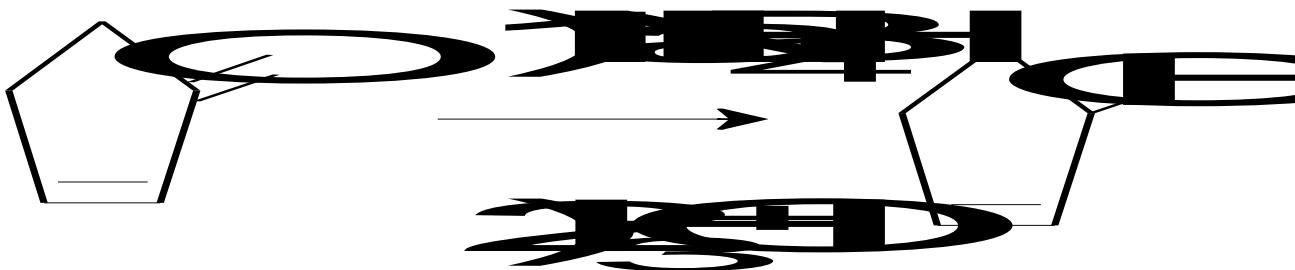


Or more commonly:



Reduction of Carbonyls

Neither of these reducing agents will affect a C=C π bond, so you can selectively reduce a carbonyl group without affecting the alkene or alkyne, but the reverse is not true, catalytic hydrogenation will affect carbonyl groups.



Oxidation of Carbonyls

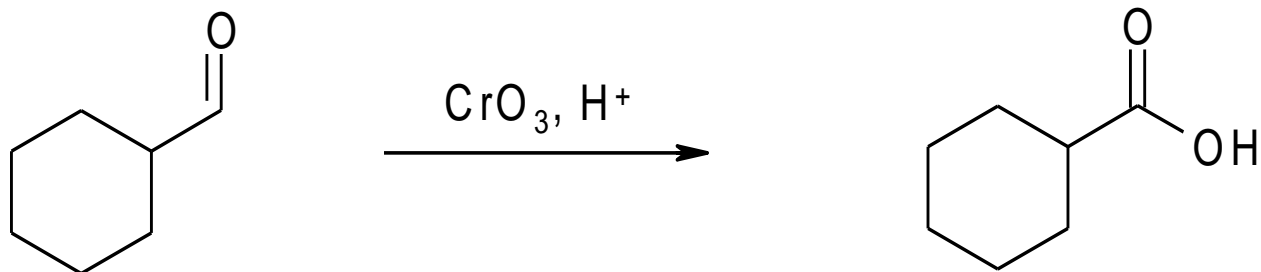
Aldehydes are more easily oxidized than ketones.

Common oxidizing reagent include:

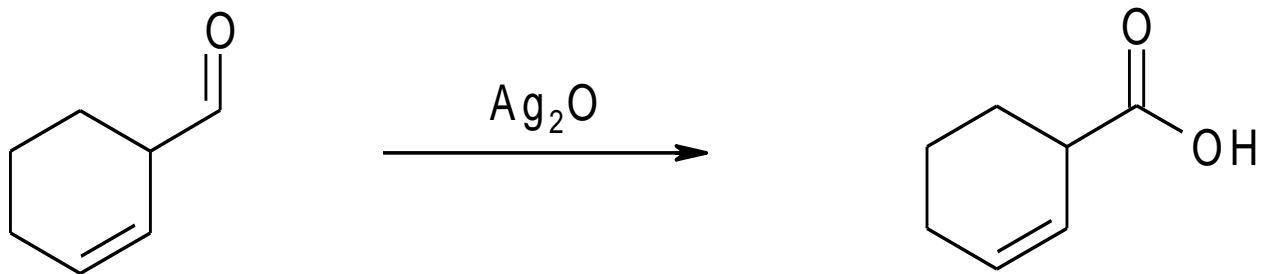
- CrO_3 , H^+ (Jones' reagent), KMnO_4 , Ag_2O and peracids
- KMnO_4 and peracids can reacts with $\text{C}=\text{C}$ π bonds

Oxidation of Carbonyls

i.e.

