PROPERTIES Section - 2

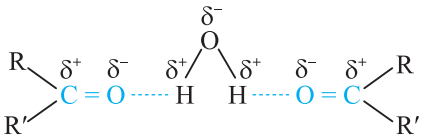
Physical Properties :

1. **State :** Methanal is a gas at room temperature. Ethanal is a volatile liquid. Other aldehydes and ketones are liquid or solid at room temperature.

2. **Boiling point :** The boiling points of aldehydes and ketones are higher than hydrocarbons and ethers of comparable molecular masses. It is due to strong molecular association in aldehydes and ketones arising out of the dipole-dipole interactions. But, their boiling points are lower than those of alcohols of similar molecular masses due to absence of intermolecular hydrogen bonding. The following compounds of molecular masses 58 and 60 are ranked in order of increasing boiling points.

	b.p. (K)	Molecular Mass
n-Butane	273	58
Methoxyethane	281	60
Propanal	322	58
Acetone	329	58
Propan-1-ol	370	60

3. **Solubility :** The lower members of aldehydes and ketones such as methanal, ethanal and propanone are miscible with water in all proportions, because they form hydrogen bond with water.



However, the solubility of aldehydes and ketones decreases rapidly on increasing the length of alkyl chain. All aldehydes and ketones are fairly soluble in organic solvents like benzene, ether, methanol, chloroform, etc.

Chemical Properties :

Aldehydes and ketones show quite a variety of chemical reactions. The carbon atom in carbonyl (keto) group shows a strong electrophillic character. The reactions are classified into Nucleophillic addition, Condensation, Reduction and Oxidation and other special reactions.

Tautomerism :

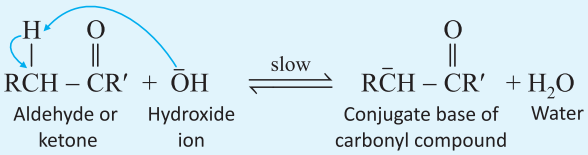
The process by which an aldehyde or ketone is converted to the corresponding enol is called enolization, or keto-enol tautomerism. Tautomerism refers to an interconversion between two structures which differ by the placement of an atom or group.

The mechanism of enolization involves two separate proton-transfer steps rather than a one-step process in which a proton jumps from carbon to oxygen. Enolization is relatively slow in neutral solution, but can be catalyzed by either acids or bases.

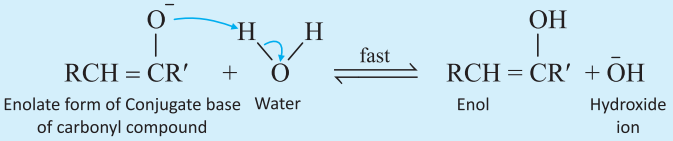
Base-Catalyzed Enolization of an Aldehyde or Ketone in Aqueous Solution

The base-catalyzed mechanism follows naturally from the behavior of aldehyde and ketones in basic solution. The reaction begins (step 1) with proton abstraction from the α–carbon to give an enolate. The negative charge in the enolate is shared by the α–carbon and oxygen. The proton transfer to oxygen (step 2) gives the enol.

Step 1 : A proton is abstracted by hydroxide ion from the α-carbon atom.



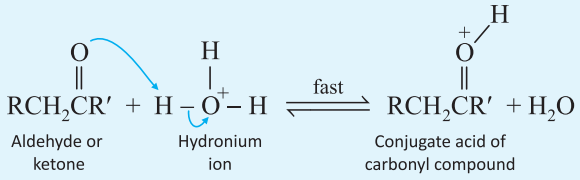
Step 2 : A water molecule acts as Bronsted acid to transfer proton to the oxygen of the enolate ion.



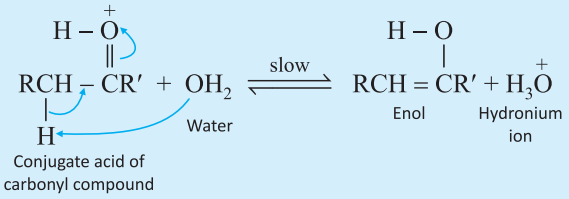
Acid-Catalyzed Enolization of an Aldehyde or Ketone in Aqueous Solution

The first step in the acid-catalyzed mechanism is protonation of the carbonyl oxygen by the acid catalyst. Protonation of the carbonyl oxygen increasing the acidity of the α hydrogen allowing it to be removed by a neutral and weakly basic solvent molecule in the second step. The product is the enol.

Step 1 : A proton is transferred from the acid catalyst to the carbonyl oxygen.

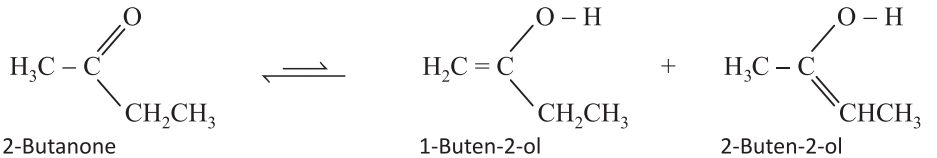


Step 2 : A water molecule acts as Bronsted base to remove proton from the α-carbon atom of the protonated aldehyde or ketone.



Both mechanisms ; acid-catalyzed and base-catalyzed consist of two proton transfer steps: proton abstraction from carbon and proton transfer to oxygen. The amount of enol present at equilibrium, the *enol content*, is quite small for simple aldehydes and ketones.

In most of the cases, the keto form is more stable than the enol by some 45–60 kJ/mol (11–14 kcal/mol). The main reason for this difference is that a carbon–oxygen double bond is stronger than a carbon–carbon double bond. Observe that in case of 2-Butanone, there will be two enol forms due to two different types of α-carbon.



Factors favouring the Kinetic Enolate or Enol :

1. Aprotic solvents. e.g. THF, Et_2O
2. Strong bases which generate a weak conjugate acid
3. Low temperature
4. Short reaction time

Factors favouring the Thermodynamic Enolate or Enol :

1. Protic solvent
2. Weaker bases which provide a relatively strong conjugate acid
3. Higher temperature
4. Long reaction time

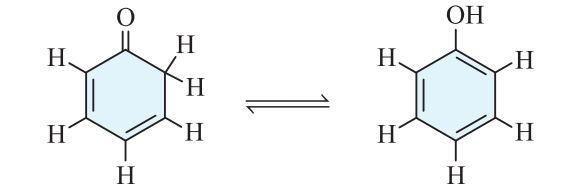
The more substituted enolate/enol is not always the thermodynamically more stable enolate ; in some cases steric hinderance can destabilise the more substituted enolate : thus in these cases the kinetic and thermodynamic enolate are the same product.

The keto form is thermodynamically more stable and enol form cannot normally be isolated. In certain cases, however, a larger amount of the enol form is present, and it can even be the predominant form. Such as :

1. Molecules in which the enolic double bond is in conjugation with another double bond.
2. Molecules that contain two or three bulky aryl groups. In these cases steric hinderance destabilizes the keto form.

Stabilized Enols :

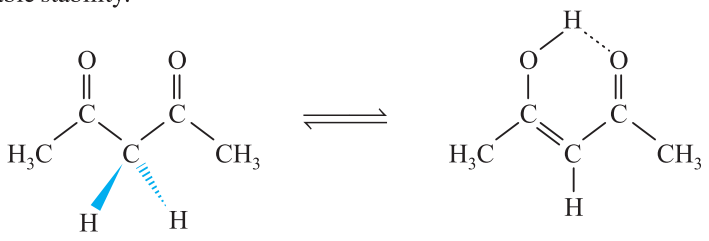
Certain structural features can make the keto–enol equilibrium more favorable by stabilizing the enol form. Enolization of 2, 4-cyclohexadienone is one such example:



2, 4-Cyclohexadienone (keto form; not aromatic) ⇌ Phenol (enol form; aromatic)

The enol form is phenol, and the stabilization gained by forming an aromatic ring is more than enough to overcome the normal preference for the keto form.

The 1, 3 arrangement of two carbonyl groups in β-diketones leads to a situation in which the keto and the enol forms are of comparable stability.



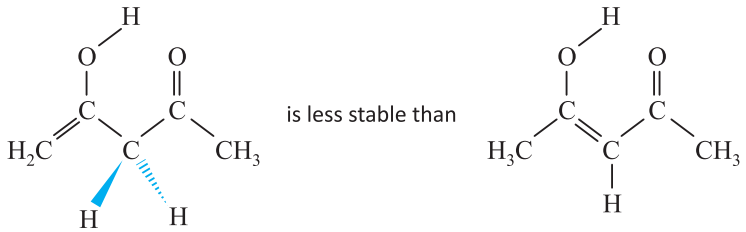
2, 4-Pentanedione (keto form) ⇌ 4-Hydroxy-3-pentene-2-one (enol form)

The two most important structural features that stabilize the enol of a β-dicarbonyl compound are :

1. Conjugation of its double bond with the remaining carbonyl group, and
2. Intramolecular hydrogen bond between the –OH group and the carbonyl oxygen

Both of these features are apparent in the above structure of the enol of 2, 4-pentanedione.

Observe that another enol of the same compound is less stable, because it does not have conjugation.

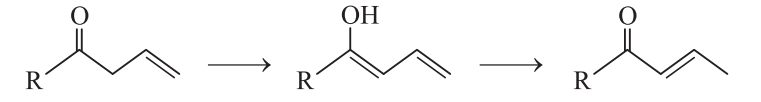


The enol content of some carbonyl compounds is as follows :

Carbonyl Compound	% Enol content	Carbonyl Compound	% Enol content
Acetone	6×10^{-7} %	$(CH_3)_2CHCHO$	1.4×10^{-2} %
$PhCOCH_3$	1.1×10^{-6} %	Ph_2CHCHO	9.1%
CH_3CHO	6×10^{-5} %	CH_3COCH_2COOEt	8.4%
Cyclohexanone	4×10^{-5} %	$CH_3COCH_2COCH_3$	80%
Butanal	5.5×10^{-4} %	$PhCOCH_2COCH_3$	89.2%

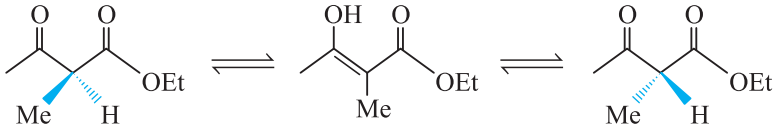
Consequence of Enolization :

1. Unsaturated carbonyl compounds prefers to be conjugated. It is difficult to keep a β, γ-unsaturated carbonyl compound because the double bond tends to move into conjugation with the carbonyl group in the presence of traces of acid or base. The intermediate is an enol in acid solution but an enolate ion in base.



β, γ-unsaturated carbonyl compound — α, β-unsaturated carbonyl compound

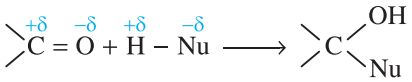
2. Any stereogenic centre next to a carbonyl group will be destroyed by enolization. Such compounds racemizes quickly.



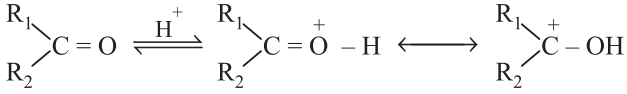
Optically pure d-isomer — Planar, achiral enol — Optically pure ℓ-isomer

(A) Nucleophillic Addition Reactions :

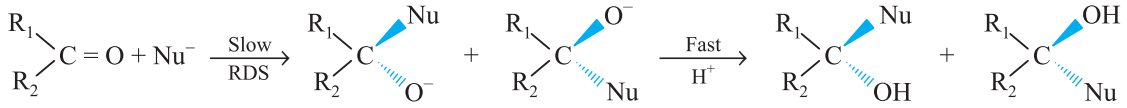
The most characteristic reactions of aldehydes and ketones are nucleophillic additions to carbon oxygen double bond via electromeric effect induced by nucleophile,



Aldehydes and ketones are susceptible to the nucleophilic addition because of the high polarity of C = O bond and the structural feature of carbonyl group (planar). Due to trigonal planar shape of carbon in carbonyl group, it is relatively open to nucleophilic attack from above or below. The positive charge on carbonyl atoms means that it is susceptible to the attack of a nucleophile. The negative charge on oxygen atom indicates that nucleophillic addition is susceptible to acid catalysis.



Mechanism of Nucleophilic Addition Reaction :



Note : **(i)** Reaction is catalysed by small amount of dil. acid as the protonation of oxygen increases the electrophilicity of carbonyl group.

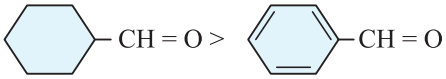
(ii) Also notice change in hybridization state of carbonyl carbon atom from sp^2 to sp^3.

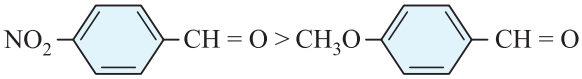
(iii) In case of aldehyde other than formaldehyde and unsymmetrical ketone, racemic mixture of product is formed during nucleophilic addition reaction of carbonyl compounds.

Factors Affecting Reactivity :

(i) **Electronic Factors :** Higher the electrophilicity of carbonyl group (i.e. $\delta+$ charge on carbonyl carbon) higher the reactivity. Electrophilic character increases due to presence of electron withdrawing group and decreases due to presence of electron releasing group on carbonyl carbon atom.