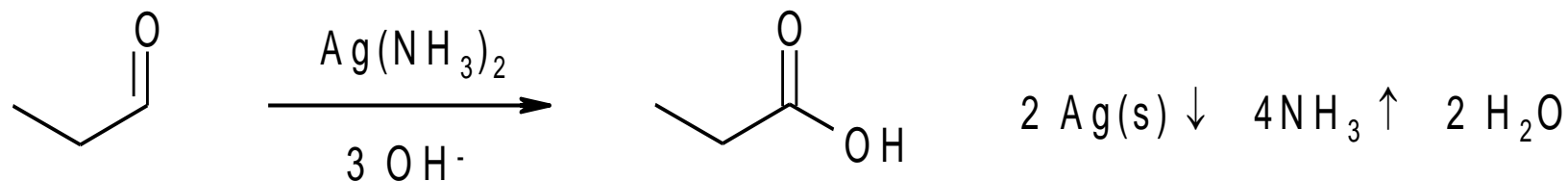


Note: Ag_2O is good if $\text{C}=\text{C}$ π bonds are present as it will not oxidize them, i.e.



Oxidation of Carbonyls

Tollen's Test: relies on the easy oxidization of aldehydes as a test.

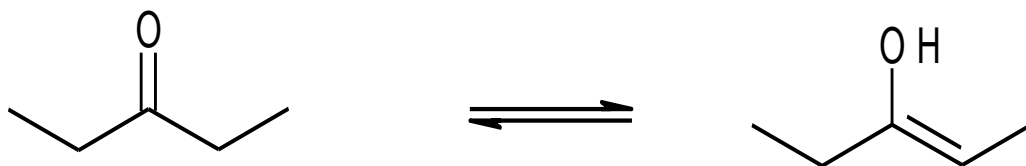


The silver deposits on the glass surface of a clean test-tube.



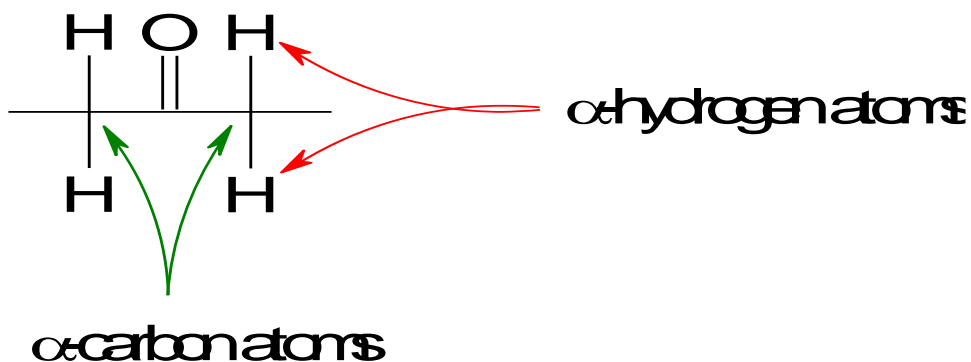
Enols

Keto-enol tautomerism: these are structural isomers not resonance structures.



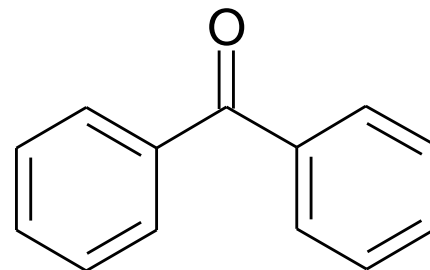
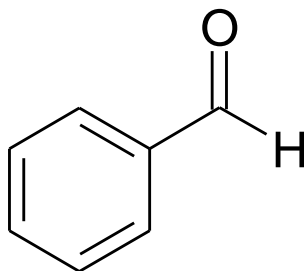
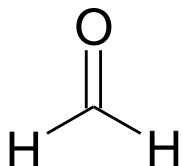
The keto form is much more stable as the C=O bond is stronger.

To have a tautomer possible there needs to be an α -hydrogen atom.



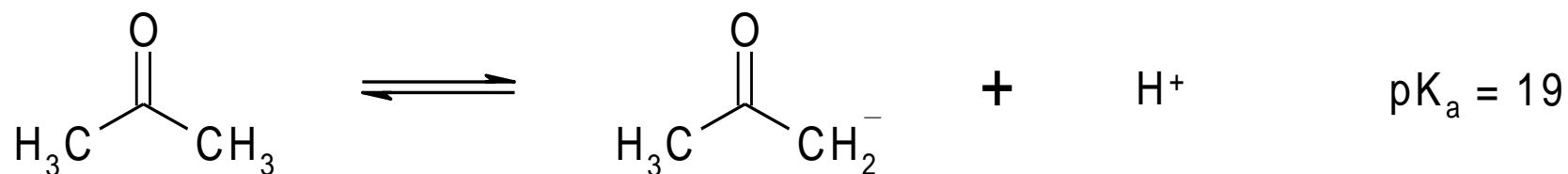
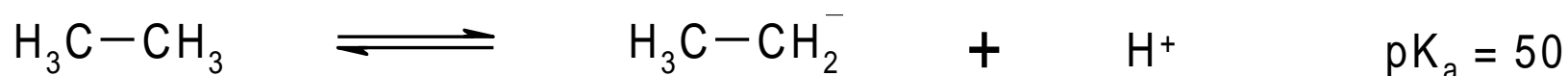
Enols

Keto-enol tautomerism: some compounds only exist in the keto form as they have no α -hydrogen atoms. i.e.