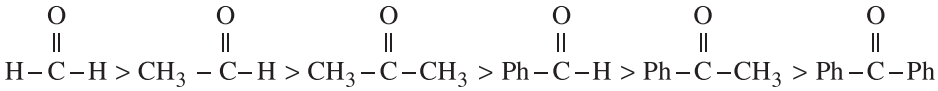
$$H-CH=O > CH_3-CH=O > CH_3-CO-CH_3$$ [+I effect of CH_3 –]


[+M effect of Ph –]


[–M effect of NO_2 – & +M effect of CH_3O –]

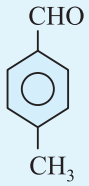
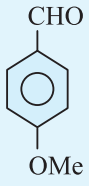
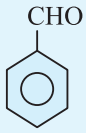
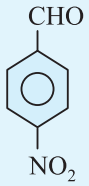
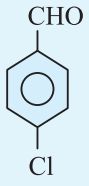
(ii) **Steric Factors :** Presence of bulkier groups or attack of bulkier nucleophile slow down rate of reaction because decrease in bond angles around carbonyl carbon atoms during product formation due to change in hybridization state of carbon form sp^2 to sp^3.

Considering the combined affect of the above mentioned factors following order of reactivity can be generalised:



Note : In general, ketones are less reactive in nucleophilic addition reactions as compared to aldehydes. Aldehydes have only one electron releasing alkyl group which disperses the positive charge on carbon to a lesser extent. Whereas, in ketones, there are two electron releasing alkyl groups which stabilise positive charge on carbon atom to a much greater extent. Apart from inductive effect, steric factor also plays some role. In ketones, the two alkyl groups at carbonyl carbon cause greater steric crowding in the addition product (having a tetrahedral structure) and make it less stable. For example, methyl tert. butyl ketone does not give nucleophillic addition reactions.

Illustration - 2 *Arrange the following in order of decreasing reactivity with respect to nucleophilic addition reaction.*

1. [I]  [II]  [III]  [IV]  [V] 

2. [I] CH_3COCH_3 [II] CCl_3COCH_3 [III] $CH_3COC_2H_5$ [IV] $CH_3COCH(CH_3)_2$ [V] $CH_3COC(CH_3)_3$

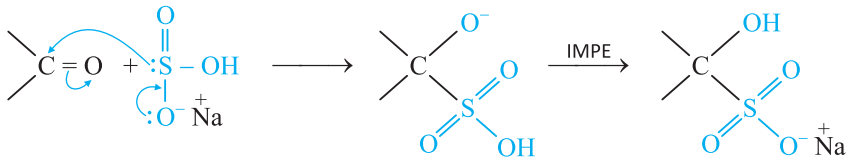
3. [I] HCHO [II] CH_3CH_2CHO [III] C_6H_5CHO [IV] $C_6H_5COC_6H_5$ [V] $C_6H_5CH_2CHO$

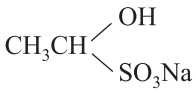
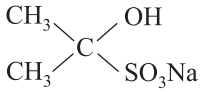
SOLUTIONS :

The case of nucleophilic addition in carbonyl compound depends upon electrophilic character of carbonyl carbon atom. This increases when EWG (–I/–M) are attached nearby to it and decreases when ERG (+I/+M) are attached near by it. In case of ketones, however large sized alkyl group also decreases reactivity due to steric crowding. On applying these concepts, the order of reactivity is observed to be as follows :

1. IV > V > III > I > II **2.** II > I > III > IV > V **3.** I > V > II > III > IV

1. Addition of $NaHSO_3$ (sodium bisulphite) : Attack of bisulphite takes place from sulphur, it being more polarisable due to less electronegativity.

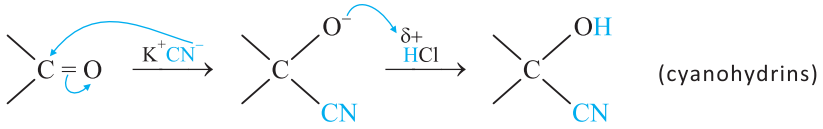


Acetaldehyde bisulphite   Acetone bisulphite

Bisulphite addition compounds are hydroxy sulphonic acid salts. These are crystalline solids insoluble in water. On heating with acidic and alkaline solutions carbonyl compounds are regenerated. Hence carbonyl compounds can be separated from other oxygen containing compounds as they don't react with bisulphites. So it serves as a method to separate, purify and preservation for carbonyl compounds. *Among the ketones, only acetone and cyclohexanone show this reaction*, as in sulphite addition products, there is lot of steric crowding, which makes products less stable. Also observe that acetophenone will also give this reaction as phenyl group does not cause any crowding.

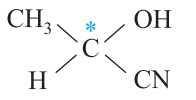
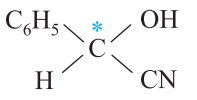
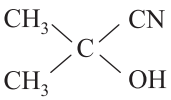
Note : Bisulphites $\xrightarrow{HCl/\Delta}$ ketones or aldehyde + SO_2 + NaCl + H_2O

2. Addition of HCN (Hydrogen cyanide) :



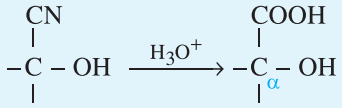
(cyanohydrins)

Note that avoid basic medium to avoid the reversibility of the above reaction.

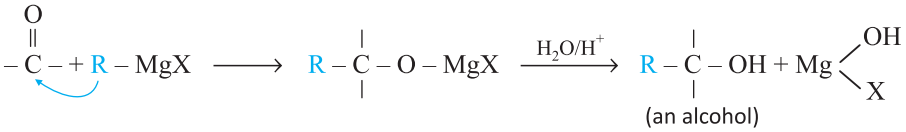
 Acetaldehyde cyanohydrin  Benzaldehyde cyanohydrin  Acetone cyanohydrin

Observe the chiral centre (*) in case of acetaldehyde and benzaldehyde.

Note : Cyanohydrins hydrolyse in acidic conditions to give α-hydroxy acids



3. Addition of Grignard Reagent (RMgX) :

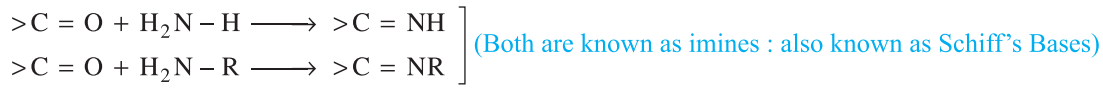


Read details of this reaction from "Chapter on Grignard Reagent" or from preparation of alcohols.

4. Addition of ammonia and its Derivatives :

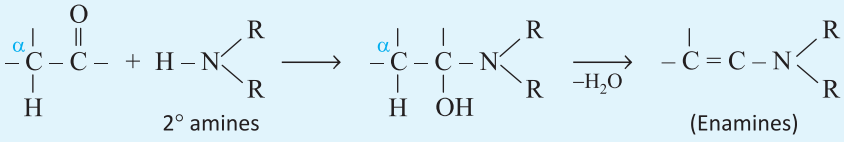
In this reaction there is nucleophilic addition followed by elimination of water. These reactions are acid catalyzed. For optimum yield of product reaction should takes place at pH = 4 – 5.

(i) of ammonia and 1° amines (RNH_2)

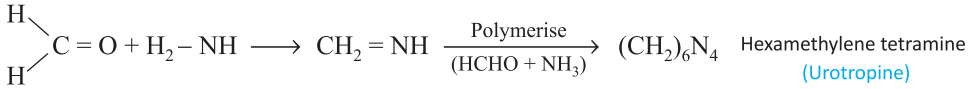


(Both are known as imines : also known as Schiff's Bases)

Note :
- RCH=NH are known as Aldimines (from aldehydes) and R_2C=NH are known as Ketimines (from ketones). Both aldehydes and ketones react similarly with primary (1°) amines to give imines.
- Aldehydes and ketones having α-hydrogen react with secondary amines (2°) to form enamines.

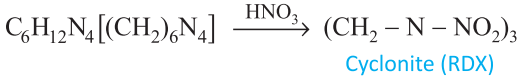


Note : Formaldehyde undergoes polymerisation with ammonia to give Urotropine (A kidney malfunctioning removing drug). Hexamethylene tetramine formed reacts with concentrated HNO_3 to give cyclonite (RDX).

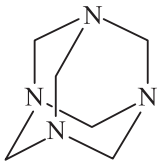


Hexamethylene tetramine (Urotropine)

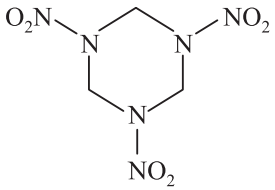
or $6\,HCHO + 4\,NH_3 \longrightarrow (CH_2)_6N_4 + 6H_2O$



Cyclonite (RDX)



(Urotropine)



Cyclonite (RDX)

(ii) of ammonia derivatives

(a) $CH_3CHO + H_2N-OH \longrightarrow CH_3CH=N-OH + H_2O$

acetaldehyde — hydroxylamine — acetaldoxime

$CH_3COCH_3 + H_2N-OH \longrightarrow (CH_3)_2C=NOH + H_2O$

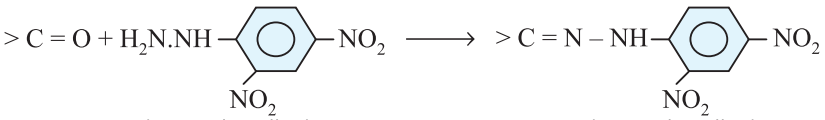
acetone — hydroxyl amine — acetoxime

(b) $>C=O + H_2N-NH_2 \longrightarrow >C=N-NH_2$

hydrazine — hydrazone

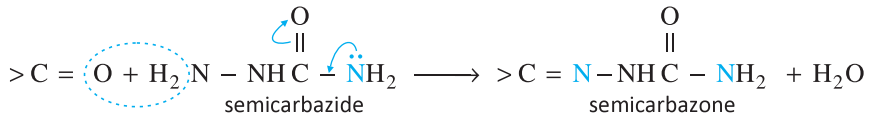
$>C=O + H_2N-NHC_6H_5 \longrightarrow >C=N-NHC_6H_5$

phenylhydrazine — phenylhydrazone



2, 4 - dinitro phenylhydrazine (Brady's reagent) — 2, 4 - dinitro phenylhydrazone (An orange precipitate)

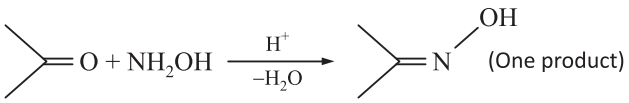
Note : The above reaction (formation of orange ppt.) is a standard Test for Aldehydes and Ketones differentiating them from other oxygen containing compounds.

(c) 

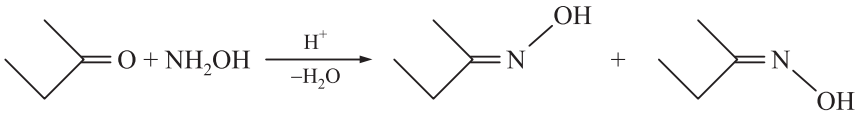
semicarbazide — semicarbazone

ℓp over this N-atom is in conjugation, so other NH_2 group will act as nucleophile.

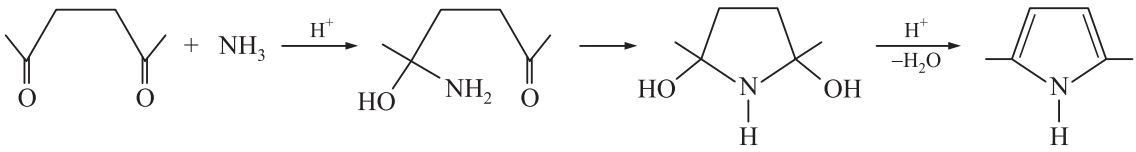
Some examples of reactions of ammonia derivatives.

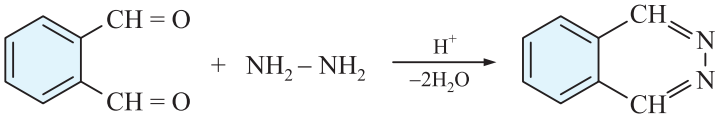


(One product)



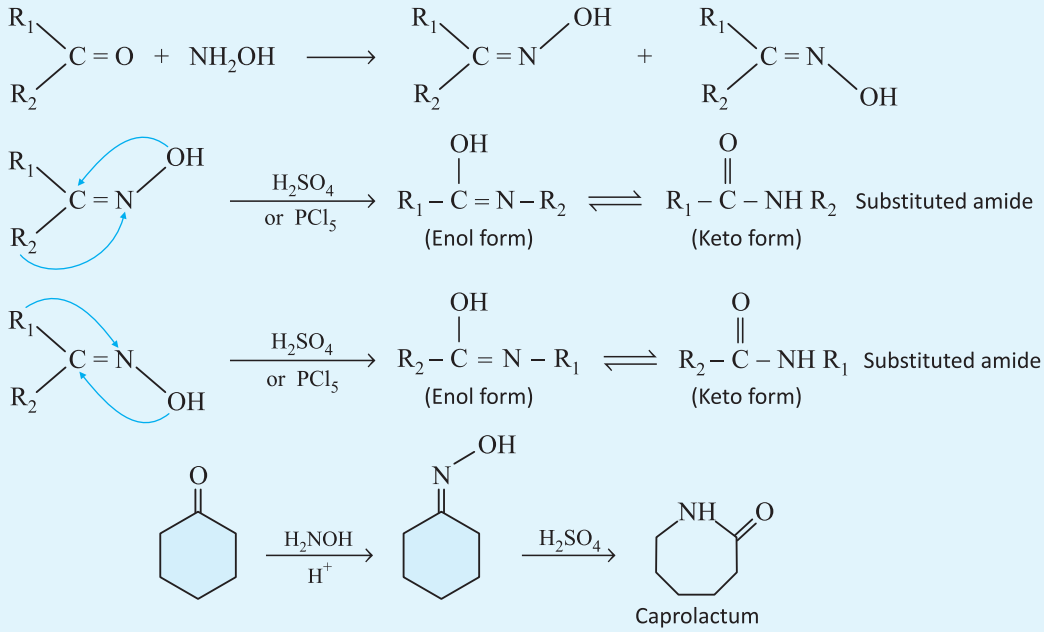
Two products due to geometrical isomerism





Beckmann Rearrangement :

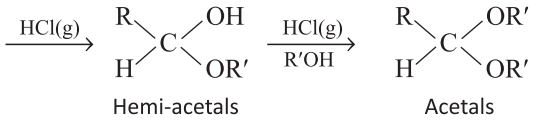
Oximes of carbonyl compounds show geometrical isomerism. They undergo rearrangement in presence of mineral acid, H_2SO_4 or Lewis acid, PCl_5 to give amides and substituted amides.



Note : 1. It is called Anti-Elimination as the group anti to –OH migrates from C to N-atom. For unsymmetrical ketone Beckman rearrangement is stereoselective.

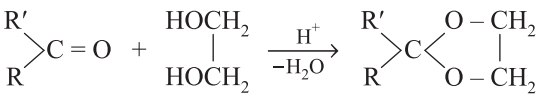
2. In case of an aldehyde, simple amides are formed. Try yourself by taking CH_3CHO and C_6H_5CHO.

5. Addition of Alcohols :



The products may be called as hemi-ketals and ketals, but chemists prefer to use hemiacetals and acetals for these also. Formation of hemiacetals and acetals is a reversible reaction. The equilibrium shifts to right i.e. favours acetals formation in presence of excess of alcohols. The acetals are isolated by neutralising the acid and evaporating the excess alcohol. If acetals are placed in water & small amount of acid is added, the acetals are converted back to aldehydes and ketones. The important aspect of this reaction is that acetals are stable in basic solutions. Acetals are not reduced by $LiAlH_4$/ether or any other reducing agent. Ketones undergo similar reaction with alcohols slowly because of less reactivity, however they can form cyclic acetals (ketals) with polyhydric alcohols (glycols) much easily.

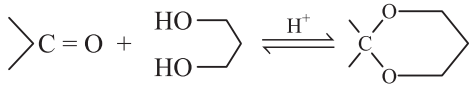
Note : Ketones and aldehydes form much stable cyclic ketals (or acetals) with excess of ethylene glycol.



(*Refer to the reaction of Glycols.*)

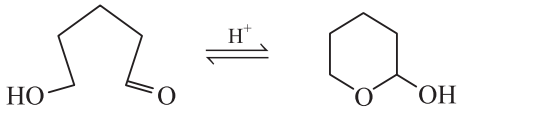
Hence aldehydes and ketones are protected from undesired reactions esp. in basic medium and from reduction.

Note : 1. Cyclic acetals can also be formed using 1, 3-propandiol.



1, 3-Propandiol Cyclic acetal

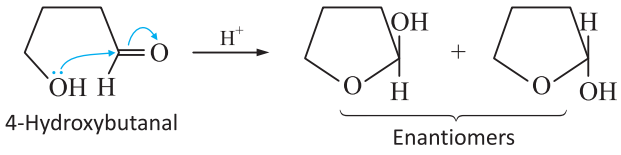
2. Usually Hemi-acetals are not stable except few cases shown below :



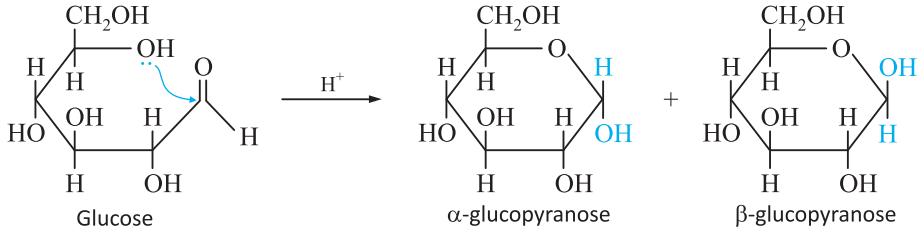
5-Hydroxypentanal Hemi-acetal (2-Hydroxypyran)

Try yourself :

Hydroxy aldehydes undergoes intramolecular hemiacetal or hemiketal formation.



4-Hydroxybutanal Enantiomers

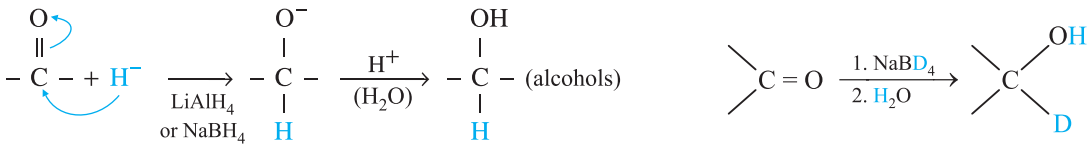


Glucose α-glucopyranose β-glucopyranose

Diastereomers

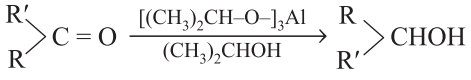
6. Addition of Hydride ion : (*Reduction*)

The important reducing agents used are : $LiAlH_4$/ether (known as LAH) ; $NaBH_4$/NaOH (or $NaBH_4/H_2O$) ; H_2/Pt



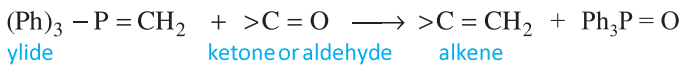
Note : **(i)** $LiAlH_4$ is powerful agent which reduces other groups such as : Acids to Alcohols ; Esters to Alcohols ; Cyanides to Amines etc., whereas $NaBH_4$ reduces only keto group to alcohols. Also note that both $LiAlH_4$ and $NaBH_4$ do not reduce double or triple bonds. $LiAlH_4$ reduces a carbon - carbon double bond in conjugation with phenyl ring.

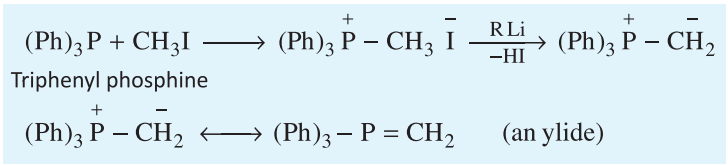
(ii) MPV Reduction (Meerwin – Ponndorf – Vereley) : The reduction of ketones can be affected by using aluminium isopropoxide in isopropyl alcohol solution. This is called as MPV reduction. Note that isopropyl alcohol is oxidised to acetone and then removed. The reducing agent used here is highly specific and used only for ketones.

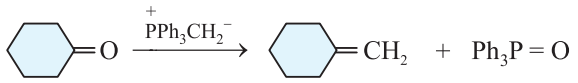


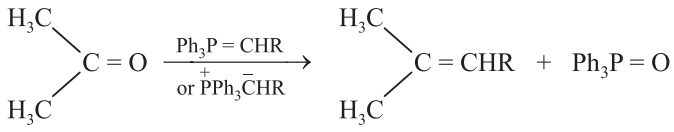
7. Addition of Ylides : (Wittig Reaction)

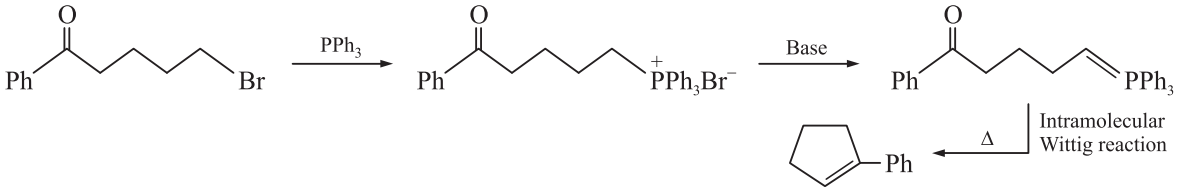
Trialkyl or triphenyl phosphines form quarternary phosphonium halides which on reaction with bases such as alkyl lithium produce strong nucleophiles known as ylides. Ylides react with keto group (both aldehydes and ketones) to give alkenes.





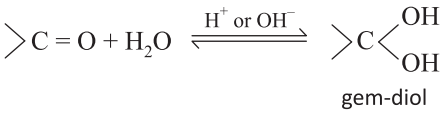


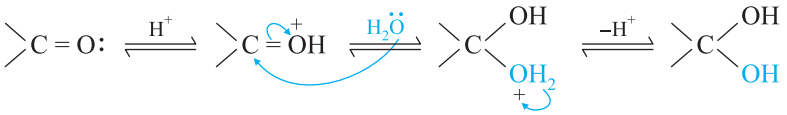




8. Addition of H_2O

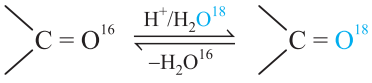
In aqueous solution, a ketone or an aldehyde is in equilibrium with its hydrate, a geminal diol. Hydration occurs through the nucleophilic addition mechanism, with water (in acid) or hydroxide ion (in base) serving as the nucleophile.

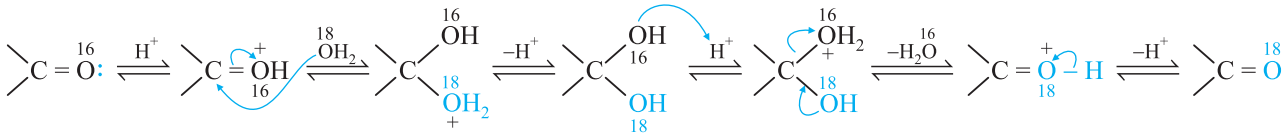




Gem-diol is unstable and loses water to form original compound.

Note : Observe the isotopic oxygen atom exchange in the given reaction :

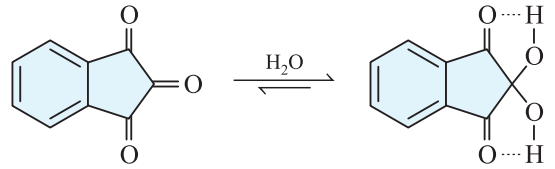




Note that the bond with heavier isotope is stronger.

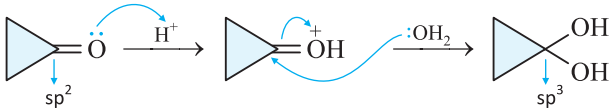
CCl_3CHO (chloral) forms stable hydrate due to –I effect (negative inductive effect) of chlorine and due to the formation of intra-molecular hydrogen bonds.

Indane-1, 2, 3-trione on nucleophilic addition of H_2O form ninhydrin.



Indane-1, 2, 3-trione (Stable gem diol) due to intramolecular H-bond (Ninhydrin)

Cyclopropanone also forms a stable hydrate.



Stable due to steric relief

9. Addition of Alkynes

Terminal alkynes (like $RC \equiv CH$) add on to carbonyl group in presence of alkoxide (RO^-) or amides (NH_2^-) forming alkynol (and alkynediol with $CH \equiv CH$). This is called ethinylation.

$$\overset{\delta+}{RC \equiv CH} + CH_3O^- \longrightarrow CH_3OH + RC \equiv C^- \quad (\text{as } Nu^-)$$

$$\overset{\delta+}{RC \equiv CH} + NH_2^- \longrightarrow NH_3 + RC \equiv C^- \quad (\text{as } Nu^-)$$

$$>C=O + R-C \equiv C^- \longrightarrow >C\begin{matrix} C \equiv C-R \\ O^- \end{matrix}$$ Addition product

$$HC \equiv CH + 2H-\overset{H}{\underset{|}{C}}=O \xrightarrow{CH_3O^-} HOH_2CC \equiv CCH_2OH$$

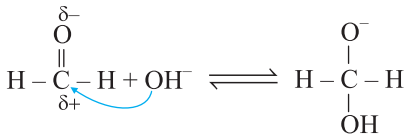
butyne diol

10. Cannizzaro Reaction : (Given by only Aldehydes with no 'α' hydrogen)

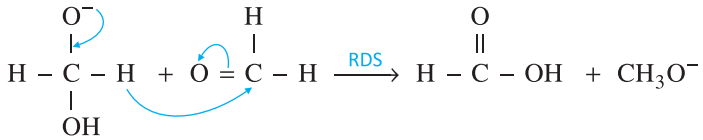
Aldehydes having no 'α' hydrogen, when heated with 50 % solution of NaOH (conc.), undergo "disproportionation reaction" known as Cannizzaro reaction. One molecule of aldehyde is oxidised to acid and the other is reduced to alcohol.

$$2H-\overset{O}{\overset{\|}{C}}-H \xrightarrow[\Delta]{NaOH} CH_3OH + H-\overset{O}{\overset{\|}{C}}-O^-Na^+$$

Mechanism : Observe that Cannizzaro reaction is third order reaction. $r = k\,[HCHO]^2\,[OH^-]$

(a) 

OH^- acts as a nucleophile and attacks carbonyl carbon in a typical 'Nu' addition reaction.

(b) 

'transfer of H^- (hydride) ion to other molecule is the RDS.

(c) $H-\overset{\overset{O}{\|}}{C}-OH + CH_3O^- \longrightarrow H-\overset{\overset{O}{\|}}{C}-O^- + CH_3OH$

Alkoxide (CH_3O^-), a strong base abstracts a proton from acid.