Enols

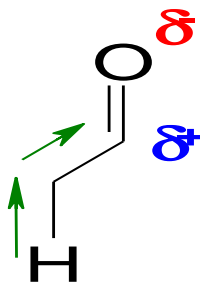
Acidity of the α -hydrogen atoms: much more acidic than a normal alkane type H atom, i.e.



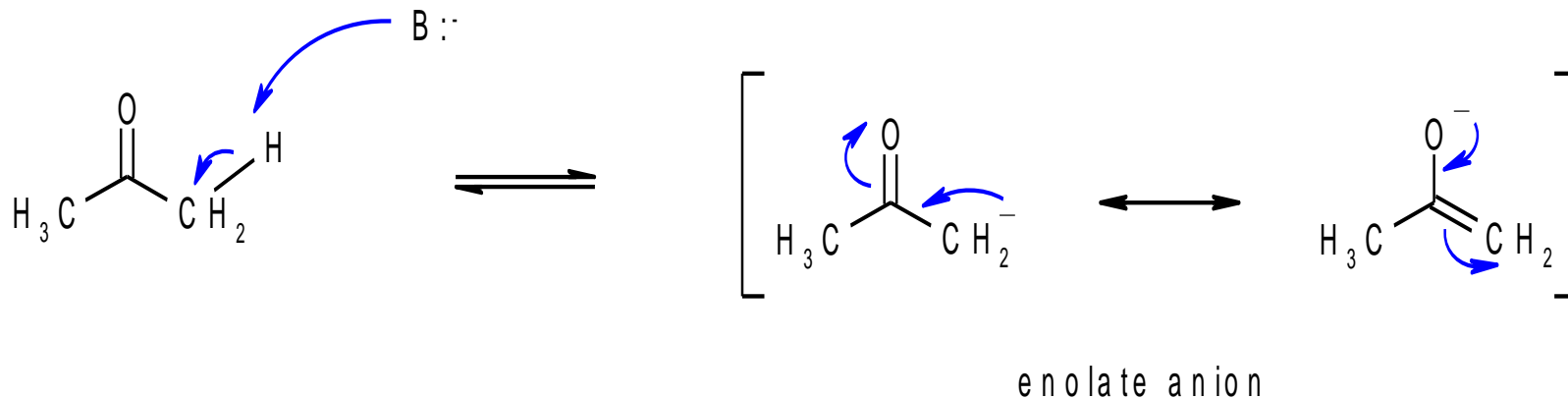
Enols

The increased acidity is a results of:

1. Inductive electron withdrawal by the carbonyl group



2. Resonance stabilization of the anion

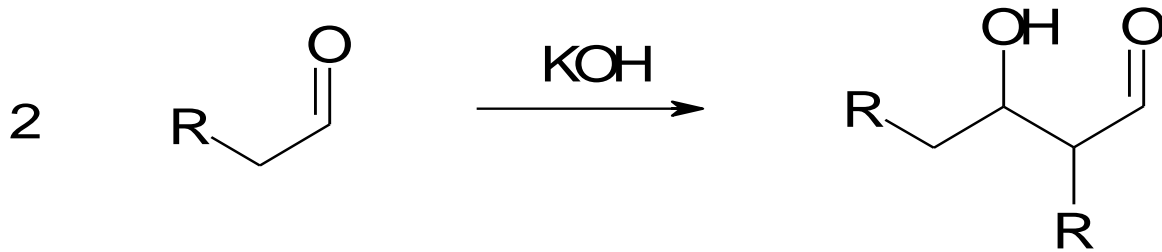


Aldol Condensation

The Aldol condensation makes use of the acidity of an α -H in aldehydes and ketones to combine two molecules together.

Enolates act as a C nucleophile (carbanion).