Note : Cannizzaro reaction is a third order reaction. $r = k\,[HCHO]^2\,[OH^-]$

Benzaldehyde does not have α hydrogen and hence it also gives Cannizzaro reaction.

$$2C_6H_5CHO + NaOH \xrightarrow{\Delta} \underset{\text{sod. benzoate}}{C_6H_5COO^-Na^+} + \underset{\text{benzyl alcohol}}{C_6H_5CH_2OH}$$

Note : Chloral is an aldehyde without α-Hydrogen atom but it does not undergoes Cannizzaro reaction.

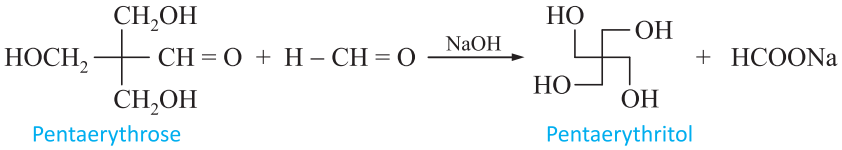
$$Cl_3C-CHO + NaOH \longrightarrow CHCl_3 + HCOONa$$

One molecule of benzaldehyde and one molecule of formaldehyde give *Cross-Cannizzaro reaction*, where formaldehyde is oxidised and benzaldehyde is reduced.

$$C_6H_5CHO + NaOH + HCHO \xrightarrow{\Delta} \underset{\text{Benzyl alcohol}}{C_6H_5CH_2OH} + \underset{\text{sod. formate}}{H-\overset{\overset{O}{\|}}{C}-\bar{O}Na^+}$$

Note : *In Cross-Cannizzaro reactions, involving HCHO, it is always oxidised and the other molecule gets reduced.*

Pentaerythrose and formaldehyde also undergoes Cross-Cannizzaro reaction to form pentaerythritol.



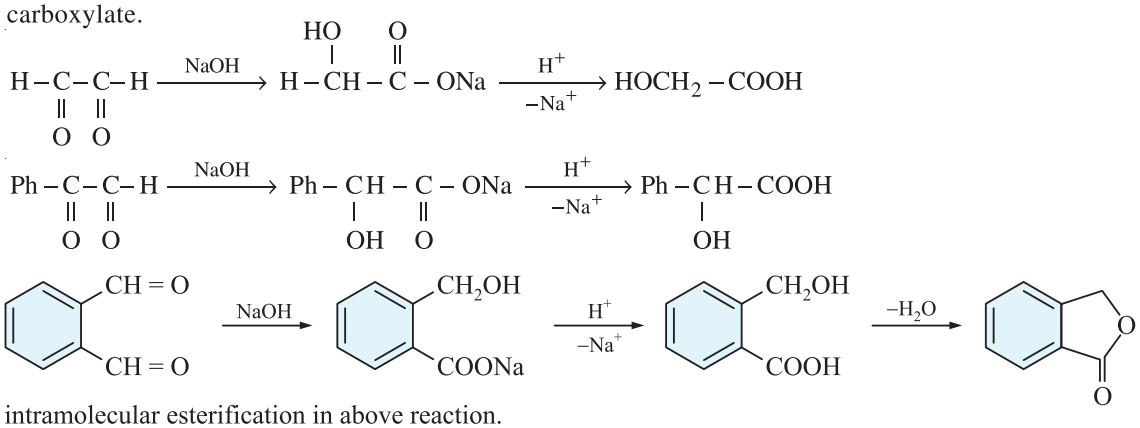
Pentaerythrose Pentaerythritol

Note : Generally, in Self-Cannizzaro reactions involving substituted benzaldehydes, one with an electron withdrawing group (–I/–M) at '*o*' and '*p*' positions react faster than those with an electron releasing group (+I/+H/+M) at '*o*' and '*p*' positions. Observe the decreasing rates of Cannizzaro reaction in given cases :

p-Nitrobenzaldehyde > Benzaldehyde > *p*-Methoxybenzaldehyde

Intramolecular Cannizzaro reaction :

Dialdehyde without α-hydrogen atoms on reaction with alkali undergoes intramolecular Cannizzaro reaction to form hydroxy carboxylate.



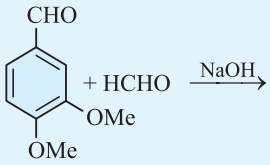
Note : Observe intramolecular esterification in above reaction.

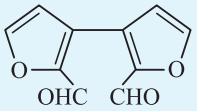
Try yourself :

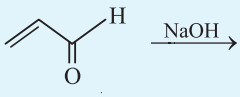
1. $2H-\underset{\underset{O}{\|}}{C}-D \xrightarrow{HO^{-}} {}^{18}$

2. $2H-\underset{\underset{O}{\|}}{C}-H \xrightarrow[D_2O]{DO^{-}}$

3. $D-\underset{\underset{O}{\|}}{C}-D \xrightarrow{OH^{-}}$

4. 

5. 

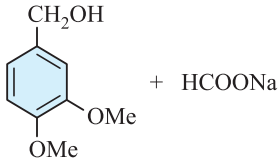
6. 

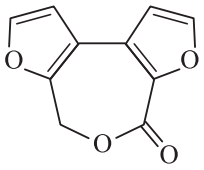
Ans :

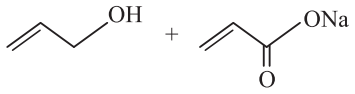
1. $D-\underset{\underset{O}{\|}}{C}-{}^{18}O^{-} + D-CH_2-OH$

2. $H-\underset{\underset{O}{\|}}{C}-O^{-} + CH_3-OD$

3. $D-\underset{\underset{O}{\|}}{C}-O^{-} + CD_3-OH$

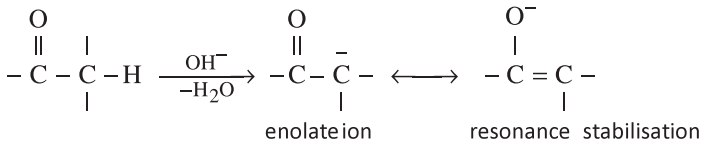
4. 

5. 

6. 

(B) Condensation Reactions :

An important nature of carbonyl compounds is unusual acidity of α-hydrogen atom (i.e., hydrogen atom adjacent to carbonyl group). Note that α-hydrogen are just more acidic than H atom in terminal alkene and alkynes. The reason of the acidity is the stability (due to resonance) of the anion formed (conjugate base), called as enolate ion, when carbonyl compounds loses α-hydrogen.



When the anion (carbanion) accepts a proton, it can do so by two different ways. It can accept the proton to form the original carbonyl compound to form keto form or it may accept the proton at oxygen to form enol form, hence the name enolate ion for the anion is given. The keto form is more stable than enol form and hence enol form tautomerises to keto form.

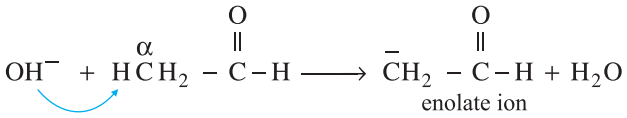
1. Aldol Reaction (Condensation) :

When aldehydes having an α-hydrogen react with dilute sodium hydroxide at room temperature, a dimerisation (condensation of two molecules) takes place producing the compounds containing both hydroxyl (OH) group and aldehyde (–CHO) group, called as al-d-ols. The aldols are β-hydroxy aldehydes. The mechanism of aldol reaction shows two characteristics of carbonyl compounds : the acidic nature of their α-hydrogen and tendency of their carbonyl group to undergo nucleophilic addition reactions.

$$\underset{\text{acetaldehyde}}{CH_3-\underset{\underset{O}{\|}}{C}H} + HCH_2-\underset{\underset{O}{\|}}{C}H \xrightarrow[10°C]{10\%\ NaOH} \underset{\text{3-hydroxybutanal (aldol)}}{CH_3-\underset{\underset{OH}{|}}{C}H-CH_2-\underset{\underset{O}{\|}}{C}H}$$

Mechanism :

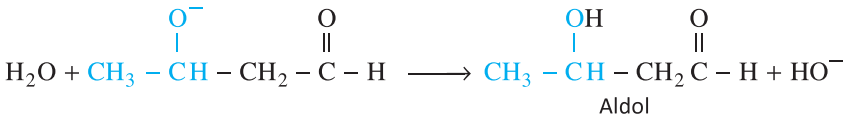
Step : I A base (hydroxide ion) removes a proton from α-carbon of one molecule of acetaldehyde to give a resonance stabilised enolate ion.



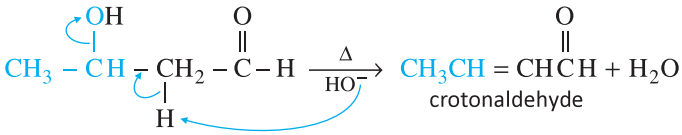
Step : II

The enolate ion then acts as a nucleophile (a carbanion) and attacks the carbonyl carbon of second molecule of acetaldehyde to form an alkoxide ion. Observe that the attack of enolate ion on the second aldehyde molecule is the rate determining step (RDS) in aldol condensation.

Step : III The alkoxide ion now removes a proton from a molecule of water to form aldol.

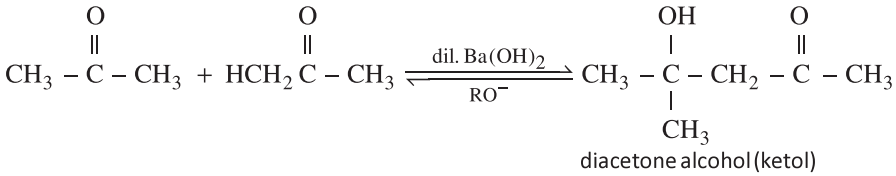


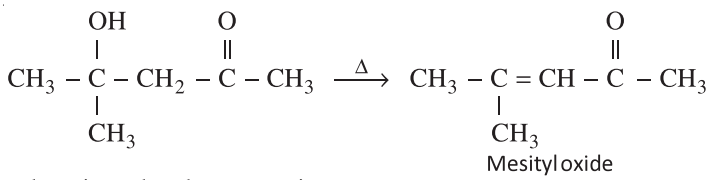
- If an aldol is heated, dehydration of aldol occurs giving (α-β) unsaturated aldehydes. The dehydration occurs easily because of the acidity of the remaining 'α' hydrogen and the high stability of the product due to conjugated double bonds. *It is a base catalysed dehydration* and proceed by E1cB reaction mechanism.



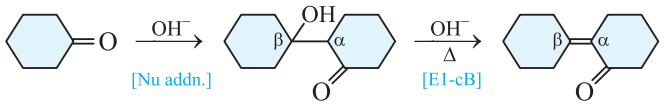
This is called as aldol condensation i.e., the formation of an unsaturated aldehyde.

- Ketones having α - hydrogen also undergo aldol condensation reaction like aldehydes to give a ketol. However this is a reversible reaction. The ketol formed gives back acetone if strong base such as alkoxide is used.

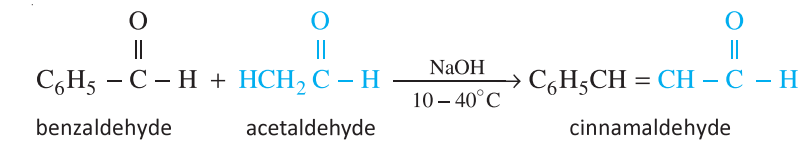


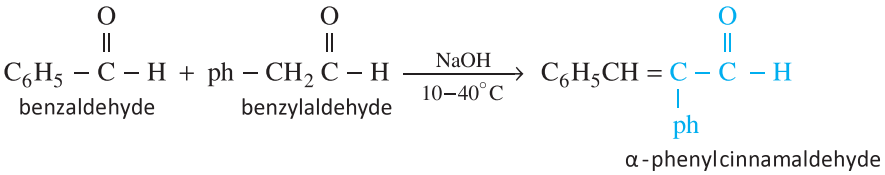


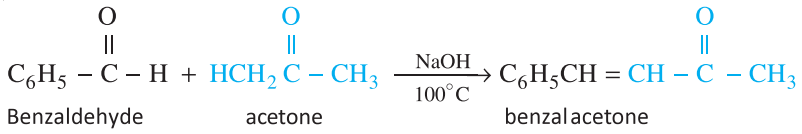
Cyclohexanone also gives the above reaction.

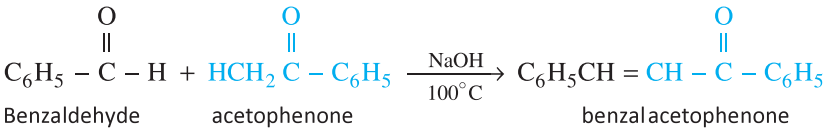


We take benzaldehyde as an aldehyde having no α hydrogen and the other compound may be any aldehyde and ketone.

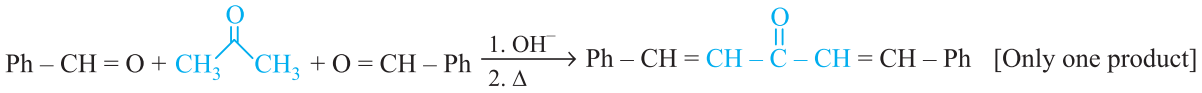








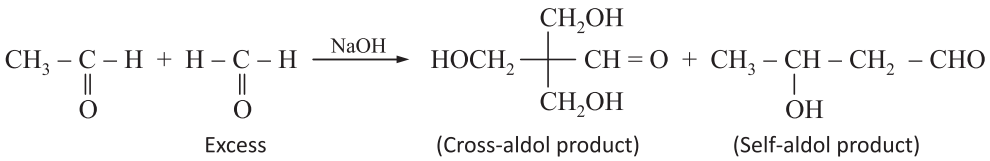
When two molecules of benzaldehyde are condensed with one molecule of acetone, Dibenzylideneacetone is formed.



Note : ➤ The same set of reactions (above) is also done with formaldehyde (HCHO) instead of benzaldehyde. It will give acrylaldehyde ($CH_2=CHCHO$) and its other derivatives.

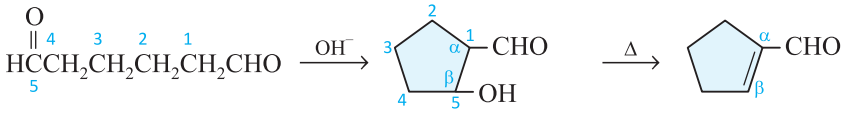
➤ If aldehydes and ketones are not present in 1 : 1 ratio then we will have a mixture of four products.

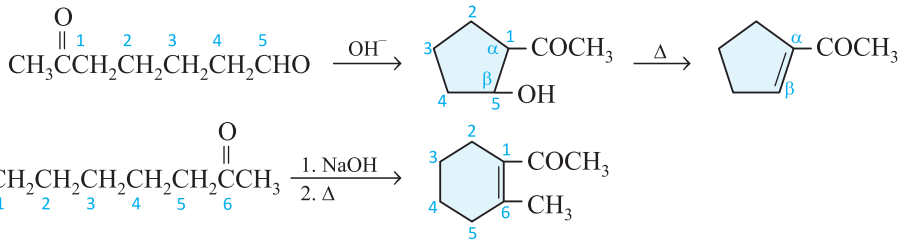
Acetaldehyde reacts with excess of HCHO to form pentaerythrose (cross product) and b-hydroxy butanal (self product)



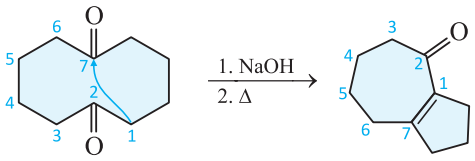
3. Intramolecular Aldol Condensation :

Using di-aldehydes, a keto - aldehyde or a di-ketone, one can bring an intramolecular aldol condensation to give a closed chain compounds having a ring of 5 – 6 members (C-atoms). It is generally enolate from ketone site of the molecule that adds to the aldehyde group on the other side of the chain. Consider some examples.



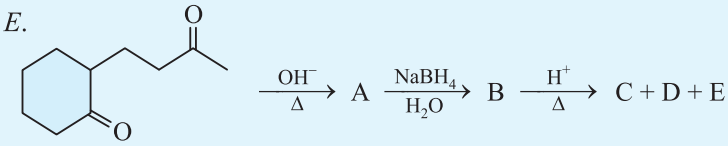


Cyclic diketone undergoes similar reaction to form bicyclic compounds.

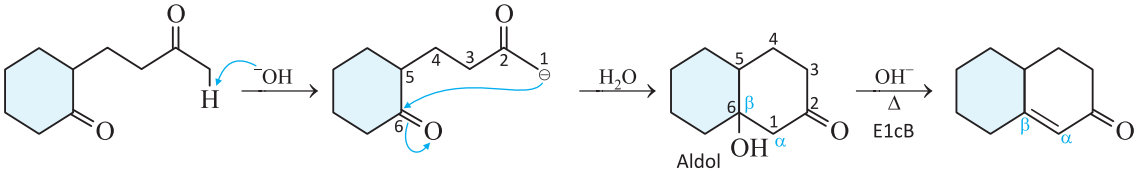


The reason that the aldehyde group undergoes addition preferentially is due to the greater reactivity of aldehyde towards nucleophillic addition generally.

Illustration - 3 *Identify the products A to E.*



SOLUTION : Visualising intramolecular '*aldol condensation*'.



Visualise the formation of allylic carbocation and its rearrangement to get three E1 products.

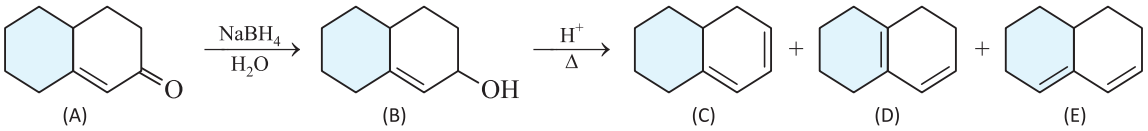
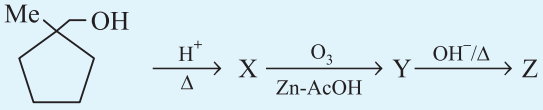
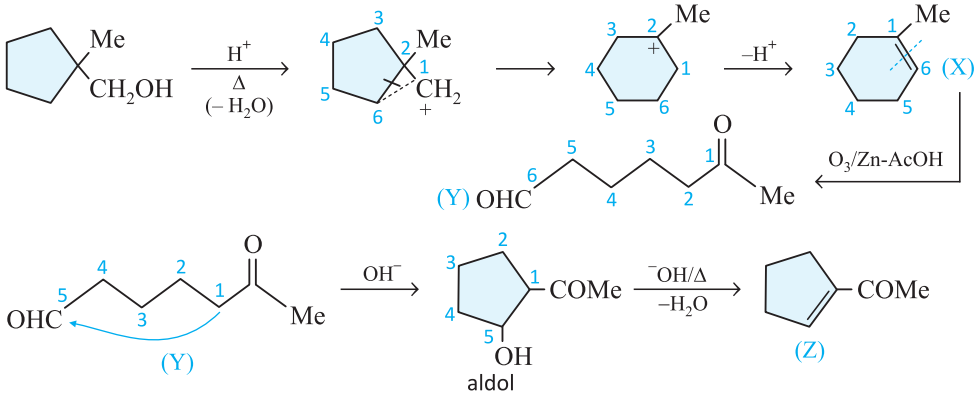


Illustration - 4 *Identify X, Y, Z in the following* :



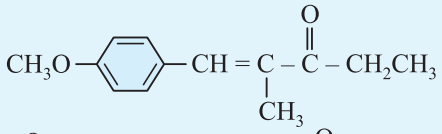
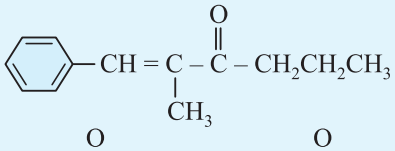
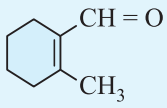
SOLUTION :



Visualise intramolecular aldol condensation

Illustration - 5 *Some of the following molecules can be synthesized in good yield using an aldol condensation.*

How *many of the following can be synthesized by aldol condensation* ?

1. 
2. 
3. 
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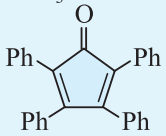
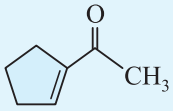
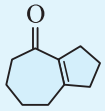
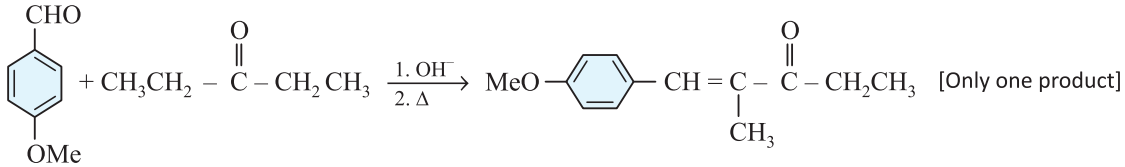
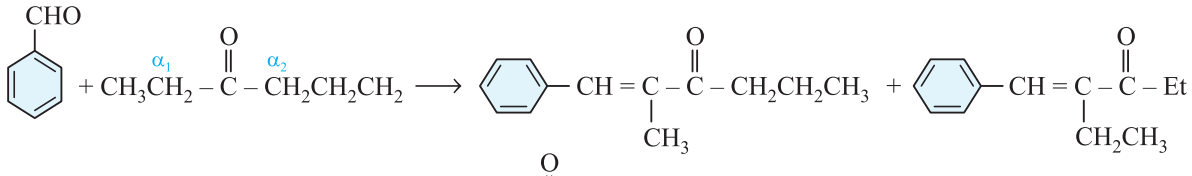
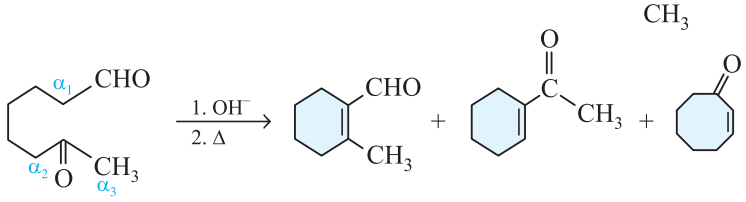
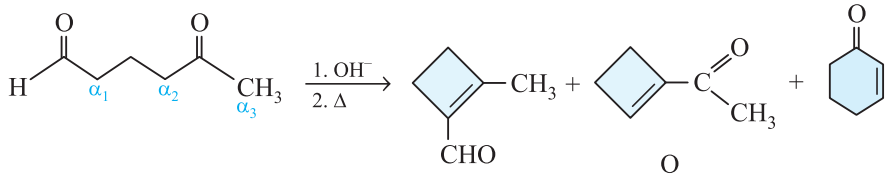
5. 
6. 
7. 
8. $(CH_3)_2C = CH - CH = O$

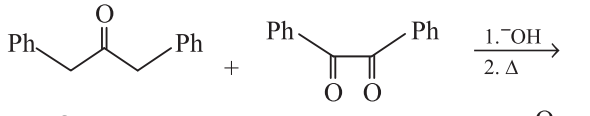
SOLUTION : Product of cross aldol condensation with aldehyde or ketone having two or more types of α - Hydrogen atoms will not be synthesized in good yield. In intramolecular aldol condensation 5 or 6 membered ring compound can be synthesized in good yield.

1. 
[Only one product]

2. 

3. 

4. 

5. 
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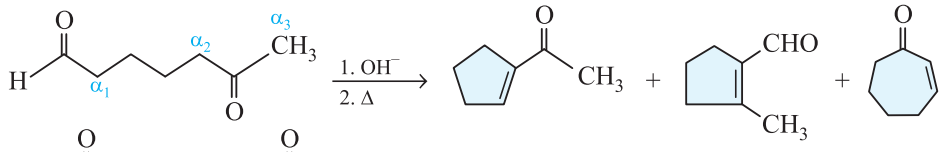
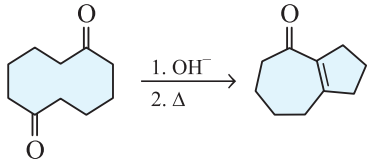
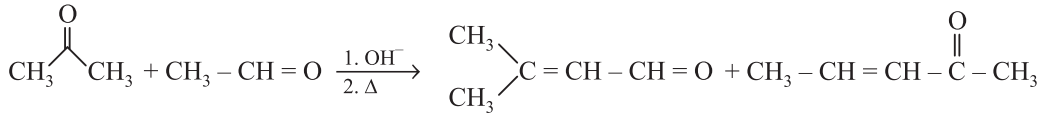
6. 

7. 
[Only one product]

8. 

Hence compounds 1, 4, 5 and 7 can be synthesized in good yield.

4. Tischenko Reaction : (only aldehydes)

Two molecules of aldehydes undergo condensation type reaction to give an ester when treated with aluminium ethoxide or isopropoxide. Note that benzaldehyde and formaldehyde will also give this reaction.

$$RCHO \xrightarrow{(C_2H_5O)_3Al} R-\overset{O}{\overset{\|}{C}}-O-CH_2R \quad ; \quad \underset{\text{acetaldehyde}}{2CH_3CHO} \xrightarrow{(C_2H_5O)_3Al} \underset{\text{ethyl acetate}}{CH_3-\overset{O}{\overset{\|}{C}}-O-CH_2CH_3}$$

5. Benzoin Condensation :

Aromatic aldehydes such as benzaldehyde (having no α-H) in the presence of cyanide ion (ethanolic KCN) as catalyst are condensed to give benzoin.

$$2C_6H_5-\overset{O}{\overset{\|}{C}}-H \xrightarrow[EtOH]{CN^-,\ H_2O} C_6H_5-\overset{O}{\overset{\|}{C}}-\underset{H}{\overset{OH}{\overset{|}{\underset{|}{C}}}}-C_6H_5$$

6. Perkin Reaction (condensation) :

Aromatic aldehydes such as benzaldehyde having no α hydrogen condenses with acetic anhydride having an α-hydrogen in presence of sodium salt of corresponding acid to form unsaturated acid. The reaction is called as Perkin reaction.