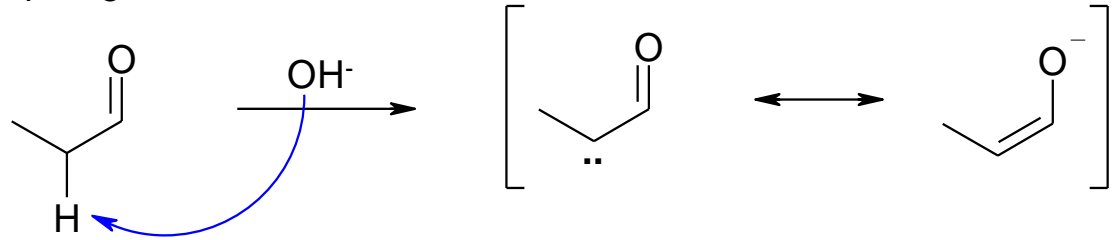
Product is a β -hydroxyaldehyde or ketone, i.e.



Aldol Condensation

The mechanism is:

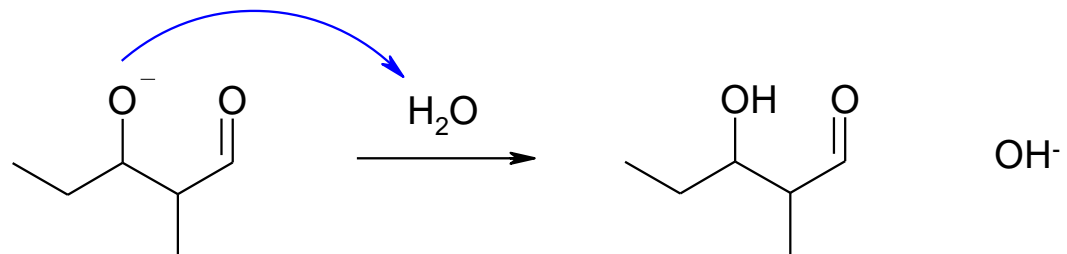
step 1: generate the enolate



step 2: nucleophilic attack by the enolate

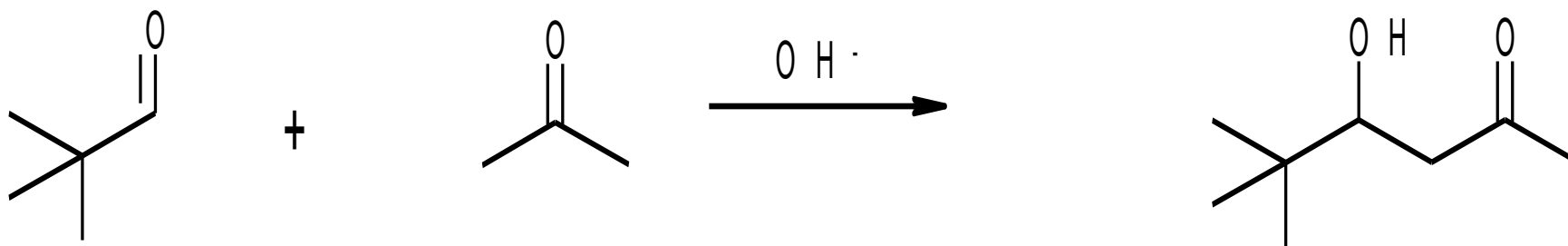


step 3: protonate the oxide



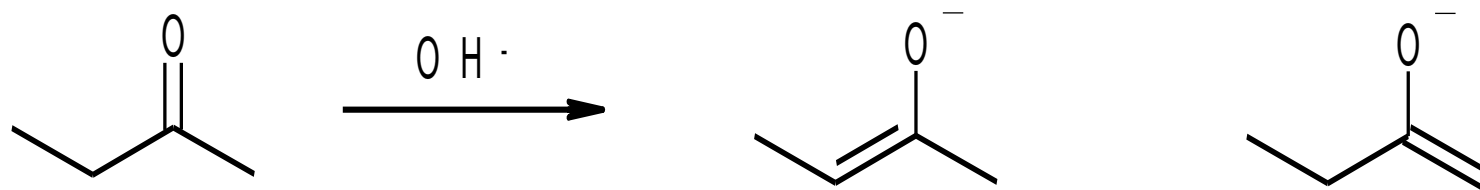
Aldol Condensation

The previous example is the condensation of two aldehydes (or ketones). A similar process can be done between two different aldehydes, but now we have to make sure only one can form an enolate or there will be a mixture of products, i.e.



Aldol Condensation

Note: ketones need to be symmetric or you could form two different enolates, i.e.



This reaction is used to synthesis a number of compounds commercially from acetaldehyde: crotonal, butanal, butanol...

Aldol Condensation

Heating the β -hydroxyaldehyde or ketone product, or the use of an acid catalyst, will cause the loss of a water molecule (an elimination reaction) to form a conjugated C=C bond, i.e.