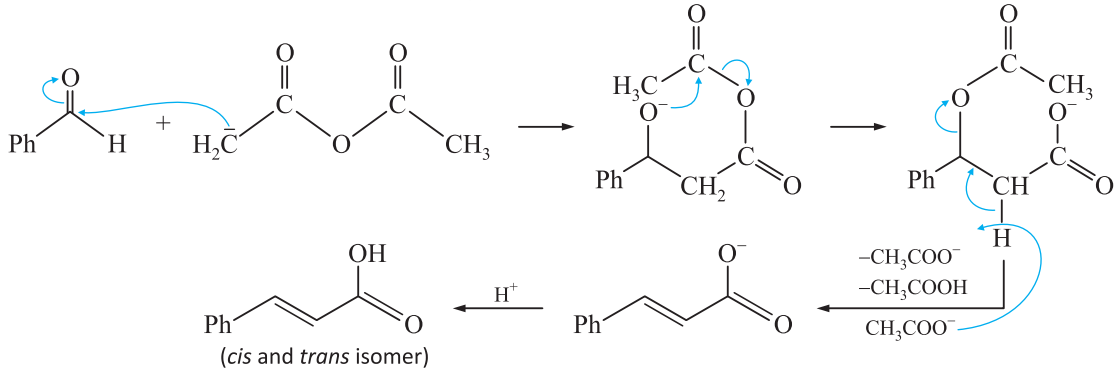
$$C_6H_5-\overset{O}{\overset{\|}{C}}-H + (CH_3CO)_2O \xrightarrow[\Delta]{CH_3COONa} \underset{\text{Cinnamic acid}}{C_6H_5CH=CHCOOH} + CH_3COOH$$

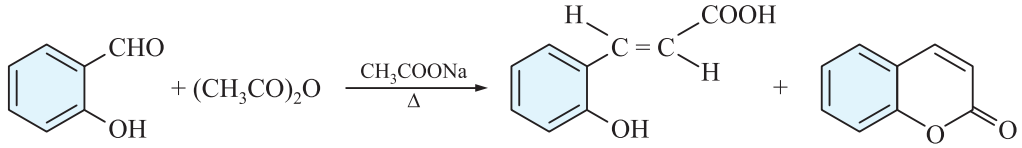
$$C_6H_5-\overset{O}{\overset{\|}{C}}-H + (CH_3CH_2CO)_2O \xrightarrow{CH_3CH_2COONa} \underset{\alpha\text{ - methyl Cinnamic acid}}{C_6H_5CH=\underset{CH_3}{\overset{|}{C}}-\overset{O}{\overset{\|}{C}}-OH}$$

Propionic anhydride

Mechanism of Reaction :

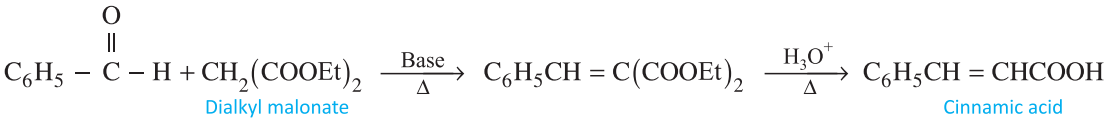
$$CH_3COO^- + H-CH_2-COOCOCH_3 \xrightarrow[-CH_3COOH]{} \bar{C}H_2-COOCOCH_3$$



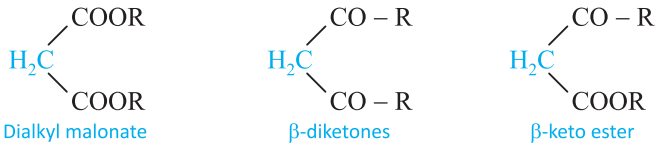


7. Knoevenagel Reaction :

The condensation of aldehydes or ketones, not containing any α-hydrogen, with compound having active methylene group is called as Knoevenagel Reaction. This reaction is catalysed by weak bases. The final product is obtained by hydrolysis of ester to form 1, 3-dicarboxylic acid which undergoes decarboxylation on heating.

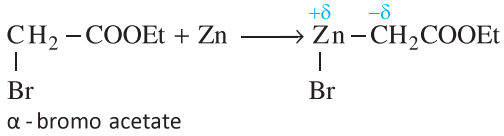


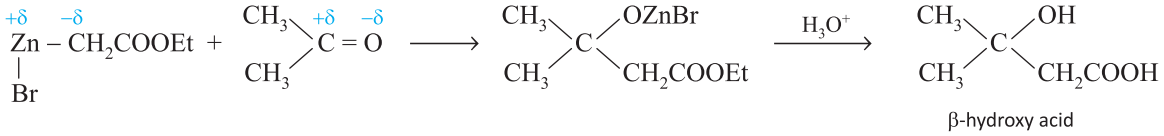
Note : An active methylene group ($-CH_2-$) is the one attached two electron withdrawing groups such as in dialkyl malonates, β-diketones and β-keto esters. However, using dialkyl malonates is referred to as Knoevenagel reaction.



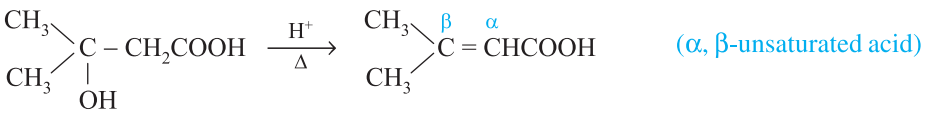
8. Reformatsky Reaction :

The Reformatsky reaction is a condensation reaction, where aldehydes or ketones react with α-halo esters, using a metallic zinc to form β-hydroxy-esters. These β-hydroxy-esters are hydrolysed in cold conditions to produce β-hydroxyacids.





➤ β-hydroxy acid loses water on heating in presence of H_2SO_4 to give α, β-unsaturated carbonyl acid.



(C) Other Reactions :

1. Oxidation of Aldehydes and Ketones :

Aldehydes : Aldehydes are very easily oxidised to carboxylic acids using oxidising agents such as $KMnO_4/OH^-$, $Cr_2O_7^{2-}/H^+$ and even by mild oxidising agents such as H_2CrO_4.

$$R-\overset{\overset{O}{\|}}{C}-H \xrightarrow[H_2SO_4]{Na_2Cr_2O_7} R-\overset{\overset{O}{\|}}{C}-OH$$

However ketones are not oxidised easily as they lack the H attached to carbonyl carbon like aldehydes. As a result, this reaction serves as a Test to distinguish Aldehydes and Ketones. Refer to the following tests.

(a) Tollen's reagent : (Ammonical solution of silver oxide $Ag(NH_3)_2OH \equiv Ag_2O$)

$$R-\overset{\overset{O}{\|}}{C}-H + 2\left[Ag(NH_3)_2\right]^+ + 3OH^- \longrightarrow RCOO^- + 2Ag\downarrow + 2H_2O + 4NH_3$$

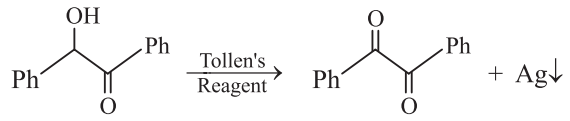
or $$R-\overset{\overset{O}{\|}}{C}-H + Ag_2O \longrightarrow R-\overset{\overset{O}{\|}}{C}-OH + 2Ag\downarrow$$

➤ *α-hydroxy ketones also form silver mirror with Tollen's reagent.*

$$CH_3-\underset{\underset{O}{\|}}{C}-CH_2-OH \xrightarrow[Reagent]{Tollen's} CH_3-\underset{\underset{OH}{|}}{CH}-COO^- + Ag\downarrow$$

$$CH_3-\underset{\underset{O}{\|}}{C}-CH_2-OH \overset{OH^-}{\rightleftharpoons} CH_3-\underset{\underset{OH}{|}}{C}=CH-OH \rightleftharpoons CH_3-\underset{\underset{OH}{|}}{CHCHO} \xrightarrow[OH^-]{[Ag(NH_3)_2]^+} CH_3-\underset{\underset{OH}{|}}{CH}-COO^- + Ag(s)$$

(Keto form) (Enol form)



α-hydroxy ketone

(b) Fehling's solution : (Alkaline solution of cupric ion complexed with sodium potassium tartrate ions)

$$R-\overset{\overset{O}{\|}}{C}-H + 2Cu(OH)_2 \xrightarrow{NaOH} R-\overset{\overset{O}{\|}}{C}-\overset{-}{O}\overset{+}{N}a + Cu_2O\downarrow + 3H_2O$$

blue Reddish brown

➤ *HCOOH responds positively to both Tollen's and Fehling's solution test.*

Note : Among the aromatic carbonyl compounds, benzaldehyde, like aliphatic aldehydes reduces Tollen's reagent. However it does not reduce Fehling's solution.

(c) Benedict's Solution Test :

In benedict's solution, alkaline solution of cupric ion is complexed with sodium potassium citrate ions instead of tartrate ions. The rest of the reaction is same as above.

Note : None of these reagents (a, b & c) oxidise double or triple bonds.

Ketones :

Ketones don't react with Tollen's, Fehling's or Benedict's solutions. This serves as a test to distinguish ketones from aldehydes. Ketones are not easily oxidised. However in presence of conc. nitric acid or acidic $K_2Cr_2O_7$, ketones undergo cleavage at C – C bond adjacent to C = O bond to give a mixture of acids.

$$R-CH_2-\overset{O}{\overset{\|}{C}}-R' \xrightarrow[\text{hot conc. } HNO_3]{K_2Cr_2O_7/H^+} R-\overset{O}{\overset{\|}{C}}-OH + R'-\overset{O}{\overset{\|}{C}}-OH$$

The fission takes in a manner that smaller of alkyl group goes with C = O group [Popoff's rule].

$$CH_3CH_2CH_2-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow[HNO_3]{\Delta} CH_3CH_2COOH + CH_3\overset{O}{\overset{\|}{C}}OH$$

Note : The oxidation of aromatic ketones can be achieved with acidic $K_2Cr_2O_7$ or even with H_2CrO_4 or Cr_2O_3/H_2O to give benzoic acid and aliphatic acid.

$$C_6H_5-\overset{O}{\overset{\|}{C}}-CH_2CH_3 \xrightarrow[H_2O]{Cr_2O_3} C_6H_5-\overset{O}{\overset{\|}{C}}-OH + CH_3COOH$$

2. Oxidation by SeO_2 :

- Oxidation of α-methyl and α-methylene group to keto group.
- Here aldehydes and ketones groups are not oxidised.
- Benzaldehyde (phCHO) and HCHO will not be oxidised due to absence of α-H atoms.

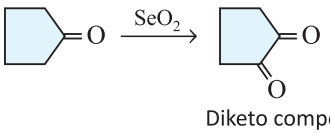
$$\underset{(\alpha\text{-methyl})}{CH_3CHO} \xrightarrow{SeO_2} OHC-CHO \quad \text{(Glyoxal)}$$

$$CH_3-CH_2-CHO \longrightarrow \underset{\alpha\text{-Keto aldehyde}}{CH_3-\overset{O}{\overset{\|}{C}}-CHO} \xrightarrow[AgNO_3]{amm.} \underset{\alpha\text{-Keto acid}}{CH_3-\overset{O}{\overset{\|}{C}}-COOH}$$

$$CH_3-\overset{O}{\overset{\|}{C}}-CH_2-CH_3 \xrightarrow{SeO_2} OHC-\overset{O}{\overset{\|}{C}}-CH_2-CH_3 \quad \text{(This product is wrong)}$$

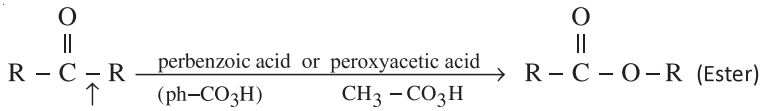
$$CH_3-\overset{O}{\overset{\|}{C}}-CH_2-CH_3 \xrightarrow{SeO_2} CH_3-\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}-CH_3$$

Note : The oxidation of α-methylene group is preferred over α-methyl group.

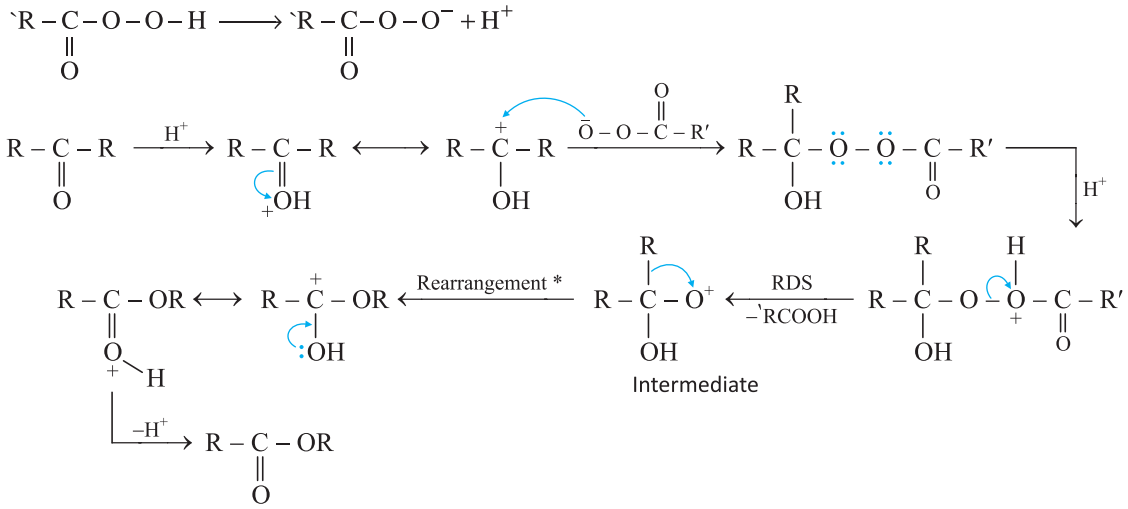


Diketo compound

3. Baeyer Villiger Oxidation: (Given Only by Ketones)

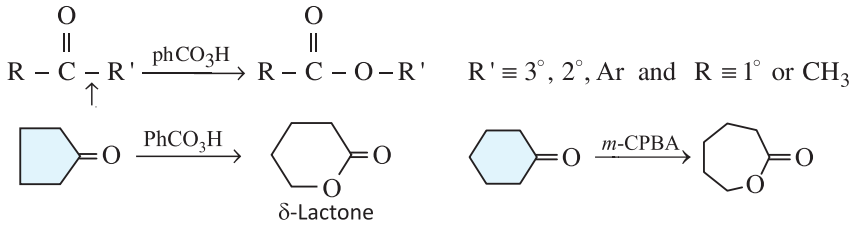


Mechanism of Reaction :



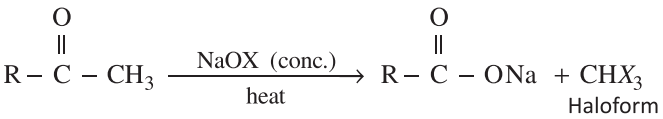
*More electron releasing group migrates from carbon to electron deficient O atom.

Migratory aptitude of a group : H– > Ph– > 3° R– > 2° R– > 1° R– > CH_3–



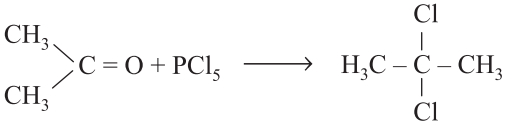
➤ Oxidation of methyl ketones by haloform reaction :

Aldehydes and Ketones having at least one methyl group linked to the carbonyl carbon atom are oxidised by sodium hypohalite to sodium salts of corresponding carboxylic acids, along with haloform.



This oxidation does not affect a carbon-carbon double bond, if present in the molecule.

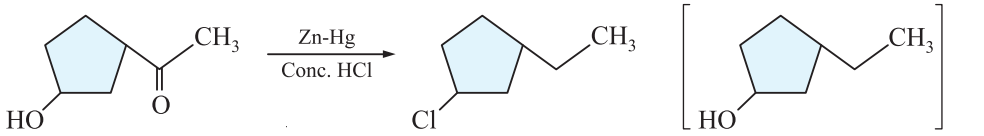
4. With PCl_5 : $CH_3CHO + PCl_5 \longrightarrow CH_3-\underset{Cl}{\overset{Cl}{\underset{|}{\overset{|}{C}}}}-H + POCl_3$ ethylidene dichloride (a gem-halide)



5. Reduction : Both aldehydes and ketones are reduced to alkanes by the following reductions.

(a) Clemmensen Reduction : $RCHO \xrightarrow[HCl]{Zn-Hg} RCH_3$

Note : This is very good for reduction of aldehydes rather than for ketones. Also keep in mind that if carbonyl compounds have a basic group or a group that can reacts with HCl, then this is not a good method as HCl is being used. In that case use Wolff-Kishner reduction method.



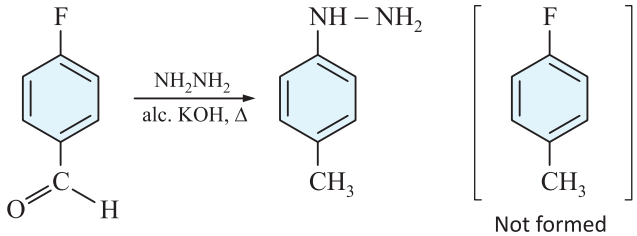
Not formed
because substrate is acid sensitive

(b) Wolff – Kishner Reduction :

$$R-\underset{\underset{R'}{|}}{C}=O + NH_2NH_2 \xrightarrow[\text{ethylene glycol}/\Delta]{NaOH} R-CH_2 + H_2O + N_2$$

$$ph-\overset{\overset{O}{\|}}{C}-CH_2-CH_3 + H_2NNH_2 \xrightarrow[\text{Ethylene glycol}/200^\circ C]{NaOH} ph-CH_2-CH_2-CH_3 + H_2O + N_2$$

Note : Wolff-Kishner reduction is very effective for reduction of ketones. Also keep in mind that if carbonyl compounds have a base sensitive group (acidic) such as $-SO_3H$, $-COOH$ etc., or group that can reacts with $NH_2 - NH_2$ or NaOH ; then this is not a good method. In that case use Clemmensen reduction.

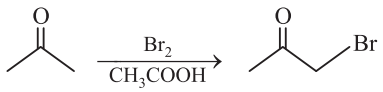


p-Fluoro benzaldehyde

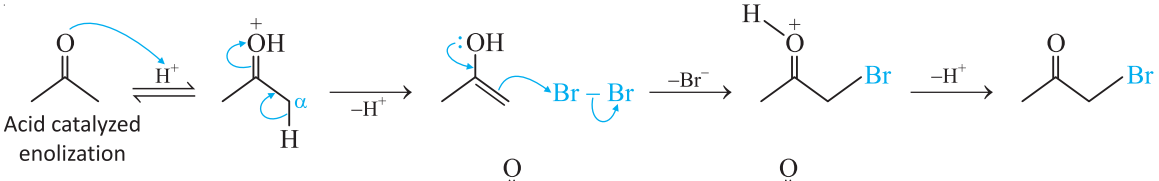
Not formed
because substrate is base sensitive

6. Halogenation (Chlorination and Bromination):

Carbonyl compounds can be halogenated in the α-position in acidic or basic solutions.

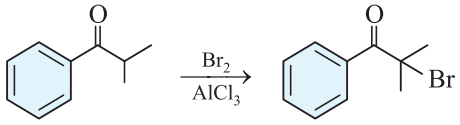


Mechanism : $CH_3COOH \longrightarrow CH_3COO^- + H^+$



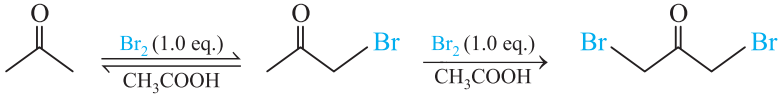
Acid catalyzed
enolization

Lewis acid make excellent catalysts for the bromination of ketones.



100% yield

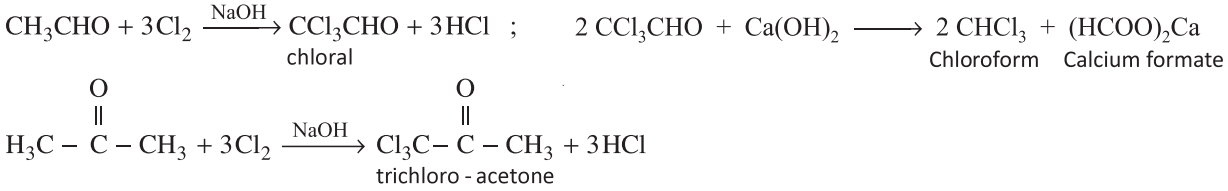
Note that bromination occurs nowhere else in the molecule-not on the benzene ring (which may undergoes S_E reaction under these conductions) nor on any other atom of the aliphatic side chain. This is because only one position can form an enol and the enol is more reactive towards bromine than the aromatic ring. Enols are more nucleophilic than simple alkene.



Second halogen goes on the other side of the carbonyl group, if it can. It is because bromoketone is less basic than acetone, so less of the reactive protonated form is present. This slows down any further electrophilic attack.

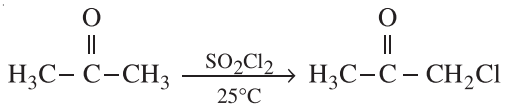
Note : Halogenation of carbonyl compounds should be carried out in acid solution.

Halogenation in basic medium results in formation of di- or tri-halosubstitution of carbonyl compounds. *Refer to halogen derivatives and recall Haloform reaction.*



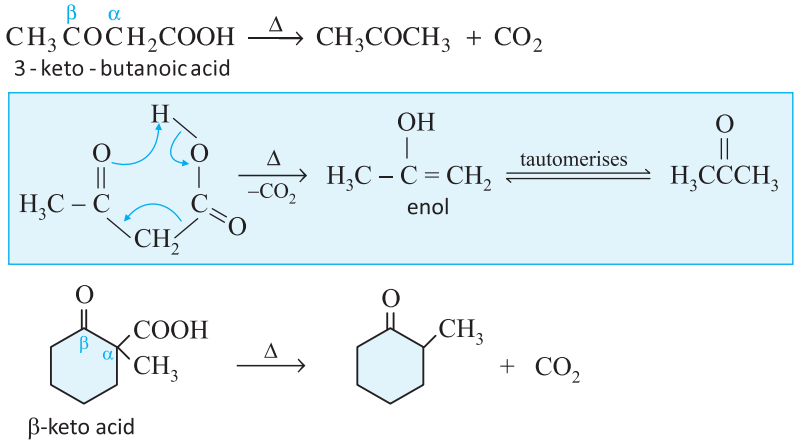
Trichloroacetone on reaction with NaOH or $Ca(OH)_2$ will result in chloroform formation.

Note : The monochlorination is readily carried out by sulphuryl chloride at 25°C.

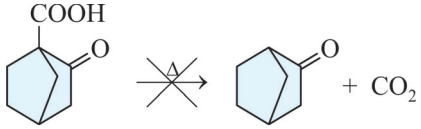


7. Action of Heat on Keto-acids :

If there is a keto group at β-position, then de-carboxylation occurs by simple heating :



Note : β-keto acid having acid group on bridge head position can't be decarboxylated by heating.



➤ α-keto acids, when heated loses CO to give acids: $CH_3\overset{\alpha}{C}OCOOH \xrightarrow{\Delta} CH_3COOH + CO$

IN-CHAPTER EXERCISE-B

Choose the correct alternative. Only one choice is correct. Questions marked with '*' may have More than one correct option.

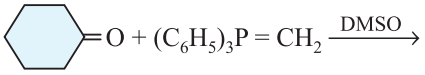
***1.** *Which of the following test can be applied to distinguish between CH_3CHO and CH_3COCH_3 ?*

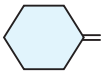
(A) *Addition of HCN* **(B)** *Fehling solution*

(C) *Tollen's Reagent* **(D)** *Iodoform test*

2. *Mixture of CH_3CH_2OH and CH_3CHO can be separated by using :*

(A) $NaHSO_3$ **(B)** NH_2OH **(C)** HCN **(D)** NH_2-NH_2

3. *The products of the following reaction are :* 

(A)  **(B)** $(C_6H_5)_3-P=O$

(C) *Both (A) and (B)* **(D)** *None*

***4.** *The following transformation can be carried out by :*

(A) *Wolff Kishner reduction* **(B)** *Clemmensen reduction*

(C) *(P + HI) mixture + Δ* **(D)** *None*

***5.** *Which of the following is an example of nucleophilic addition ?*

(A) $C_6H_5\overset{\overset{O}{\|}}{C}CH_3 \xrightarrow{NH_2NH_2,\ H^+} C_6H_5\overset{\overset{NNH_2}{\|}}{C}CH_3$ **(B)** $C_6H_5\overset{\overset{O}{\|}}{C}CH_3 \xrightarrow{LiAlH_4} C_6H_5\overset{\overset{OH}{|}}{C}HCH_3$

(C) $CH_3CHO \xrightarrow[HCl]{Zn-Hg} CH_3CH_3$ **(D)** $CH_3CHO \xrightarrow[H^+]{NH_3} CH_3CH=NH$

6. *Propanal and propanone, both have same molecular formula (C_3H_6O), what do you except about their boiling points ?*

(A) *Both have same boiling point*

(B) *Boiling point of propanal is higher than the boiling point of propanone*

(C) *Boiling point of propanal is lower than the boiling point of propanone*

(D) *Nothing can be predicted*

7. *Which of the following is least reactive with a nucleophile ?*

(A) *Methanal* **(B)** *Propanone* **(C)** *3-Pentanone* **(D)** *2-Pentanone*

***8.** *Which of the following statements is(are) true ?*

(A) *Cannizzaro reaction is given by aldehydes with no α–H in presence of alkali*

(B) *Aldol condensation is given by aldehydes with α–H in presence of alkali*

(C) *Aldol condensation can also be given by aldehydes and ketones with α–H in presence of acids*

(D) *Claisen-Schmidt reaction is between benzaldehyde and formaldehyde in hot alkaline solution*

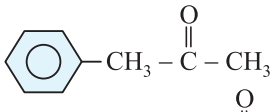
***9.** *Among the following compounds, which will react with acetone to give a product containing* $\rangle C=N-$ *?*

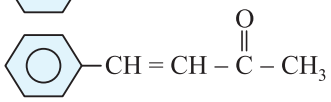
(A) $C_6H_5NH_2$ **(B)** $CH_3NHC_6H_5$ **(C)** $C_6H_5NH-C_6H_5$ **(D)** $C_6H_5NH.NH_2$

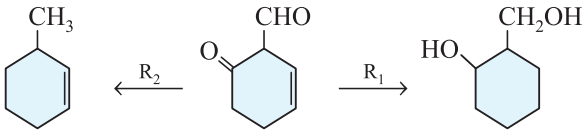
10. *Reactivity of HCHO (I), CH_3CHO (II) and C_6H_5CHO (III) is in order :*

(A) *I > III > II* **(B)** *III > II > I* **(C)** *I = II > III* **(D)** *I > II > III*

*11. *The compounds which give Iodoform test is(are) :*

(A)  (B) $CH_3CH_2NH_2$

(C)  (D) CH_3CHO

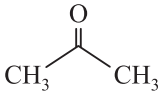
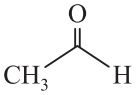
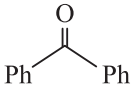
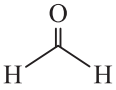
12. 

R_1 and R_2 are reducing agents. They can be :

(A) R_1 is Ni/H_2, *R_2 is Clemmensen's reagent* (B) *R_1 is Ni/H_2, R_2 is Wolff-Kishner's reagent*

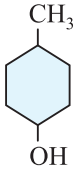
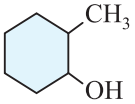
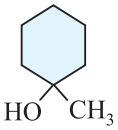
(C) *Both are correct* (D) *None of these*

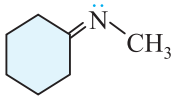
13. *The order of reactivity of phenyl magnesium bromide with the following compounds is :*

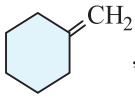
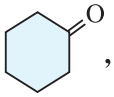
I.  II.  III.  IV. 

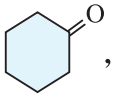
(A) *IV > II > III > I* (B) *IV > I > III > II* (C) *II > I > III > IV* (D) *IV > II > I > III*

14. *Which of the following alcohols cannot be obtained by a hydride reduction of an aldehyde or a ketone ?*

(A)  (B)  (C)  (D) *All of these*

15. *Imine (A) can be prepared by :*  (A)

(A)  , CH_3CHO (B)  , CH_3NH_2

(C)  , CH_3NHCH_3 (D) *None of these*

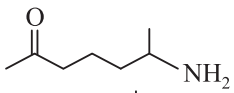
16. *Identify A in the given reaction setup.* $A \xrightarrow{50\%\ NaOH} HOCH_2 - COONa$

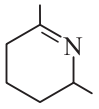
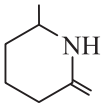
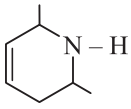
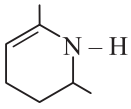
(A) $HOOC - CHO$ (B) $HOC - CHO$ (C) $HOCH_2 - CHO$ (D) $HOCH_2 - CH_2OH$

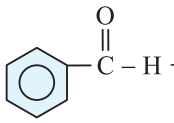
17. $C_3H_6O \xrightarrow{OH^-} \xrightarrow[\Delta]{NaHSO_4} CH_3CH_2CH = \overset{CH_3}{\overset{|}{C}}CHO$

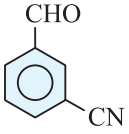
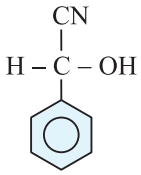
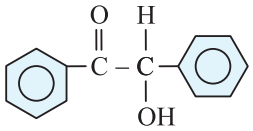
Thus, C_3H_6O is :

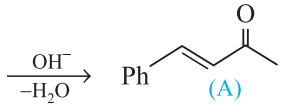
(A) CH_3COCH_3 (B) CH_3CH_2CHO (C) $CH_2 = CHCH_2OH$ (D) $CH_3\overset{OH}{\overset{|}{C}} = CH_2$

18.  $\xrightarrow{H^+}$ P + H_2O. *P should be :*

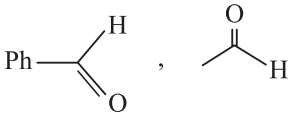
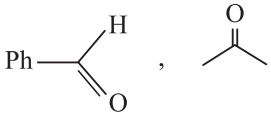
(A)  (B)  (C)  (D) 

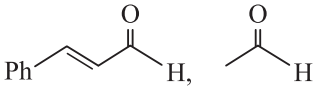
19.  P should be :

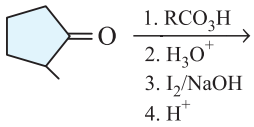
(A) **(B)**  **(C)**  **(D)** 

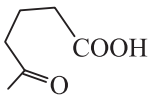
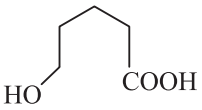
20. *Compound A is formed by aldol reaction between B and C* : 

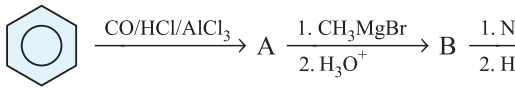
B and C are :

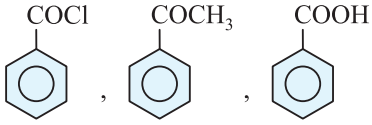
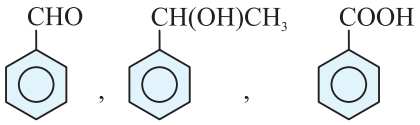
(A)  **(B)** 

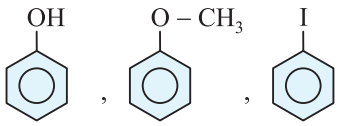
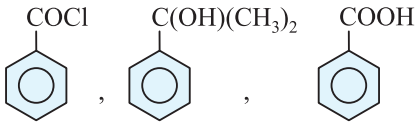
(C)  **(D)** *None of these*

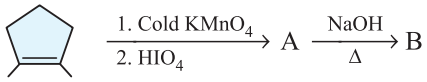
21.  The product A should be :

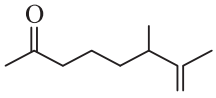
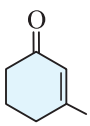
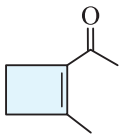
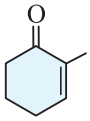
(A) **(B)**  **(C)**  **(D)**

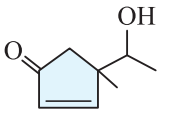
22.  A, B, C are respectively :

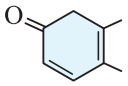
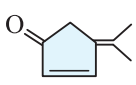
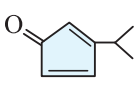
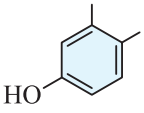
(A)  **(B)** 

(C)  **(D)** 

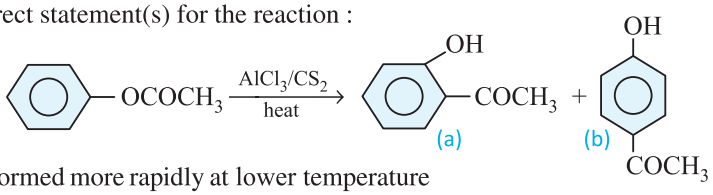
23. Consider the sequence of reactions :  The product B is :

(A)  **(B)**  **(C)**  **(D)** 

24.  Major product :

(A)  **(B)**  **(C)**  **(D)** 

***25.** Choose the correct statement(s) for the reaction :

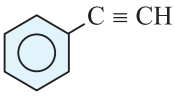
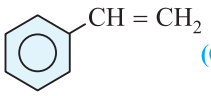
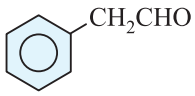
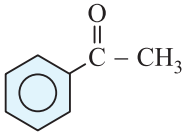


(A) (b) is formed more rapidly at lower temperature

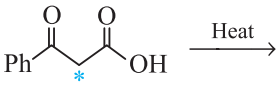
(B) (b) is more volatile than (a) **(C)** (a) is more volatile than (b)

(D) (a) is formed in higher yields at lower temperature

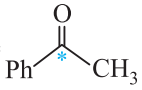
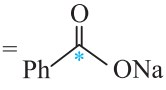
26. $A \xrightarrow[1\%HgSO_4]{20\%H_2SO_4} B \xrightarrow{I_2+NaOH} C + C_6H_5COONa$ The reactant 'A' is :

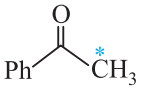
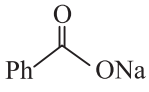
(A)  **(B)**  **(C)**  **(D)** 

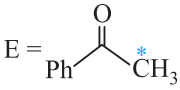
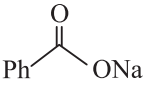
27. In the following reaction sequence, the correct structures of E, F and G are :

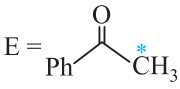
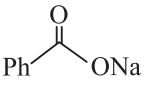


(* implies ^{13}C labelled carbon)

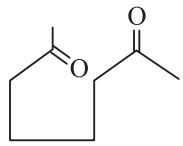
(A) E =  F =  $G = CHI_3$

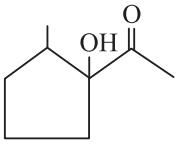
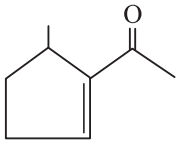
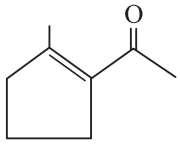
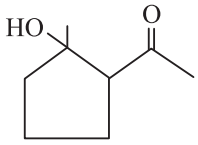
(B) E =  F =  $G = \overset{*}{C}HI_3$

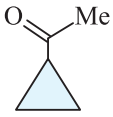
(C) E =  F =  $G = CHI_3$

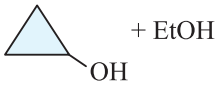
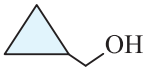
(D) E =  F =  $G = \overset{*}{C}H_3I$

28. *Compound (A) given below can undergo intramolecular aldol condensation reaction, when heated in alkali to give* :

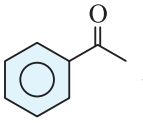
A : 

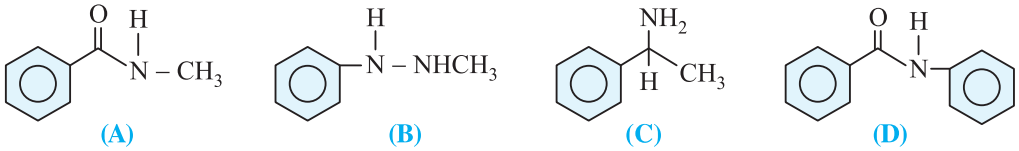
(A)  **(B)**  **(C)**  **(D)** 

29.  $\xrightarrow{CF_3CO_3H} A \xrightarrow[Ether]{LiAlH_4} B + C$. The product(s) B and C are :

(A)  **(B)** MeOH + 

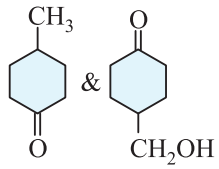
(C) **(D)** $CH_3CH_2CH_2OH + EtOH$

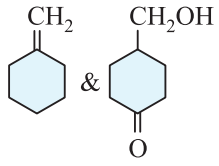
30.  $\xrightarrow[H^+]{NH_2OH} X \xrightarrow{Na/C_2H_5OH} Y$ Identify Y in the following sequence :

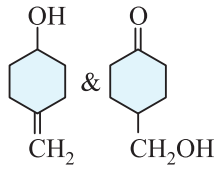


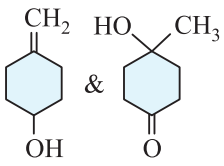
(A) **(B)** **(C)** **(D)**

31. (B) $\xleftarrow[2.\ H_2O_2/OH^-]{1.\ B_2H_6}$ H_2C=⬡=O $\xrightarrow{NaBH_4}$ (A) A and B respectively are :


(A)


(B)


(C)


(D)

For Questions 32 - 34

Consider the following reaction sequence :

$C_7H_8 \xrightarrow[2.\ KCN/DMSO]{1.\ NBS/CCl_4} A$ $\qquad$ $A + C_6H_5CHO \xrightarrow[C_2H_5OH]{C_2H_5ONa} B$ $\qquad$ $B \xrightarrow[\Delta]{H_3O^+} C$

32. $C \xrightarrow[H^+]{H_2O} D \xrightarrow{H_2CrO_4} \xrightarrow{\Delta} E$

Which of the following is (are) true about the compound E ?

I. It does not respond to Tollen's Test **II.** It gives positive iodoform test

III. It forms diphenyl ethylene on reaction with $N_2H_4/(CH_2OH)_2/KOH$

The correct option is :

(A) I **(B)** I, II **(C)** I, II, III **(D)** I, III

33. Identify the compound (F) and (G) : (E) $\xrightarrow{SeO_2}$ (F) $\xrightarrow[H_2O]{NaBH_4}$ (G)

The compounds (F) and (G) are :

(A) PhCOCOPh and PhCOCH(OH)Ph **(B)** PhCOCOPh and PhCH(OH)CH(OH)Ph

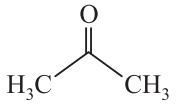
(C) $PhCH_2CH_2Ph$ and PhCOCH(OH)Ph **(D)** PhCOCOPh and PhCOOH

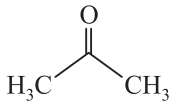
34. E + HCHO $\xrightarrow[\Delta]{OH^-}$ H $\xrightarrow[H^+,\Delta]{K_2Cr_2O_7}$ Product(s). The product(s) may be :

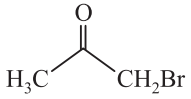
(A) PhCOCOPh only **(B)** PhCOOH and PhCHO

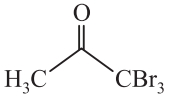
(C) PhCOOH only **(D)** Oxidation of (H) is not possible

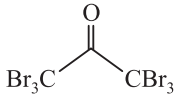
35. After completion of the reactions (I and II), the organic compounds(s) in the reaction mixtures is(are) :

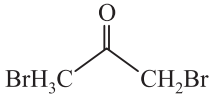
Reaction 1 :  (1.0 mol) $\xrightarrow[\text{Aqueous (NaOH)}]{Br_2\ (1.0\ mol)}$

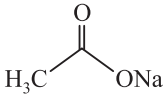
Reaction 2 :  (1.0 mol) $\xrightarrow[CH_3COOH]{Br_2\ (1.0\ mol)}$


[P]


[Q]


[R]


[S]


[T]

$CHBr_3$ **[U]**

(A) Reaction 1 : P and Reaction 2 : P **(B)** Reaction 1 : U, acetone and Reaction 2 : Q, acetone

(C) Reaction 1 : T, U, acetone and Reaction 2 : P **(D)** Reaction 1 : R, acetone and Reaction 2 : S, acetone